PREFACE

The third volume of textbook systematically presents the material on the nervous, the cardiovascular and the lymphatic systems according to the current curriculum for medical universities.

In addition to providing general anatomical information, each section of the textbook includes material on the development, variations, and anomalies of organs and systems. The textbook also emphasizes clinical applications of the presented information. We paid particular attention to the substantiation of general principles in the study of anatomy: the correlation between the structure and function, the integrity of the organism, and the unity of the organism with its external environment.

Each section ends with practice questions, which allow students to self-evaluate their progress. In preparing this textbook, we have been guided by the pedagogical expertise of many Ukrainian scientists-anatomists who became the co-authors of this work (Bobryk I. I., Kyiv; Voloshyn M. A., Zaporizhzhia; Holovatskyi A. S., Uzhhorod; Iliin I. I., Odesa; Kiriakulov H. S., Donetsk; Koveshnikov V. H., Luhansk; Kozlov V. O., Dnipropetrovsk; Kostylenko Yu. P., Poltava; Luzin V. I., Luhansk; Lupyr V. M., Kharkiv; Pykaliuk V. S., Simferopol; Romenskyi O. Y., Vinnytsia; Sikora V. Z., Sumy; Fedoniuk Ya. I., Ternopil; Shutka B. V., Ivano-Frankivsk. All co-authors followed a uniform representational style depicting a modern scientific state of the subject in a given unit of the textbook.

In the textbook, we used new anatomical terminology, approved by FCAT (San Paulo, 1997). Ukrainian equivalents of the terms are presented in accordance with the book “International Anatomical Nomenclature” edited by Professor I. I. Bobryk and Professor V. H. Koveshnikov (Kyiv, 2001).

Illustrations were borrowed from the manuals and textbooks accompanied by the authors’ additions and revisions. The majority of the drawings made from the specimens are original.

The organization of the material on human anatomy into units corresponds to the curriculum of the credit/module-based educational system.

I wish to acknowledge and express my appreciation to N. H. Mykula, N. P. Mishenko, V. V. Mavrich, and O. S. Bolhova for their help in preparing this textbook for publication. Apart from this I’m truly greatful to Mrs. Larysa Sankova and Ms. Eugenie Bekova, who made the English translation of the book.

Comments, suggestions, and critique aimed to improve this textbook are welcomed by the authors and will be taken into consideration in further editions.

Professor V. H. Koveshnikov

SHORTENINGS KEY

a.	– arteria	– artery
aa.	– arterie	– arteries
art.	– articulation	– joint
artt.	– articulations	– joints
for.	– foramen	– opening
forr.	– foramina	– openings
lam.	– lamina	– plate
lamm.	– laminae	– plates
lig.	– ligamentum	– ligament
ligg.	– ligamenta	– ligaments
m.	– musculus	– muscle
mm.	– musculi	– muscles
n.	– nervus	– nerve
nn.	– nervi	– nerves
nucl.	– nucleus	– nucleus
nucll.	– nuclei	– nuclei
r.	– ramus	– branch
rr.	– rami	– branches
sul.	– sulcus	– sulcus
sull.	– sulci	– sulci
sut.	– sutura	– sutura
sutt.	– suturae	– suturae
v.	– vena	– vein
vv.	– venae	– veins

NERVOUS SYSTEM

INTRODUCTION

Nervous system – the system of integration and regulation

The chief purpose of the nervous system is to maintain communication between the organism and the environment and to control functioning of the organs and systems of the organism *per se*.

The animal organisms receive data on environment in the form of various stimuli accepted by the sensory organs. The receptors transform the energy into the nervous impulses transmitted by the afferent nerve fibers to the CNS for processing and generation of the appropriate response. The outcome impulses reach the respective effectors to form the body response. This so-called external function of the nervous system provides communication and adaptation of the organism to the continuously changing environment.

Another important function of the NS is the internal function, which constitutes coordination of organs and systems' activities. This function provides integration of separate parts of the organism and homeostasis maintenance. The internal function is tightly connected with the humoral regulation and thus the nervous and endocrine systems form a functional unit.

Nervous system subdivisions

The nervous system has two major subdivisions: the central nervous system (CNS), which consists of the brain and spinal cord and the peripheral nervous system (PNS), which comprises the cranial and spinal nerves and the vegetative ganglia and plexuses.

Depending on the area affected, the nervous system is subdivided into somatic and vegetative (autonomic) divisions. Somatic division supplies the *soma* organs (skin, sensory organs, skeletal muscles, bones and joints) and thus performs external function of the NS. Vegetative division in turn supplies the *viscera*, heart, blood vessels, smooth muscles and glands. Vegetative division also has two subdivisions: sympathetic and parasympathetic, which possess opposite effects on the organism. The vegetative division performs the internal function.

