ORIGINAL ARTICLE

CONTENTS

Structural peculiarities of the vascular plexuses of the cerebral ventricles during postnatal ontogenesis

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ABSTRACT

Aim: To study the structural features of vascular plexuses of the cerebral ventricles at different stages of ontogenesis.

Materials and Methods: The results of the study were obtained by examining the vascular plexuses of the ventricles of the human brain. Brain specimens from people aged up to 86 years were examined. Macro-, micro- and submicroscopic, light-optical, and statistical methods were used to establish the morphological features of the structure and innervation and to identify the nerve-receptor apparatus of the vessels and tissue substrate of the vascular plexuses of the human brain ventricles at different stages of ontogenesis.

Results: Research has shown that the vascular plexuses of the ventricles of the human brain consist of epithelium and connective tissue with a large number of blood vessels. The plexus has villous and non-villous parts. The epithelium is represented by light and dark cells of cubic and flattened shape. The stroma of the vascular p lexus consists of collagen fibrils, protofibrils, and fibers enclosed in the ground substance. Fibroblasts are located here singly and in groups. A large number of microvilli and cilia are found on the apical surface of epithelial cells. The nuclei of epithelial cells are located near the basement membrane of the epithelium and can take on various shapes. Contacts between epithelial cells are most often in the form of tight junctions. A small number of macrophages and mast cells are found at the border with epithelial cells. It should be noted that vascular plexuses, in terms of vascularization, are organs with dual blood supply (trophic and functional). The basis of the vascular plexus is formed by blood vessels, which, after entering the thickness of the plexus, branch off from the main vessels running along the plexus into a microcirculatory bed with a highly complex structure. We have established that the diameters of microvessels undergo changes during ontogenesis that correlate with changes in the plexus itself, occurring simultaneously with the development of the brain.

Conclusions: The basis of the vascular plexuses of the cerebral ventricles is formed by a collection of blood vessels – from muscular arteries to capillaries, which come into contact with the ependymal epithelium in the villi of the plexus. The microcirculatory bed is adapted to its connective tissue environment and is closely functionally related to the epithelium of the vascular organ. Capillaries with polar arrangement of fenestrated endothelial cells on the side of the vascular plexus epithelium predominate, indicating their active transport function and participation in the function of the blood-cerebrospinal fluid barrier as part of the blood-brain barrier. Microvessels undergo changes during ontogenesis that correlate with changes in the plexus itself, which occur simultaneously with the development of the brain and reflect the functional loads of the vascular plexus.

KEY WORDS: vascular plexuses, cerebral ventricles, ventricles of the brain, postnatal ontogenesis, microscopy, blood vessels, microcirculatory bed

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INTRODUCTION

The macroscopic anatomy of the vascular plexuses of the ventricles of the human brain is well described in the literature [1]. The vascular plexuses of the ventricles, as derivatives of the soft meninges, connect the circulatory and nervous systems and participate in cerebrospinal fluid dynamics [2, 3, 4]. The disruption of the functions of these structures is associated with the onset of some serious diseases of the central nervous system, in particular, hydrocephalus, intrauterine hydrocephalus, schizophrenia, epilepsy, and Alzheimer's disease, which is based on the atrophy of the epithelium of the vascular plexuses [5, 6].

The role of blood vessels in brain metabolism, cerebrospinal fluid formation and outflow, and in maintaining the stability of its pressure and physicochemical composition is universally recognized and indisputable.

Significant advances in modern neurosurgery, the growth of surgical interventions in the area of the cerebral ventricles and vascular plexuses, experimental

and clinical studies conducted on these structures, and attempts at their transplantation [7, 8, 9] increase curiosity in studying the morphology of neurovascular and tissue structures and their interactions, which is the main task in solving many unresolved issues in neurology and neurosurgery.

The relevance of the study is also determined by the scale of vascular pathology of the brain, which arises from sclerosis of the vascular walls and occupies a significant share in the list of diseases.

AIM

To study the structural features of the vascular plexuses of the cerebral ventricles at different stages of ontogenesis.

MATERIALS AND METHODS

The results of the study were obtained by studying the vascular plexuses of the ventricles of the human brain. Brain specimens from people aged up to 86 years were examined. The structure of the vascular plexuses of the ventricles of the human brain was studied using various methods at different stages of ontogenesis.

