Peculiarities of the Autonomic Nervous System

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By

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Since the arrival of the COVID-19 pandemic, scientific publishing activity has changed radically. In the field of science and research, it is often not possible to carry out many scientific activities within the home office environment. The preparation of publications is being postponed. The COVID-19 pandemic also contributed to a delay in the creation of this scientific monograph.

CONTENTS

w. Differences in the structure of the aortic plexus
x. Innervation of lesser pelvis organs in men
y. Innervation of lesser pelvis organs in women
z. Differences in the structure of the spermatic plexus

ANNOTATION

The main goal of this book is to provide the reader with a better understanding of the involvement of the peripheral autonomic nervous system (ANS) in various pathologies.

The first chapter is a general part. The standard anatomical description, course and deviations of ANS formation are contained in the second and the third chapters of this book. The fourth chapter deals with the influence of ANS variations on the clinical picture. In the literature on peripheral ANS, insufficient attention is paid to the mechanics and semiotics of its disorders. We have not encountered work focused on morphological variations in the formation of the entire ANS on both sides. Anatomical and surgical textbooks usually do not sufficiently consider the anatomical peculiarities of peripheral ANS, which can complicate the solution of many pathologies. This study is the first complete description of morphological peculiarities related to the clinic of the entire peripheral ANS bilaterally (ganglia of sympathetic trunk, vertebral and prevertebral part of the ANS, branches, anastomoses including connections with the spinal system) and their possible impact on the clinical picture. Asymmetry was observed, and their occurrence was dependant on the type of ANS. The variations were numerous. Their preoperative diagnosis is difficult or even impossible.

In this work, we provide a systemic view of the sources and distribution of nerve plexuses and ganglia on both sides depending on the type of ANS. This brings us closer to a correct understanding of inconsistency – peculiarities in the development of pathological processes, differences in the clinical picture of different people and inconsistent success in operations. Missing or lack of preoperative wariness can lead to damage to the autonomic nervous system.

Variations affect the clinical picture. The acquired knowledge can be helpful in clarifying clinical signs and symptoms in internal medicine or surgery. It can also be useful for doctors of other specialties in dealing with

abdominal pain and small pelvic surgery (gynaecological operations, prostate surgery, colorectal surgery). It can also serve in the undergraduate and postgraduate education of medics and doctors.

LIST OF ABBREVIATIONS

aa. – arteriae (arteries)
ACTH – adrenocorticotropic hormone
ACH – acetylcholine
AChE – acetylcholinesterase
AIDS – acquired immune deficiency syndrome
ANS – autonomic nervous system
ant. – anterior
a./art. – arteria (artery)
ATP – adenosine triphosphate
CA – carcinoma
CCK – cholecystokinin
CNS – central nervous system
CT – computed tomography
DMV – dorsal motor nuclei of the vagus nerve
ENS – enteric nervous system
EPSP – excitatory postsynaptic potentials
ext. – externus
FB – fibres
Fig. – Figure
GABA – ɣ-aminobutyric acid
ggl. – ganglion
GSN – greater splanchnic nerve
H&E – haematoxylin and eosin staining
ChAC – choline acetyltransferase
IHP – inferior hypogastric plexus
inf. – inferior
IPSP – inhibitory postsynaptic potentials
lig. – ligamentum
LSN – lesser splanchnic nerve
m. – musculus (muscle)
MV – multivesicular bodies (corpuscula)
n. – nerve
NA – noradrenaline / norepinephrine
Na+ – sodium ion
NDNV – nucleus dorsalis of the vagus nerve

NGF – nerve growth factor
nn. – nervi (nerves)
NO – nitric oxide
NT – narrow tubules
NTS – nucleus tractus solitarius
NVB – neurovascular bundle
PSNS – parasympathetic nervous system
r. – ramus
rr. – rami
SNS – sympathetic nervous system
SV – synaptic vesicles
sup. – superior
VACHT – vesicular acetylcholine transporter
VIP – vasoactive intestinal peptide
VL – fibres
5-HT – serotonin
WT – wide tubules