Neuron – the structural functional unit of the nervous system

The structural functional unit, which provides physiological properties to CNS, is a neuron (neurocyte). The neurons are surrounded by supportive and nourishing cells that form the framework called neuroglia.

The neurons possess a unique feature – generation and transmission of nerve impulses in response to stimulus (mechanical, electrical, chemical etc.). Specialized contacts between nerve cells (synapses) allow transmission of the signals to other neurons.

Approximate counting put the number neurons at 10 to 100 billion (10^{11}) cells of various shapes and sizes (5 to 135 μm).

The neuron consists of the body (soma), which comprises the nucleus and surrounding cytoplasm called **perikaryon.** Numerous cytoplasmatic processes transmit the nerve impulses. Depending on processes number the neurons are subdivided into multipolar, bipolar and pseudounipolar (unipolar).

Multipolar neurons

Neurons of this type have numerous *dendrites* and single *axon* (Fig. 1):

- *dendrites* (from Greek **"Dendron"** – a tree) are short numerous arborizing processes that never leave CNS limits; they receive signals from other neurons and transmit them to neuron's *soma;*
- *axon* (from Greek **"axon"** – axis) is a single long process, which may leave CNS limits. These processes transmit the signal from the *soma* to respective organ. Axon's length varies from 1 mm up to 1 m. Multipolar neurons feature variety of shapes and sizes.

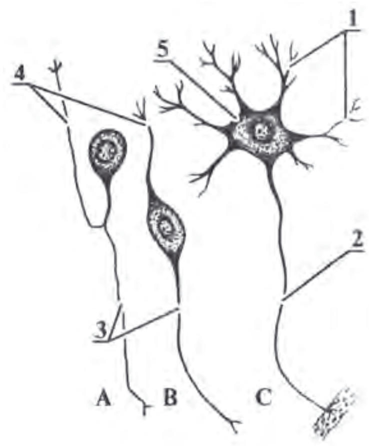

Fig. 1. Structure of neurons. A – pseudounipolar neuron; **B** – bipolar neuron; **C** – multipolar neuron. 1 – dendrites; 2 – axon; 3 – peripheral process; 4 – central process; 5 – body of neuron.

Bipolar and pseudounipolar neurons

Bipolar neurons have two processes that run from opposite cell poles. Most of bipolar neurons in evolution progress as seen in developing embryo transform into pseudounipolar as the result of merging of separate processes. These cells seem to have one process, which at a short distance branches like a T to form two processes (fibers) – peripheral and central:

- the *peripheral fiber* (equal to dendrite) runs to periphery and ends with receptor. It conducts the signal to the soma;
- the *central fiber* (equal to axon) conducts impulse from the soma and thus runs to CNS.

Some areas such as retina, sensory ganglia of VIII cranial nerves and olfactory region of nasal mucosa retain true bipolar neurons.

Functional classes of neurons

From functional point of view sensory, motor and association (interneurons) are distinguishable:

- *sensory (afferent)*[1] *or reception* neurons reside mainly in sensory ganglia of spinal and cranial nerves (outside CNS); they are pseudounipolar neurons (sometimes unipolar);
- *motor (efferent) neurons* transmit impulses to peripheral organs (e.g. muscles and glands). They are multipolar neurons i.e. their bodies reside within CNS or vegetative ganglia while processes mostly leave CNS limits;

[1] – **afferens** (Lat.) – bringing in

- *interneurons (association neurons)* transmit signals only within CNS. They link sensory and motor neurons and belong to intermediate computing network.

Sensory (input) and motor (output) neurons count several millions cells and interneurons constitute 99.9 % of CNS neurons. Interneurons thus play key role in data processing and determine complexity of structure and functioning of CNS.

Receptors

Receptors are the specialized nerve terminations of sensory neurons located in various tissues, where stimulus transforms into nerve impulse. Depending on location, the following types of receptors are distinguishable:

- **exteroceptors,** which reside in skin, mucous membranes and specialized tunics of the sensory organs (retina, membranous labyrinth etc.). They receive stimuli from environment. This type of sensitivity is called exteroceptive (pain, temperature, tactile, sight, olfactory and taste);
- **proprioceptors** are the sensitive nerve terminals in muscles, tendons, fasciae, periosteum and joint capsules). This type of sensitivity is called proprioceptive. Proprioceptive impulses are responsible for spatial orientation and feeling of both active and passive movements;
- **interoceptors** are located in the viscera (stomach, heart, lungs, liver etc.) and blood vessels. This type of sensitivity is called interoceptive.