Anatomical dissection method. The brain, carefully removed from the skull of the cadaver, was placed in a desiccator with a formalin solution of increasing concentration (1% - 2 days, 3% - 2 days, 5-6% - 2 days, and 10% - 1 week). In addition, additional fixation was performed with a 3% formalin solution through the lower wall of the third ventricle (substantia perforata posterior) using a long needle, which was inserted to a depth of 1–1.5 cm and injected with 15–20 ml of the specified solution. Five brain specimens were fixed in this manner. The brain was in a "floating" state in the desiccator. Next, a series of horizontal cuts were made with a brain knife from the dorsal surface of the brain to the transverse fibers of the corpus callosum. Then the anterior horns of the lateral ventricles were opened and the brain knife was directed obliquely downward, opening the basal nuclei. Additionally, a scalpel and scissors were used to open the walls of the lower and posterior horns of the lateral ventricles, in which vascular plexuses were found. To demonstrate the central part of the lateral ventricles and the third ventricle, the corpus callosum was removed and the vault of the brain was dissected.

After isolating the epiphysis, the upper and posterior walls of the fourth ventricle were opened, revealing the vascular plexus of the fourth ventricle.

To study the structure of the microvascular bed of the ventricular vascular plexuses, the method proposed by V.V. Banin et al. was used.

For electron microscopic examination, material from the vascular plexuses extracted from the ventricular cavity immediately after opening was used. The material was placed in a Petri dish with a 2.5% solution of glutaraldehyde in 0.1M phosphate buffer. The vascular plexus was stretched on a transparent inert plastic plate with holes, after which the Petri dish was placed on the table of an MBS-9 binocular magnifier, where pieces measuring 0.3 x 0.5 cm were studied and cut out from various areas of the vascular plexus. These pieces were placed in fresh portions of 2.5% glutaraldehyde in 0.1 phosphate buffer (pH 7.2–7.4). This was followed by washing in phosphate buffer, followed by post-fixation with osmium fixative according to Milongi (1962) for 2 hours, washing and dehydration in alcohols of increasing concentration, impregnation, and casting in EPON-812 polymer resins. The sections were prepared on an LKB-III ultramicrotome. Contrasting was performed with uranyl acetate and lead citrate according to Reynolds (1963). The ultrathin sections were examined in a Hitaci HU-12A electron microscope.

The results obtained were subjected to computer processing using various variational, descriptive, and dispersion methods, Student's t-test, F-test, D-test, and ANOVA dispersion analysis.

The results obtained were processed using variational, descriptive, and dispersion methods. The results obtained were processed using variational, descriptive, and dispersion methods. The mounted preparations were photographed using a Zenit ET camera on low-sensitivity Micrat or RF-1 film, as well as an Olympus or Canon digital camera.

RESULTS

The vascular plexuses of the ventricles of the human brain are vascular organs consisting of a base and villi, which macroscopically in newborns and children appear as gray or dark red strands.

By the period of sexual maturity, the vascular plexuses are almost indistinguishable in appearance from those in adults. At this age, the vascular plexuses of all ventricles of the brain macroscopically appear as granular strands of red or yellowish-red color.

During this period, bubble-like, cystic indentations containing clear or yellowish fluid are observed in some vascular plexuses of the lateral and third ventricles of the brain. These formations can occur in various areas of the plexus in clusters or individually.

In the vascular plexuses of the ventricles of the brain in people over 60 years of age, cystic formations may appear as small bubbles or single large bubbles filled

with clear fluid. No cysts were observed in the vascular plexuses of the fourth ventricle.

In adults, the vascular plexus is a complex of blood vessels with accompanying connective tissue.

Microscopic analysis has revealed all the structural elements of vascular plexuses, including blood vessels of various diameters, nerve bundles, and fibers. It turns out that the initial structure of the organ is connective tissue stroma, which is a modified soft meningeal membrane located at the base of the plexus. Blood vessels and nerve fibers pass through it.

The entire stromal-vascular complex is covered on the outside by epithelium. Since the total area of the epithelial covering is larger than the area of the stromal-vascular complex, the surface becomes folded and villous.

Among the villi, one can distinguish between simple and more complex, large villi consisting of many lobes. Complex villi are mainly located at the edges of the plexus and consist of a large number of small villi forming lush branches.