INTRODUCTION

We wrote this book with the aim of making it easier for students and physicians to understand the complexity of the peripheral nervous system, including the autonomic, in relation to diagnosis and treatment. It can be an illustrative addition to undergraduate education for students as well as postgraduate education for physicians. Although the pictures look complicated at first glance, they are detailed enough to help a neurologist, a neurosurgeon or a physician of other specializations to revive the memory of the anatomical variability of the autonomic nervous system. The book will prove useful in studying anatomy. We mention the literature in the text only where it is necessary. The monograph is not large in scope, but it is beneficial for understanding the full range of variations of the autonomic nervous system.

It is based on the specific professional experience of the author and is a supplement to previous monographs on the variability of the peripheral nervous system. The structure of the autonomic nervous system, due to its unpredictability, can sometimes be perceived as very complex, sometimes as unsolvable. It is not possible to write solutions in the form of some mathematical expression or formula. We have to reconcile with a serious fact: sometimes we know the laws that govern the observed system, laws are also very simple; nevertheless, it is impossible to determine what the next development of the system will be. Even behind the seemingly complex beauty of nature, it is necessary to look for the repetition of simple rules. It turns out that natural creations, including body building, in many cases resemble a fractal approach.

CHAPTER I

GENERAL PART

Some variability in dimensions, form, structure and position is natural for the human body and its internal organs. Simply said, this is a tolerated natural variability. Any deviation exceeding the expected variability is commonly referred to as an anomaly [1]. It is caused by a different developing process during the formation of individual structures. It may be caused by genetic, chromosomal or environmental influences [1, 2]. Based on functional and cosmetic differences, anomalies are classified as small or large [3, 4]. While large anomalies are a common cause of disease, disability and death, small ones often have no medical consequences [2–4]. Therefore, small anomalies sometimes need a clear distinction from variations. Their incidence ranges from 7% to 41%, while the incidence of large anomalies ranges from 2% to 3% [4]. The term small anomaly is used to describe morphological defects that can be observed from the outside (flat occiput, hypotelorism, cleft vulva, microglossia, pigmented spots, shawl scrotum, cubitus valgus, prominent heel, etc.) [3, 4]. The presence of several small anomalies may indicate the presence of other, much more serious defects [2, 3]. Small anomalies differ from variations as they can be associated with large anomalies [2]. The term anomaly or malformation is used when structural changes normally have a negative effect on the function of the organism, as opposed to variations. However, under certain circumstances, even small, harmless variations can have a negative effect [5]. The history of anatomical variations is closely connected with the history of anatomy itself, with the history of searching for and establishing images of the normal structure and composition of the human body. The ancient anatomists Galen (129–200 BC) and Vesalius (1514–1564) drew attention to individual variations. Therefore, expressions such as always, often, sometimes, rarely, and very rarely can be found in their works. Claudius Galen was the first to describe Galen's anastomosis – ramus communicans nervi laryngei cum nervo laryngeo

inferiori, as well as venae cerebri internae and vena cerebri magna. Andreas Vesalius described anatomical variations of bones, muscles and blood vessels in his work *De Humani Corporis Fabrica Libri Septem* (1542). To understand the structure of the human body, he used dissection as the main instrument.

Several centuries were needed to establish normality, abnormality and variations of the human body. This knowledge, based on the work of many anatomists, biologists and clinicians, goes on to the presence in books and articles focused on the anatomical variations that under normal circumstances do not affect the function of the body.