Synapses

Neurons form vast networks with the help of processes that contact to form unique type of connections called synapses. Neuron's processes may contact other neuron's soma or processes forming thus various types of synapses. Typically, one neuron may possess 1000 to 10000 synapses for continuous evaluation of the incoming signals to form output impulses of appropriate frequency. There are two major types of synapses: excitatory and inhibitory. Total number of CNS related synapses is approximately 10^{14} (100 billion).

CNS language – electrical and chemical

Stimulus intensity encoding is provided by frequency and duration of electric impulses. Nerve impulse causes release chemical substances (neurotransmitters) like acetylcholine, norepinephrine, dopamine, etc. into synaptic cleft. They act on postsynaptic neuron changing its electric activity thus sending certain data. Some synapses possess direct electrical data transmission.

Myelin sheath

Most of the axons feature especially thick whitish sheath formed of fatlike substance – myelin. Such fibers are called myelinated. Myelin serves as insulation and promotes faster impulse transmission. Neuron's bodies and dendrites are devoid of myelin.

White and grey matters

Visual examination reveals in brain and spinal cord two well distinguishable areas called the white matter and the grey matter.

The *grey matter,* **substantia grisea,** represent the areas where myelin-devoid neurons' bodies concentrate. The grey matter forms the *cortex of brain,* **cortex cerebri,** the *cortex of cerebellum,* **cortex cerebelli,** the *nuclei* (Lat. Id.) of the brain and spinal cord and the *columns,* **columnae,** of the spinal cord.

The *white matter,* **substantia alba,** corresponds to the areas that contain myelinated neurons' processes. White substance forms the *fibers,* **fibrae,** and *tracts,* **tractus.**

Reflex principle of CNS functioning. Works of I. N. Sechenov, C. Sherrington and I. P. Pavlov

Basic principle of the entire nervous system functioning is the reflex (from Lat. **"reflexus"** – reflected). I. N. Sechenov in his "Brain reflexes" demonstrated that nervous system functions basing on various reflexes. This principle is universal for the entire nervous system and extends onto psychic activities. In the beginning of the 20th century the famous English physiologist C. Sherrington discovered laws of reflex activities of the spinal cord and thus put the basis under distinguishing of nervous system units.

The concept of reflex principle reached its maximum development in classic works of I. P. Pavlov. In addition to congenital unconditioned reflexes, he discovered quite a new type of conditioned reflexes acquired by animals and humans in the process of individual development. Anatomical substrate for the reflex is the reflex arc.

Practice questions:

1. What is the chief function of the nervous system?
2. Name divisions of the nervous system.
3. What is the structural functional unit of the nervous system?
4. What elements are distinguishable in the multipolar neuron?
5. Give characteristic of processes branching in pseudounipolar neurons.
6. Describe functional classification of the neurons.
7. Name types of receptors related to their location.
8. Give definition of the synapses.
9. How do the NS elements communicate?
10. Name main differences between grey and white substances.
11. What is the basic principle of NS functioning.

EVOLUTION OF THE NERVOUS SYSTEM

1. Nervous system in invertebrates

Origination of the nervous system

Unicells and inferior metaphytes have no distinguishable nervous system. Initially, any cell is able to accept stimulus and produce a response to it. As the animals develop several cell layers that form the body, the superficial and deep layers appeared under different conditions in regard to environmental stimuli. Impulse transmission from superficial to deeper layer became a concern. In evolution process, first nerve cells derive from the external epithelial lining of the animal's body (ectoderm). Primitive nervous system first appears in Coelenterata (hydras, jellyfish etc.). Prototypes for the nervous cells were single ectodermic cells, which developed extra sensibility to environmental changes. Their cytoplasm processes allowed transmission of the signals to muscle-like (myoid) cells, which acquired contraction ability.

Single-neuron stimulus transmission

It is quite possible that first system to appear at early evolution stages was the single-neuron transmission system. Nerve cells located in the ectoderm and thus in contact with ambient reach the deeper myoid cells with their processes. In any case, stimulation of the nerve cell results in predictable reaction – muscle fibers contraction and animal's reaction.

Origination of double-neuron chain

Evolution of the nervous system resulted in increase of nervous cells number and differentiation of sensory and motor neurons. The neurons form numerous connections and join into vast network below ectoderm. This type of NS is called diffuse or network-type. Neurons located in ectodermic epithelial layer (sensory) form contacts (synapses) with sub-epithelial neurons (motor), which in turn contact the muscular or glandular cells located within the body. Thus, the double-neuron (monosynaptic) connections provide advanced data processing.