The epithelium covering the vascular plexus is composed of cubic cells arranged in a single row. The epithelial lining and the surface of the villi are well visible when stained with Schiff's reagent. It is attached to the underlying basement membrane. The average height of the cells is 15 μm. In cross sections, the profile of the epithelial cells is polygonal, more often hexagonal. The nucleus is round, occupies a central position in the cell, has a nucleolus, and diffusely distributed chromatophilic granules. The cytoplasm contains the usual set of organelles.

So, the vascular plexuses of the ventricles of the brain consist of connective tissue, epithelium, and blood vessels. They are divided into a villous part, which contains a huge number of villi covered with a single layer of epithelium.

In preparations, you can see different types of villi containing links of the microcirculatory bed with twisted and loop-shaped passages. Villi can be of different sizes, from small to large, and are located singly or in various combinations. Large blood vessels are located in the center of large villi, surrounded by a wide-looped network of fibers, while capillaries pass through small villi, located in the center of the villi. Some capillaries have a wide lumen and can be located in close proximity to the epithelial lining, while others with a narrow lumen are located in the deeper layers of the vascular plexus. Many blood vessels are contained in the connective tissue stroma of the plexus. The vessels of the microcirculatory bed mainly flow towards the epithelium of the vascular plexus. Most of them have a straight course, compared to the microcirculatory bed of the villi, and some of them, which are thinner, meander, approaching or moving away from larger vessels.

The vascular plexuses of the ventricles of the human brain have a well-developed blood supply and a complex organization of the microcirculatory bed. This reflects the general principle of vascularization of the brain, which is in special hemodynamic conditions.

The third ventricle is supplied with blood by the lateral and medial choroidal arteries, which originate from the posterior cerebral artery and branches of the superior cerebellar artery, as well as branches of the anterior choroidal artery. They supply blood to the vascular covering – the vascular plexus of the third ventricle, the quadrigeminal plate, the optic tubercle, and the walls of the third ventricle. In the thickness of the plexuses, the arteries divide into arterioles, which spread throughout the vascular plexus.

The microvessels intertwine and anastomose with each other, ensuring adequate blood supply to all parts of the villous and non-villous parts of the plexus. At the edge of the plexus, they form microarcades, which in the cluster-like part deepen into the fringes of the villi. The microcirculatory bed makes up most of the vascular plexus: there are precapillaries, capillaries, and postcapillaries connecting the arteriolar and venular parts of the vascular plexus.

The vascular plexuses of the third and fourth ventricles, compared to the vascular plexuses of the lateral ventricles, are less rich in villi.

On semi-thin sections of the vascular plexus of the fourth ventricle, wide and narrow capillaries of the villi and tissue substrate with a thin endothelial lining are visible. Connective tissue elements accompany the bloodstream. The epithelial lining is represented by cubic cells arranged in a single row, with distinct, rounded or oval-shaped, centrally located nuclei. Prismatic-shaped cells are also found. Among the epithelial cells, there are cells with light and "dark" cytoplasm. They are in different phases of the secretory cycle.

The vessels that deliver blood to the microcirculatory bed of the vascular plexus are arterioles, which branch off from the villous arteries and their branches.

They usually occupy a more lateral, external position relative to the venules that accompany them.

Following the periphery of the vascular plexus, first-order arterioles (A1) branch and anastomose with each other: numerous second-order arterioles (A2) originate from them, whose diameter does not exceed 35-55 μm. which retain a single continuous layer of smooth muscle cells in their wall.

Arterioles and their branches are clearly directed towards the villi, where they break down into a huge number of capillary loops with a wide lumen, which