Medicine needs more and more accurate knowledge of the variability of the construction of the human body to improve diagnosis and treatment. About 10% of misdiagnoses are based on ignoring of anatomical variability [6, 7]. Newer and newer screening methods have opened the door for the research of anatomical variations. Our work is focused on deviations from the norm – variations of the autonomic nervous system (ANS) and their relationship to the surrounding structures, which often determines the success of the operation. The results of anatomical studies are needed for a more accurate interpretation of both preoperative and clinical findings. Knowledge of the structure is a means of achieving the goal, which is the most perfect treatment of the patient. Imperfectly examined, incorrectly selected for surgery or inadequately operated upon patients will not have a good postoperative result despite considerable efforts. This can result in new or significant symptoms or deficits. The introduction of the operating microscope in the late 1960s significantly improved the results of operations. Good visibility of the operating field, optical magnification of the corresponding structures, and their perfect lighting and fine micro-instrumentation allows gentle and precise operation. We relied on the work and knowledge of K. Kapeller [8, 13], P. Haninec [9, 10], J. Šteňo [11] and E. Zvěřina [12]. The works of K. Kapeller and P. Mráz [13, 14] on the 'axonal flow' of autonomic nerves [13, 14] and on the transport of noradrenaline [15] are significant.

Tissue injury causes the disruption and destruction of cells whose fragments can no longer live. Tissue damage causes local changes that

lead to the removal of dead cells and the healing of the defect. Neurons are the only cells in which, after damage to parts of their body (axon), the damaged part of the axon is regenerated and functional unity is modified. Most of the information was obtained from the observation of structural manifestations occurring during the regeneration of peripheral nerves.

Unmyelinated axons are usually completely or partially enveloped by the Schwann cell cytoplasm. The uncovered part of the axon is in direct contact with the basal membrane.

Axons running in the interstitial between Schwann cells are newly regenerated axons that grow distally towards the site of injury: already after 20 minutes, at a distance of 0.5–1.5 mm proximally to the lesion site, the first occurrence of lateral axoplasmic unmyelinated axons was observed, which were connected by a narrow peduncle to the maternal axon. The content of the peduncle and the projection was intact and connected with the axoplasm of the maternal axon. These protrusions withdrew from the maternal axons most often in the period from 20 minutes to 1 hour. As similar formations of larger dimensions were more common in later periods, they might be regenerated axons that continue to grow [13].

We consider the mass occurrence of small axonal profiles associated with enlarged axons in the early period after surgery to be newly regenerated axons.

In the literature devoted to the peripheral nervous system, the issue of anatomy, histology and function is elaborated upon in some detail. However, in the aspect of monitoring pathogenesis, including peripheral nerve trauma, insufficient attention is paid to the mechanism and semiotics of ANS disorders. The basis for the correct understanding of these disorders must be the peculiarity of the structure of plexuses, peripheral nerve trunks and the ANS. These peculiarities can explain the contradiction and diversity of clinical manifestations. Functional insufficiency of vascular innervation is observed when nerves are damaged; the damaged limb shows a tendency of the vessels to spasm and a reduction in their adaptive possibilities due to irritation of vascular

structures. Reaction to heat – thermal irritation – is often repercussive in nature, indicating a lack of sympathetic vascular fibres. Disruption of sweating in the case of peripheral nervous system disorders has a segmental character, corresponding to the zone of loss of sensitivity. Based on the degree and nature of sweating disorders, we can judge the course and prognosis. The condition of the skin trophy and bones, especially causalgia, has an important place in the disruption of the ANS and is manifested by a number of clinical symptoms. Variations are numerous in the ANS.

The diversity and variability of clinical manifestations in nerve injuries in different people is due to the fact that one and the same nerve contains different amounts of myelinated and unmyelinated fibres. The largest number of autonomic nerve fibres is located in the median nerve (n. medianus) and the tibial nerve (n. tibialis).

Atypical localization of problems is explained by the presence of anastomoses of the damaged nerve with the surrounding nerves. It is caused by partial damage to the nerve conduction; the cause may be the scar tissue, intraneural neuromas and fibrous changes. The sympathetic nervous system is of great importance in the genesis of causalgia.

The aim of this work is to point out the anatomical variations of the autonomic nervous system and their participation in the clinic. Our own observations, some of which are presented, are the result of several years of systematic work on the cadavers of previously healthy people who died by violent death, most often in car accidents or sudden death. Work on variations of the ANS has allowed us to describe anatomical abnormalities on both sides.