Origination of association neurons

As evolution progresses, the nervous cells concentrate in certain places of the body to form nodes (ganglia), which are segmental nervous centers. This type of NS is called ganglion-type. Association neurons transmit signals from one neuron to another. Thus, at this evolution stage three types of neurons are distinguishable: sensory, association and motor. In this case, sensory (afferent) neurons as a rule lose direct connections with motor (efferent) neurons. Association neurons take over communication functions providing thus complex data processing and integration of NS.

At this evolution stage, the annelids and arthropods exhibit intensive development of neurons in the cranial end of the body leading to formation of larger ganglia. Insects feature epipharyngeal ganglion, developed distinctly better than in other species, which gives certain grounds to identify it as brain.

2. Nervous system in chordates

Origination of tubular nervous system

Chordates possess quite different type of NS compared to invertebrates. Neurons concentrate in the walls of tube that runs along the dorsal body wall. The anterior dilated end of the tube represents the brain while the body-related portion forms the spinal cord.

Tubular nervous system probably originates from longitudinal ectodermic plate in chordates progenitors. This plate lies dorsally and consists of sensory epithelium. Further, it incorporates into a body to form neural groove open dorsally. The groove edges eventually fuse to form a tube. The lancelet possesses the most primitive CNS as it lacks brain[1] and features incompletely fused neural tube (Fig. 2).

Segmentation of the neural tube

The body of chordates features metameric structure therefore the neural tube has distinct segments also distinguishable in superior vertebrates. Each body segment is related to respective neural tube segment and the spinal cord consists of identical segments. Number of neural segments is equal to number of body segments. The ventral portion of the tube gives rise to motor neurons, which form the ventral roots supplying the muscles. The dorsal portion in turn gives rise to sensory neurons, which form the dorsal roots related to the integuments. In all vertebrates beginning from cyclostomes, the sensory neurons leave the spinal cord to form spinal ganglia visible as a bulge on the dorsal root. In lampreys, both roots run as separate nerves while in fish and other vertebrates the roots join to form mixed spinal nerve. The spinal nerves originate from the respective neural segment and correspond to the body segments.

Origination of the brain

The cyclostomes are the first to develop a brain – a primitive organ, which appears as a small extension on the cranial end of neural tube. The brain in cyclostomes has several distinguishable compartments.

Fish also possess underdeveloped brain yet all brain compartments featured by superior vertebrates are distinguishable:

1) the *forebrain,* **prosencephalon,** comprising telencephalon and diencephalon;

2) the *midbrain,* **mesencephalon;**

3) the *rhombencephalon* (Lat. Id.) comprising metencephalon and myelencephalon.

The forebrain in fish as a rule features underdeveloped hemispheres but well developed olfactory parts. This compartment has well differentiated nuclei of the corpus striatum, the pineal and the pituitary glands. The midbrain is best developed compared to other compartments and contains vision and auditory centers. Structures within the phombencephalon are represented with the cerebellum and the medulla oblongata. The latter develops vital regulatory centers as respiratory, circulatory and digestive (the vagus nerve nuclei).

[1] – actually, the cranial end of the neural tube in lancelet has a small dilation considered by some authors as brain

Differentiation of the brain in terraneous vertebrates

In amphibians, most significant changes to the brain occur in the telencephalon. The hemispheres undergo considerable development due to the nuclei of corpus striatum. The olfactory bulbs and the midbrain are also well developed.

The reptiles exhibit further development of the diencephalon (namely the thalamus) which has separate sensory nuclei. The hemispheres of the telencephalon are represented with the nuclei of corpus striatum, which control the animal's movements. The reptiles however feature better-developed *archicortex* (Lat. Id.) which is vestigial in amphibians. The archicortex in reptiles resides in the portion of hemisphere, which corresponds to the hippocampus in superior vertebrates.

Moreover, the lateral surface of hemisphere appears to contain several primordias of the *neocortex* (Lat. Id.).

Telencephalon in birds is larger than in reptiles, yet the cerebral cortex is underdeveloped as well and the hemispheres are represented with the nuclei of corpus striatum.