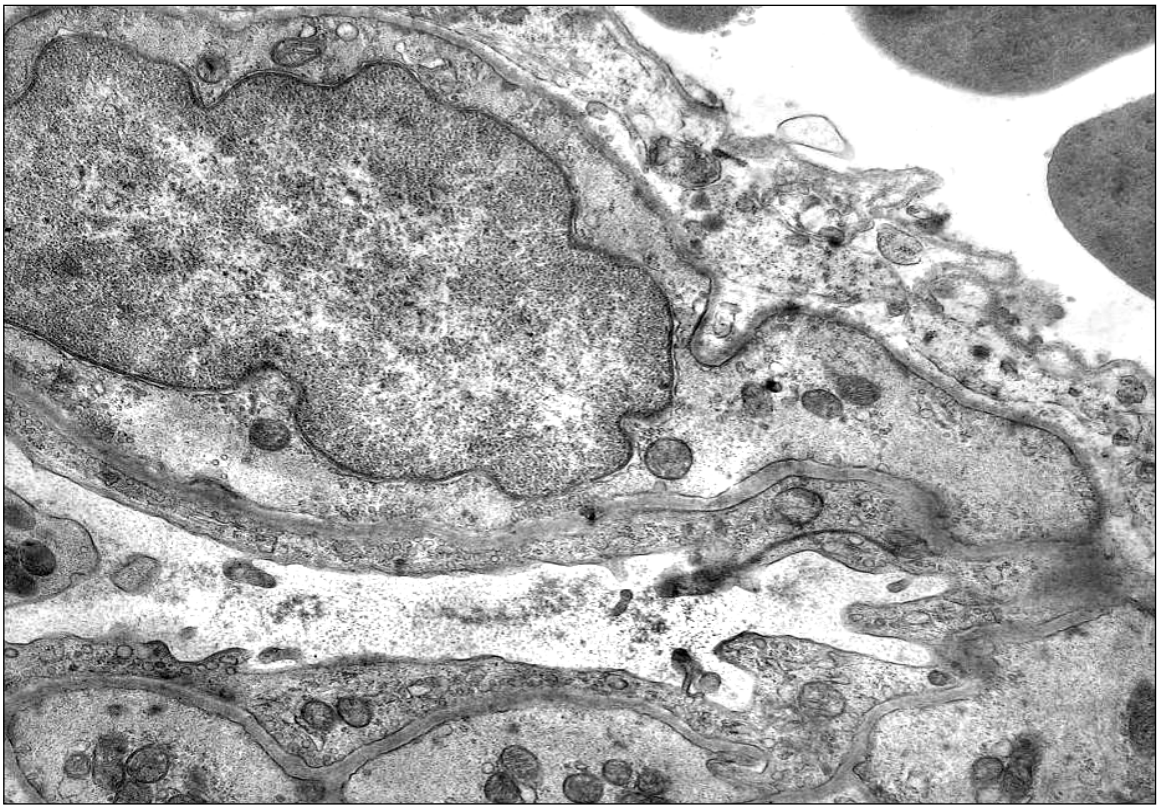

Fig. 1. Structure of the arteriolar wall of the vascular plexus of the cerebral ventricle. Electron micrograph. X 25000. Tunica media

enter the villi. Anastomoses between homogeneous arteriolar microvessels are quite common and have an arcuate appearance: the loops of vessels are distributed in the marginal zones of the vascular plexus as if in tiers.

The transition of arterioles into precapillaries (precapillary arterioles) occurs gradually. The latter directly form blood capillaries and ultimately form a cellular network.

Several precapillary arterioles branch off from each arteriolar arcade, which are mainly connected to the fragment of the capillary network located near this arcade.

Some of the precapillary arterioles supply blood to the capillaries that are part of adjacent fragments, which are topographically connected to neighboring arteriolar arches through their system of precapillaries. Blood from the capillaries collects in venules and veins.

These anatomical connections between the precapillaries and the exchange microvessels are important for changing the amount of blood flowing into the capillaries, which helps regulate cerebral blood flow, intracranial pressure, and the volume of cerebrospinal fluid that penetrates through the capillary wall into the ventricular lumen.

In the villus stalk, the arteriole branches off to secondary villi. In this case, each lobe of the complex villus has its own precapillary arteriole. Sometimes the afferent vessel continues without branching and reaches the top of the villus, passing into a marginal capillary loop. The other end of the loop becomes an efferent vessel – a postcapillary venule.

At the stage of blood delivery to the ependyma of the vascular plexus, there are muscle structures formed by smooth muscle cells at the points where the arterioles and precapillaries branch off from the main trunk.

This means that at the points where the arterial vessels of the plexus divide, there are areas with a more developed muscle layer.

As a result of their periodic contraction or relaxation, selective regulation of a small vascular basin, two or more capillaries, into which the corresponding precapillaries branch, is achieved.

Differentiation of vessels is complicated by the fact that precapillary arterioles do not have the wall typical of arterioles. There are almost no smooth muscle cells in it.