In the available literature, we have only found scattered works devoted to this issue. We have not found any work focused on the bilateral detection of anatomical deviations in the formation of the entire peripheral ANS.

We monitored the anatomy and abnormalities of the peripheral ANS and their possible impact on the clinic. Twenty cadavers were examined (17 men and 3 women). The age of the cadavers ranged from 30 to 86 years. We followed cadavers without congenital or detected anomalies, cancer,

orthopaedic deformities, spinal or abdominal operations within 24 hours of death. In all of them, the autonomous system was clarified bilaterally; the body was in a supine position.

Subsequently, a 'scarf' skin incision was made on both sides along the clavicle to its lateral part. We deflected the skin and subcutaneous tissue upwards. The clavicles were separated from the sternal manubrium, the ribs were cut in the middle axillary line and the anterior chest wall was removed. First, we prepared the vagus nerve (n. vagus), sympathetic trunk (truncus sympathicus), spinal nerves (nn. spinales) and their branches, and the phrenic nerve (n. phrenicus). In older cadavers, the elasticity of the nerves and their strength were significantly reduced.

 After examination and removal of the lungs and mediastinal contents, the parietal pleura was carefully retracted to reveal the thoracic prevertebral sympathetic chains, ganglia and thoracic splanchnic nerves, with most of the diaphragm removed except for parts fixed to the posterior thoracic wall. After identification of the thoracic sympathetic ganglia, sympathetic chain and thoracic splanchnic nerves, connections between the ganglia and thoracic splanchnic nerves were studied.

Access to the neural structures of the abdominal cavity, including the ANS, was from a longitudinal section in the midline from the xiphoid process to the symphysis, bypassing the umbilicus. The incision was made through the linea alba and the anterior wall of the peritoneal sac, exposing the peritoneal cavity. An oblique incision along the mesentery was made from the suspensory muscle of the duodenum towards the caecum. The ascending and descending colons (colon ascendens, colon descendens) were mobilized by incision of the right and left paracolic mesenteric roots (radices mesenterii), and the sigmoid colon (colon sigmoideum) was separated from the rectum. The intestines, pancreas and remaining posterior parietal peritoneum were swept up to reveal the infrarenal retroperitoneum. After examination and removal of the abdominal organs, the coeliac plexus became clearly visible throughout. Increased attention was paid to the renal vessels, urethra, lower mesenteric and gonadal vessels, and plexuses.

Aortic plexus dissection was complete after identification of lumbar splanchnic nerves in interaortocaval fat. The right splanchnic nerves were monitored from behind to locate the right sympathetic chain and forward to isolate the preaortic nerves – the aortic plexus, followed by dissection of the left sympathetic chain and left lumbar splanchnic nerves to provide a basis for examining each preaortic nerve to differ intermesenteric nerves from the aortic plexus (16), from those inside the mesenteric plexus and which we have classified as intraperitoneal branches of the mesenteric plexus.

The position of the ganglia and nerves was documented photographically. Tissues identified as ganglia were excised for histological examination as well as for immunohistochemical analysis and verification.

Histological techniques were used to reliably identify ganglia obtained during dissections to determine if the identified structures contained neurons and cell bodies.

Ganglia removed during dissections were immediately fixed in 10% formaline solution for 24 hours and then embedded in paraffin. The samples were cut to a thickness of 5 µm and examined microscopically. All ganglia obtained were stained with haematoxylin-eosin (H&E).

Cell bodies were identified based on the qualitative characteristics of peripheral sympathetic ganglia – neurons with eccentrically deposited nuclei and a significant content – of cytoplasmic lipofuscin surrounded circumferentially by irregularly arranged satellite cells between elongated nuclei of the Schwann cells. Cell bodies of the vagus nerve were formed by large, pigment-depleted pseudo unipolar cells. The prehypogastric ganglion had a typical elongated shape with a dark centre and a length between 3 and 6 mm. In the pelvic part, we monitored the superior and inferior hypogastric plexuses, the rectal plexus and the vesical plexus, connections with the sympathetic trunk. In preparation for elucidating the autonomic innervation of the lesser pelvic organs, we also focused on the anatomy and deviations of neurovascular bundle formation in the pelvic structures.