Evolution of the brain in mammals

In mammals, development of neocortex appears to take a leading part in the entire brain evolution process, which in turn results in development of hemispheres of telencephalon and especially the neocortex. In all other vertebrates, the hemispheres consist of the nuclei of corpus striatum that are responsible for instinctive behavior. In mammals, the brain cortex features higher regulatory centers for important functions of the organism – visual, auditory, tactile, etc. and motor centers for voluntary movements of skeletal muscles. Primary olfactory portions of the hemispheres lag behind the rest of compartments and move ventrally and deeper into the telencephalon. Those portions are represented with the olfactory bulbs, olfactory tracts and related *paleocortex* (Lat. Id.) and *archicortex* (Lat. Id.) of the hippocampus.

In inferior mammals, surface of the hemispheres is smooth for lack of sulci and gyri. The superior species in turn develop numerous gyri delimited by sulci that give furrowed look to hemispheres. The sulci and gyri are quite expressed in hoofed animals, carnivora, cetaceans and primates. Neocortex becomes the base of conditioned-reflex activities that originate from experience. Also neocortex acquires associative areas responsible for intellectual activities.

Because of intensive growth of the cortex, the white matter and the corpus callosum that joins the hemispheres also exhibit intensive development. The hemispheres cover underlying compartments of the brain and therefore the neocortex has another name **pallium** (the cloak).

The cavity of neural tube in mammals transforms into the ventricles of brain and the central canal of the spinal cord.

Hierarchical arrangement of the brain compartments

The fundamental point of brain evolution in vertebrates constitutes origination of new structures with every next stage of evolution but not replacement of the older structures with new. Studying the brain, one should always keep in mind that the central nervous system of the superior vertebrates and the humans comprise both old and relatively new brain compartments. The new compartments develop later yet they feature functional domination over the old ones. The newest among all compartments is the neocortex that reaches maximum development in humans. The neocortex acquires superior regulatory centers that subordinate underlying compartments. This can be determined as corticalization of cerebral functions. Therefore, the CNS features hierarchical arrangement that provides most effective employment of superior brain compartments by committing data processing and precise computations to underlying compartments with loopback principle featured. Due to interrelations system, the cortex and subcortical regulatory centers communicate continuously and thus function as single whole.

3. Features of the human brain

In evolution process, weight of the brain enlarged due to continuous increase of neurons number. Human brain is one of the largest compared to other mammals. Larger animals possess larger brain. So human brain weighs 1400 grams, dolphin brain – 1800 grams, elephant brain – 5200 grams and in whales – 7000 grams.

Relative brain weight quotient (brain mass divided by body mass) is larger in small mammals. In humans, the quotient is lower than in some small primates and some other animals. In order to exclude body weight influence on brain weight, the "square weight index" is calculated as quotient of absolute and relative weight values. This index puts the humans into leading place among the rest of animals (32.0). In elephant, the index equals 9.62, in subhuman primates – up to 7.35, in dolphins – 6.72 and in carnivora – 1.14 etc.

Humans feature considerable domination of brain over the spinal cord and within the brain – domination of telencephalon over the rest of compartments. Another feature of human brain is well-developed frontal lobe, which is generally responsible for behavior of individual. In superior apes, the frontal lobe occupies 16 % of the entire hemisphere area and in humans – up to 30 %. Alongside with this, the cerebral cortex constitutes 40 % of the entire hemispheres volume and houses about 70 % of all CNS related neurons. Surfaces of hemispheres have numerous sulci and fissures that delimit numerous gyri.

Functional features of the cerebral cortex provide possibility of full possession of abstract thinking, which in turn provides the base for speech functions. This is the key feature that makes the human brain outstanding among the rest of animals.

DEVELOPMENT OF CNS IN HUMANS

Formation of neural tube from ectoderm

CNS arises on early stages of embryo development from the external embryonic plate. At the 19th day of embryo development, the neural plate detaches from the dorsal surface of the ectoderm (Fig. 2). Very soon, the neural plate gives rise to neural groove, which becomes the base of future CNS.

At the 4th week of development, intensive cell division leads to incorporation of the neural groove into the mesoderm; its edges fuse at midline thus forming the neural tube. Initially, the neural tube is open and has anterior and posterior openings – the neuropores that close sooner after.

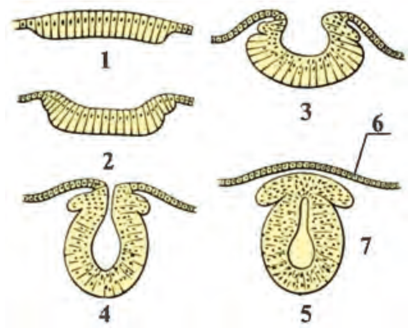

Fig. 2. Development of the nervous system (scheme). 1 – neural plate; 2, 3 – neural groove; 4, 5 – neural tube; 6 – epidermis; 7 – neural crests.

Formation of neural crest

Before fusion, the edges of neural groove give rise to lateral cell masses that run along the tube. Somewhat later, these masses develop into paired neural crests that undergo segmentation and give rise to spinal ganglia and the ganglia of cranial nerves. The ganglia comprise the bipolar neurons that further transform into pseudounipolar neurons.

Apart from this, some cells from the neural crests give rise to autonomic ganglia.

Differentiation of the neural tube

In the beginning, the neural tube is quite thin and consists of some layers of undifferentiated cells that further differentiate into neuroblasts that give rise to neurons and into spongioblasts that give rise to neuroglia and ependyma.

Neuroblasts exhibit intensive growth, which results in thickening of neural tube wall and gradual decrease of its density. At the end of the fourth week, the cranial end develops three dilations called primary vesicles because of thin walls and large cavities filled with fluid.

Three primary vesicles

The biggest anterior dilation matches the frontal region of embryo's head (Fig. 3). This vesicle is called the *forebrain* or *prosencephalon* (Lat. Id.). Smaller middle vesicle, *midbrain* or *mesencephalon* (Lat. Id.) is delimited from the rest of compartments by minor narrowed areas. The caudal vesicle is called the *hindbrain* or *rhombencephalon* (Lat. Id.); it is continuous with the spinal cord.

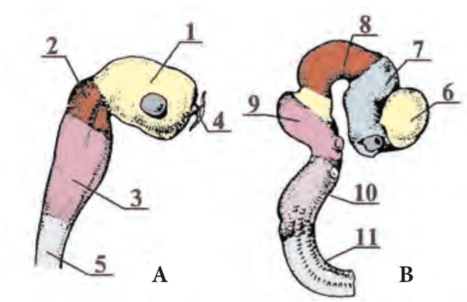

Fig. 3. Development of human brain (scheme) A – stage of three cerebral vesicles; **B** – stage of five cerebral vesicles. 1 – prosencephalon; 2, 8 – mesencephalon; 3 – rhombencephalon; 4 – vesicula optica; 5, 11 – medulla spinalis; 6 – telencephalon; 7 – diencephalon; 9 – metencephalon; 10 – myelencephalon.

Formation of five secondary cerebral vesicles

The stage of three vesicles is transient, and by the end of the fourth week, the neural tube undergoes further subdivision with formation of five cerebral vesicles. These vesicles give rise to respective compartments of the brain.

Secondary subdivisions affect only cranial and caudal vesicles while the middle one remains unchanged. Thus, in the beginning of the second month of development, the brain appears to comprise five secondary vesicles as follows:

1) The *telencephalon* (Lat. Id.);

2) The *diencephalon* (Lat. Id.); both telencephalon and diencephalon originate from the prosencephalon;

3) The *midbrain* or *mesencephalon* (Lat. Id.) that originates from the middle primary vesicle;

4) The *metencephalon* (Lat. Id.);

5) The *myelencephalon* (Lat. Id.); the last two compartments originate from the rhombencephalon, which is the caudal primary vesicle.

Formation of neural tube flexures

Apart from secondary vesicles, the neural tube develops several flexures that result from area-dependent growth intensity. The flexures are directed both ventrally and dorsally. The most remarkable of the dorsal flexures is the parietal flexure located in the area of middle vesicle. Another dorsal flexure is visible on the border between the fifth vesicle and the spinal cord. Somewhat later, another remarkable flexure appears in the area of pons. This so-called pontine flexure is directed ventrally.

Differentiation of the brain

Hemispheres primordia become evident in the telencephalon area at the sixth week of development. They grow quite rapidly and eventually almost cover other compartments. Small prominence on ventral surface of each hemisphere gives rise to rhinencephalon primordium.

Within the hemispheres, the nuclei of corpus striatum grow and protrude into the lateral ventricles. Cerebral cortex develops on the surface of hemispheres.

Sulci and gyri become distinguishable in the beginning of the second half of embryo development. The lateral (Sylvian) sulcus is the first to appear on hemisphere surface, next comes the central (Rolando's) sulcus followed by the calcarine sulcus and other. During last months of development, the surface of hemispheres acquires characteristic furrowed look. Cavities within the telencephalon transform into the lateral ventricles.

In the diencephalon, the most intensive growth is observed on the lateral side, where the sensory nuclei of thalamus reside. Here also the epithalamic region with featured pineal body develops. The ventral portion of the diencephalon gives rise to subthalamic region and posterior lobe of pituitary. The cavity of diencephalon transforms into unpaired third ventricle. Diencephalon also gives rise to optic vesicles protruding ventrally; they in turn differentiate into retina, optic nerves and optic tracts.