Partial retroperitoneal clarification of the pelvic splanchnic nerves entering the pelvic plexus from the anterior, lateral and laterocaudal approaches was followed by removal of the pelvic organs by separating the peritoneum from the symphysis. The semi-circular movements of the fingers of both hands gradually separated the viscera of the small pelvis from its wall to the right, left and back, until the fingers of both hands touched themselves behind the rectum. We stretched the whole complex cranially and severed the urethra in men under the prostate and in women under the bladder, in whom we also severed the vagina and rectum. We pulled or sharply separated the rectum from the anterior surface of the sacrum, cut the peritoneum on its both sides and removed the entire complex of viscera from the small pelvis. Subsequently, we prepared pelvic plexus and nerve structures innervating the bladder, prostate and seminal vesicles lying laterally, cranially and dorsally from the prostate between the bladder and the rectum. We dilated the inguinal canal with two fingers up to half of the scrotum. By pressing on the lower pole of the scrotum, we pushed the testis and epididymis upwards and clarified the spermatic plexus and the plexus deferens. The fascial structures covering the sacral nerve roots were excised. Parasympathetic nerve roots were identified after detachment from the anterior nerve roots S2–S4 and dissected along their forward course to their exit at the lateral border of the rectum.

In all cadavers, the lumbosacral plexuses became clear on both sides from the anterior approach after evisceration.

The lumbar plexus was clarified after dissection of the psoas major muscle (m. psoas major). The lumbar plexus is formed in the psoas major muscle by ventral branches L1–L4 with or without the contribution of T12.

The main lumbar nerve roots and their branches were located along the surface of the most dorsolateral part of the vertebral bodies and intervertebral discs. The lumbar plexus is formed laterally from the intervertebral foramina and passes through the psoas major muscle.

The nerves of the sacral plexus are located on the anterior surface of the piriformis muscle (m. piriformis). The branches of the iliac vessels are

near the roots S1, S2 and S3. The sacral plexus is formed by the ventral branches of S1–S3 with the contribution of S4 and a very important lumbosacral trunk formed from the roots of L4 and L5. The border root involved in the formation of plexuses is the L4 root, which in some cases is largely involved in the formation of the lumbar plexus and in other cases of the sacral plexus. The L4 root does not always play the role of the border root; sometimes this happens to be the L5 root. As in the upper limb, some trunks of the lower limb receive more fascicles from higher positioned nerves than the low caudal form. With the prefixed type, the roots T12 and L1 are thicker. Then, the root L4 contributes more significantly to the sacral plexus and the roots S3 and S4 are missing. The involvement of the L4 root in the formation of the sacral plexus was seen in all cases. In neither case did we encounter a missing connection between the plexuses. The prefixed type occurred in two cases, postfixed in one case. In cases of the prefixed plexus, the thick lumbosacral trunk (truncus lumbosacralis) was present and only the roots S1 and S2 were present during the formation of the sacral plexus, and the nerves of the sacral plexus protruded from roots L5, S1 and S2. In the postfixed type, the lumbosacral trunk was thin and the roots S3, S4 and S5 were also present. In the postfixed type, the root S3 may have several fibres normally carried in the root S2, and the contribution of S4 may be larger [17]. The root damage differs from damage to individual nerves in that the palsies are usually partial and are located depending on the segmental innervation of the muscles.

The S4 root does not innervate any muscles in the limb. The coccygeal plexus (plexus coccygeus, S5–Co) serves as a purely somatosensitive innervation of the skin around the coccyx. Sometimes the junction from S4 and sometimes from S3 is connected. This small network is situated on the coccygeal muscle (m. coccygeus), and motor fibres exit from it. They contribute to the innervation of the elevator ani muscle (m. olevator ani), coccygeal muscle (m. coccygeus) and anococcygeal nerves (nn. anococcygei).