The mesencephalon gives rise to tectal plate and cerebral peduncles and its cavity transforms into the aqueduct (Sylvian aqueduct).

Dorsal portion of metencephalon gives rise to cerebellum while the ventral portion – to the pons. The fifth vesicle transforms into the medulla oblongata. The metencephalon and the medulla oblongata share the cavity of rhombencephalon that transforms into the fourth ventricle. Its floor is represented with the rhomboid fossa called so for characteristic shape.

Development of the spinal cord

As the neural tube grows, its walls become thicker and the cavity transforms into the central canal. The primordium of spinal cord becomes separated into ventral and dorsal portions by the *longitudinal sulcus* **(sulcus limitans)** that runs along the internal surface of the central canal on each side.

Later on, the wider ventral portion gives rise to ventral columns of grey matter. Here, the neuroblasts differentiate into big motor neurons; their axons grow and quit the spinal cord to form the ventral (anterior) roots.

Some cells migrate from the ventral columns to lateral portions and form the lateral columns that comprise the autonomic nuclei.

The dorsal portion gives rise to the dorsal columns of grey matter with featured sensory nuclei.

The central processes of pseudounipolar neurons located within the spinal ganglia primordia grow in direction of the ventral columns and form the ventral (posterior) roots of spinal cord.

At the end of third month, the grey matter appears fully differentiated while the white matter is not well distinguishable in this period.

Further, the processes of neurons exhibit rapid growth and acquire myelin sheath that results in formation of white matter that encloses the gray matter. Myelinization of the nerve fibers begins from the second half of embryo development and continues after birth.

Spinal cord growth lag

The spinal cord fully matches the vertebral canal up to the third month of development. Later on, spinal cord lags behind body growth and the caudal part of spinal cord even undergoes involution and eventually transforms into *filum terminale* (Lat. Id.).

Further, the vertebral column ever leads over the spinal cord and as far as the cranial portion of it attaches to the brain growth lag is observed in caudal portion. Shortening of the caudal portion resembles ascending (sometimes called “spinal cord ascent”). In newborn, the caudal end of spinal cord reaches L3 and in adult individuals, it is found between LI and L2.

The roots and spinal ganglia develop at first months of embryo life when the spinal cord matches the vertebral canal so the roots leave the spinal cord at right angle and run to respective intervertebral foramina. As the result of “spinal cord ascent”, the roots take skewed route and some even run vertically down within the vertebral canal before reaching the respective outlets. Thus, the roots of lower ten segments of spinal cord (lower four lumbar, five sacral and coccygeal segment) form the *cauda equina* (Lat. Id.) that comprises the *filum terminale* (Lat. Id.).

Practice questions:

1. Give definition of network-type nervous system.
2. Discuss the structure of ganglion-type nervous system.
3. Describe formation of tubular nervous system in chordates.
4. Discuss brain phylogeny basing on CNS features in:
   a) fish;
   b) amphibians;
   c) reptiles;
   d) mammals.
5. Discuss the essence of brain compartments hierarchy.
6. Discuss features of human brain.
7. Do intellectual abilities depend on brain weight?
8. Describe development of CNS in humans.
9. What primary vesicles develop on the cranial end of neural tube?
10. Name the secondary vesicles.
11. Describe the flexures of neural tube.
12. Describe development of spinal cord.
13. What processes lead to formation of cauda equina?

THE SPINAL CORD, MEDULLA SPINALIS

Terminology

Synonym **"myelos"** (Greek) gives rise to "myelin", poliomyelitis and other clinical terms.

EXTERNAL FEATURES

The spinal cord appears as whitish flattened strand 40–45 cm long and 1 cm thick. It occupies the vertebral canal and expands from the foramen magnum to upper border of L2 (Fig. 4). Its caudal end terminates with the *medullary cone,* **conus medullaris,** with *filum terminale* (Lat. Id.) that arises from the end of it.

The upper portion of the filum terminale consists of nervous tissue and is a rudimentary distal portion of the spinal cord. This 15 cm long portion is called the *spinal part of filum terminale,* **pars spinalis fili terminalis;** it runs downwards surrounded by the roots of lumbar and sacral nerves. Below S2, the filum comprises only spinal meninges. This portion is 8 cm long; it attaches to periosteum of the second coccygeal vertebra. In this portion, the *dural part,* **pars duralis,** and *pial part,* **pars pialis,** are distinguishable.