In the cervical region, we defined the level of the vertebrae by manually subtracting from the cranio-cervical junction and the roots by subtracting from the C2 root. In the prefixed type, the C4 root was involved in the

formation of the brachial plexus in two cases (10%). In the postfixed type, in one case (5%) the root T1 and T2. The T1 root in such cases has a lot of fibres normally carried in the C8 root, and the T2 contribution to the plexus may be greater. In the lumbosacral region, the roots were defined on the basis of their participation in the formation of plexuses. In the prefixed type, the front branch from the root L4 was thicker or as thick as roots L5, S1 and S2. A thicker lumbosacral trunk was present. In the postfixed type, the connection from the root L4 to the root L5 was thin, and the front roots S3, S4 and S5 were more distinct.

Many variations of cervical, brachial and lumbosacral plexus formation are, in addition to atypical clinical and electromyographic findings, a source of diagnostic confusion. It is important to comprehend what nerve functions are transmitted in different parts of the plexus. At the same time, it is necessary to think that due to the presence of various connections between the roots of the plexus, the innervation of the muscles and the symptomatology of the ANS may change. With the prefixed type, the nerve roots receive more fibres from the higher positioned spinal nerves. Damage of higher positioned spinal roots or nerves is accompanied by a much more widespread lesion on the periphery than is caused by the same damage in the postfixed type [16, 17].

Vertebromedullar topography

Considering the unequal length of the spinal canal and spinal cord for locating spinal cord segments, it is true that:

- the first four neck segments are in the range of the C1–C4 vertebrae
- segments C5–C8 and T1 are in the range of C5–7 and T1 vertebrae
- segments T2–T12 lie in the range of vertebrae T2–T9
- segments L5–S2 lie in the range of the vertebra L1 in a woman and in a man in the upper half of the vertebra L1
- the S3–Co segments lie in the range of the L1 vertebra

The position of the distances of the roots protruding from the individual spinal segments can be determined by the projection on the spinal projections of vertebras.

Chipault's rule:

1. on the cervical spine, +1˝ is added to the spinal process

2. + 3" is added on the chest

3. the caudal part of the spine T11 and the gap between T11–T12 determines the roots of segments L3–L5

4. the spine T12 and intervertebral space T12–L1 determines the height of the roots of nerves S1 and S5

CHAPTER II

CONSTRUCTION AND STRUCTURE OF THE PERIPHERAL AUTONOMIC NERVOUS SYSTEM AND ITS VARIATIONS

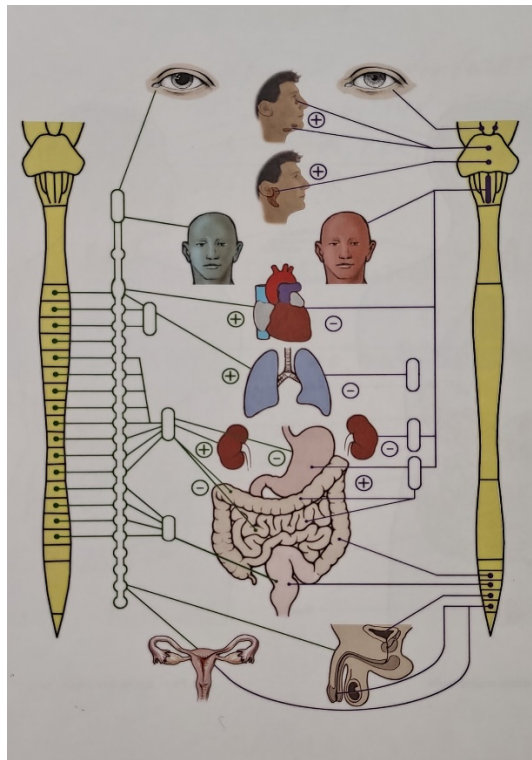The ANS has three sections (sympathetic, parasympathetic and enteric).

Figure II. 1: Scheme of the structure of the autonomic nervous system. Adapted from Putz, R, Pabst, R. Sobotta's atlas of human anatomy, Part 1: Head, neck, upper limb. Grada, 2006, p.29.

The ANS (Fig. II. 1) not only innervates the internal organs, vessels and glands but also participates in the innervation of skeletal muscles. This system is the primary mechanism for managing important functions. The sympathetic nervous system is a 'rapid response mobilization system' and the parasympathetic system is a 'slower activated and suppressing system', but this also has exceptions, for example in sexual arousal and orgasm. In addition, autonomic centres are known in the brain – the limbic-hypothalamic-reticular complex – and in the spinal cord. There are several described variants, anomalies and deviations from the norm, which are so numerous that they not only blur the understanding of the norm itself but also exclude any possibility of understanding some patterns in the construction of the peripheral section of the ANS.

Existing, although considerably incomplete comparable anatomical and embryological data suggest that in lower vertebrates, in which the initial metamery is somewhat preserved (fish), each segment corresponds to one ganglion located on the ventral surface of the vertebral column. The number of ganglia, then, corresponds to the number of segments the nerves of which are ganglia connected through communicating branches (rr. communicantes). Interganglionic branches (rr. interganglionares) are absent in lower vertebrates, as a result of which the sympathetic trunk forms a series of separate ganglia. In addition, ganglia are present in them scattered between the internal organs, in their walls. Mammals have the sympathetic trunk consisting of separate ganglia connected to each other by interganglionic branches (rr. interganglionares) and with spinal nerves with the help of rami communicates. Dividing of the system into vagus nerve (n. vagus) and sympathetic nerves did not occur completely. For example, in dogs, the vagus nerve and sympathetic trunk on the neck are tied into a single fibrous sleeve, which is divided in the upper part of the chest. In addition, in dogs there are multiple connections between the ganglia, the coeliac ganglion and the vagus nerve, which form the anterior and posterior plexuses in the stomach area.

The development of limbs in vertebrates is accompanied by a disruption of segmentality in the structure of peripheral nerves. This manifested itself in the formation of plexuses between the nerves of those segments that are involved in the formation of organs of movement. This process is also

reflected in the ANS. Here, the initial segmental placement of the ganglia is changed to connect the individual ganglia, that is, a reduction of their number in certain sections (cervical, lumbar and partially sacral). These processes take place to some extent in parallel with the separation of the sympathetic nervous system from the system of the vagus nerve. Data from studies of a comparable anatomy led to the conclusion that in the early stages of development of the peripheral section of the ANS, segmental deposition of divided ganglia of the sympathetic trunk is present. In the next stage, the ganglia are connected to each other with the help of interganglionic branches, in some species even forming two strains – the collateral sympathetic trunk (truncus sympathicus collateralis). The formation of the sympathetic trunk arises to some extent in parallel with the separation of the vagus nerve system from the sympathetic system also with the concentration of ganglion masses, especially in the boundaries of segments involved in the formation of limbs. The sympathetic trunk and prevertebral ganglia have their origin in the ectoderm.

Already in the period when the neural groove is cleaved from the ectoderm and changes into a neural tube, the cell strips are separated on both sides from the ectoderm. They are so-called ganglion strips that extend rostrally to the mesencephalon. These are then divided into cell clusters, which form the basis of the spinal ganglia and ganglia of some cranial nerves (temporarily XII. and XI., and permanently X., IX., VIII., VII. and V.). Spinal ganglion cell projections grow into the periphery, where they branch or connect to the bases of receptors and grow into the neural tube. Here, they connect directly or indirectly to nerve cells, whose efferent fibres grow towards the effectors. Both take place at a very early stage; the connection to the periphery is ensured from the beginning at least by plasma junctions. The neural crest is not only a source of spinal, cranial and autonomic ganglia, but also cells of other types – Schwann cells enveloping peripheral nerve fibres, pia mater, arachnoid cells, perineural epithelium, pigment cells and mesenchymal cells (mesoectoderm), from which the basics of the visceral skeleton of the head develop. From the neural tube and the ganglial crest, the whole nervous system develops, with some exceptions, when the sensory cells arise directly from special thickening of

the ectoderm, the so-called placode. These include, for example, nerve cells and olfactory nerve fibres.