Clinical applications. As far as the spinal cord ends on the level of L2, this appears to have great clinical significance because space between L3 and L4 can be used for safe puncturing of vertebral canal with variety of purposes.

Enlargements of spinal cord

In spinal cord, there are two enlargements distinguishable:

- the *cervical enlargement,* **intumescentia cervicalis,** that appeared as the result of accumulation of the neurons and the nerve fibers that are responsible for supply of the upper limbs; it occupies the area from the fourth cervical to the first thoracic segment;
- the *lumbosacral enlargement,* **intumescentia lumbosacralis,** that houses the mass of neurons and nerve fibers that supply the lower limbs; it occupies the area from the second lumbar down to third sacral segment.

The animals that lack limbs (snakes) lack enlargements as well.

Fissures and sulci

The surface of the spinal cord features sulci and fissures as follows:

- the *anterior median fissure,* **fissura mediana anterior,** deeper one, it runs along the anterior surface from beginning down to the terminal portion of the spinal cord; it separates the spinal cord into left and right halves;
- the *posterior median sulcus,* **sulcus medianus posterior,** not that deep, it runs in the same fashion as previous; from the sulcus the *posterior median septum,* **septum medianum posterior,** that physically separates left and right halves of the spinal cord arises;

- the *anterolateral sulcus,* **sulcus anterolateralis,** paired, it passes the anterior roots;
- the *posterolateral sulcus,* **sulcus posterolateralis,** also paired, it passes the posterior roots.

The funiculi

The sulci that run along the white matter delimit several regions called the funiculi:

- the *anterior (ventral) funiculus,* **funiculus anterior,** delimited by the anterior median fissure and the anterolateral sulcus;
- the *lateral funiculus,* **funiculus lateralis,** delimited by the anterolateral and posterolateral sulci;
- the *posterior (dorsal) funiculus,* **funiculus posterior,** delimited by the posterolateral and posterior median sulci.

The roots of spinal nerves

The roots of spinal nerves are distinguishable along the whole length of spinal cord. They form two vertical rows. Each root consists of the *rootlets,* **fila radicularia** (Fig. 5). There are two types of the roots – the anterior and the posterior:

- the *anterior (motor) root,* **radix anterior (motoria),** it arises from the anterolateral sulcus and contains a set of axons of motor neurons located within the anterior columns; the anterior roots number 31 pair;
- the *posterior (sensory) root,* **radix posterior (sensoria),** it is a set of central processes of sensory pseudounipolar neurons located within
- the spinal ganglia; the posterior roots also number 31 pair.

The spinal ganglion, ganglion spinale

The spinal ganglion belongs to posterior root and is situated inside the intervertebral foramen around the junction of the

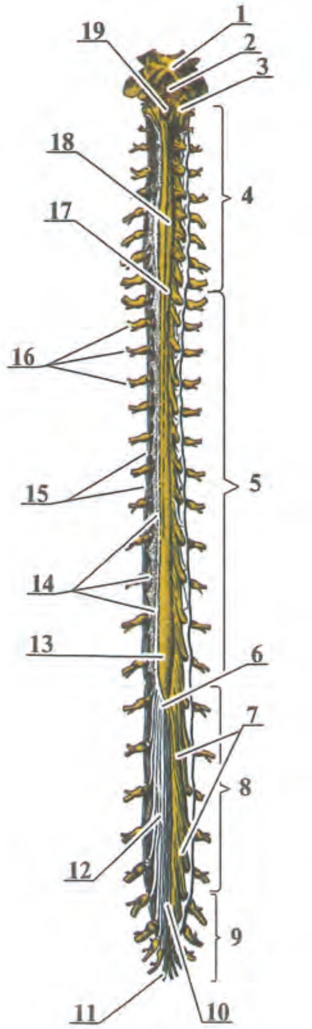

Fig. 4. The spinal cord with the roots and the spinal nerves (posterior view).
1 – tectum mesencephali; 2 – fossa rhomboidea; 3 – pedunculus cerebellaris inferior; 4 – nn. spinales cervicales (C1–C8); 5 – nn. spinales thoracici (Th1–Th12); 6 – conus medullaris; 7 – cauda equina; 8 – nn. spinales lumbales (L1–L5); 9 – nn. spinales sacrales (S1–S5); 10 – filum terminale; 11 – n. spinalis coccygeus; 12 – filum terminale, pars spinalis; 13 – intumescentia lumbosacralis; 14 – lig. denticulatum; 15 – dura mater spinalis; 16 – ganglia spinale; 17 – sulcus medianus posterior; 18 – intumescentia cervicalis; 19 – obex.

CONTENT