In the seventh week of development, cells marked as sympathicoblasts travel out of the sympathetic trunk area and form larger or smaller groups, the so-called paraganglia. These are derivatives of the neural crest. The adrenal medulla of the kidney belongs to the chromaffin paraganglia. They differentiate into cells that produce adrenaline and norepinephrine. We call them chromaffinoblasts. In the seventh to eighth week of development, chromaffinoblasts separate from the bases of neighbouring sympathetic ganglia and migrate to the bases of the adrenal gland. The cells also separate from other bases of the sympathetic ganglia and form separate cell clusters – the aortic paraganglion (Zuckerkandl's organ) near the aorta as well as the carotid body (glomus caroticum) in the place of branching of the common carotid artery (a. carotis communis).

Communicating branches (rr. communicantes) are the protrusions of neuroblasts on which the cells migrate to the periphery; in the next stage they become postganglionic axons of cells forming the sympathetic centre, which is located in the lateral horn of the spinal cord (intermediolateral nucleus) and spreads from the first thoracic to the second lumbar segment.

Their myelinated axons spread from the spinal cord through the ventral roots in parallel with the motor axons that supply skeletal muscles. Shortly after the junction of the dorsal and ventral roots of the spinal nerve, the preganglionic sympathetic axons, which are derived from the neuroepithelia of the neural tube, leave the spinal nerve like the white communicating branches (rami communicantes albi). These subsequently enter one of a series of sympathetic ganglia and form synapses from the neural crest derived by postganglionic neurons. When migrating sympathetic neuroblasts reach the site where the sympathetic chain ganglia – the sympathetic trunk – form, they spread cranially and caudally, reaching approximately the level of adults.

The white communicating branches (rr. communicantes albi) are not only intended for the nearest sympathetic ganglion, but bend inside the sympathetic trunk cranially and caudally, while the fibres from T11 to L3

bend only caudally. Each of the sympathetic trunk ganglia thus receives preganglionic fibres from a large number of spinal nerves.

 Preganglionic sympathetic neurons (axons) terminate either in the ganglia of the sympathetic trunk chain or continue to more distant sympathetic ganglia, forming synapses with second-order cell bodies by postganglionic sympathetic neuroblasts. The axons of some non-myelinated postganglionic neuroblasts leave the ganglia of the chain as a parallel group and enter the nearest spinal nerve as the grey communicating branches (rami communicantes grisei), where these axons continue in the spinal nerve until they reach peripheral targets – places such as sweat glands and blood vessel walls. The axons of other postganglionic sympathetic neurons leave their corresponding ganglia and grow as nerve fibre plexuses to the viscera. As visceral and vascular rami, they can occur either as periarterial plexuses or separately. Some of the sympathetic neuroblasts migrate further into the area in front of the aorta and form the so-called prevertebral ganglia. They are involved in the formation of plexuses (coeliac, mesenteric and hypogastric) and in the wall of the organs of the digestive system submucousal plexus (Meissneri) and myenteric plexus (Auerbachi). Some of the cells go to the internal organs and group into the peripheral ganglia.

The number of postganglionic fibres emanating from the sympathetic trunk ganglia or from the prevertebral ganglion is much greater than the number of preganglionic fibres.

Between the vagus nerve and sympathetic nerves, many conjunctions are found, and even a migration of cells from the superior cervical ganglion to the nodosum ganglion of the vagus nerve is observed.

The latter is confirmed by the presence of sympathetic fibres and cells in the strain of the vagus nerve. In contrast, parasympathetic nerve fibres and cells in the sympathetic trunk are observed.

Thus, the sympathetic trunk, the coeliac plexus and their branches represent one genetic unit. Considering comparable anatomical and embryological data, we can assume that by slowing down the development of the sympathetic system, it can be found during cell migration, that is, to communicating branches even near the roots, small ganglia and segmental