The inner surface of the arterioles of the vascular plexus of the cerebral ventricle is lined with a continuous layer of endothelial cells, which are thinned in the peripheral sections, except for the nucleus area, and are 40-50 μm long and up to 7 μm wide. Thick and thin microfilaments are present in their cytoplasm. The lamellar complex, cytoplasmic network, free ribosomes, and micropinocytic vesicles are located throughout the cell surface. Outside, the endothelial and subendothelial lining of the arterioles is surrounded by connective tis-

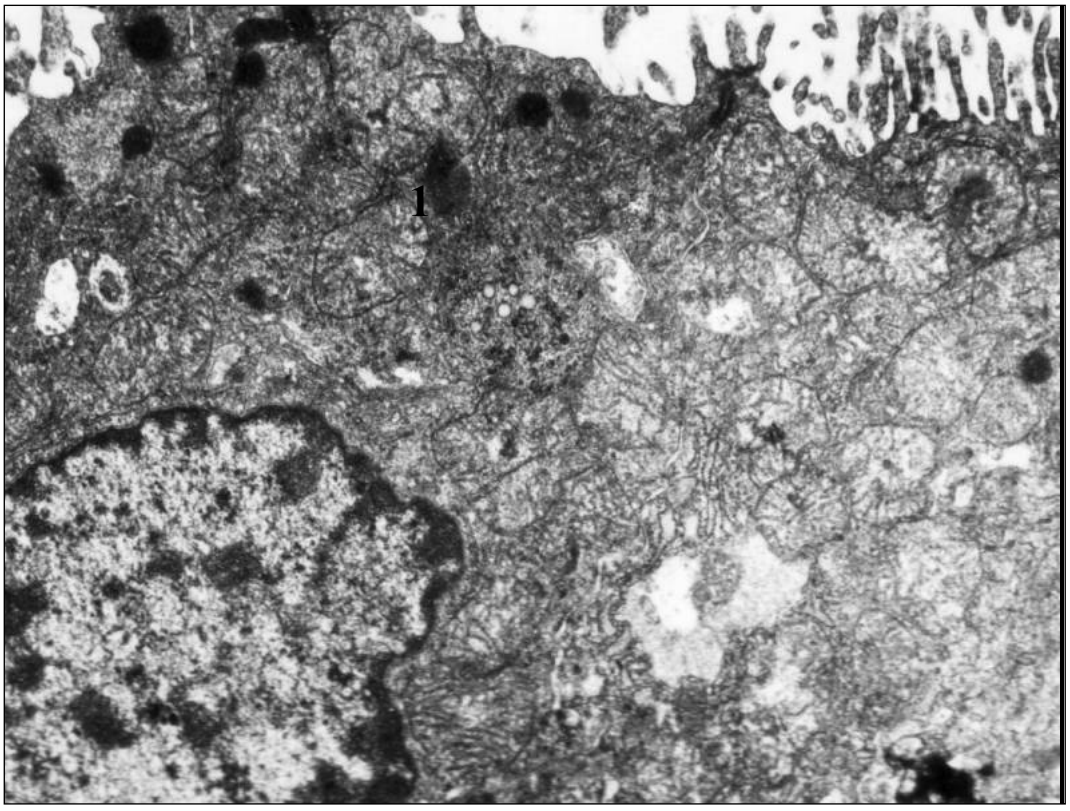

Fig. 2. Epithelial cell of the vascular plexus. Electron micrograph. X 20000

sue, with a layer of ground substance and a few fibrous elements, and there is an internal elastic membrane.

The microfilaments are well defined and directly adjacent to the basal surface of the endothelial cells. They are oriented in a variety of directions and intertwine.

The material localized in the subendothelial zone of the inner membrane is characterized by high electron density. The density of fibrillar elements in different areas is uneven and takes on the appearance of a heterogeneous spotted structure. Collagen fibers, elastic elements, and smooth muscle cells are also often found here. The elastic membrane is not a continuous formation. It contains numerous fenestrae through which the processes of endothelial cells can penetrate.

This membrane structure helps make the vessel more flexible.

The tunica media of the arteriolar wall (Fig. 1) is made up of two or three layers of smooth muscle cells, which are mostly arranged in a circular pattern. Smooth myocytes are spindle-shaped, with uneven serrated edges.

Cell sizes are not constant within the wall of the same vessel. The nuclei are round or oval in shape, depending on the projection of the section.

Often, folds form on their surface, giving the nucleus an irregular shape.

In areas of the cytoplasm free of myofilaments, mitochondria are well defined, located around the nucleus, but they often form abundant clusters at the periphery of the cell. Some of them are associated with elements of a well-developed endoplasmic reticulum.

Canaliculi of the cytoplasmic network are identified, which are sometimes lost between myofibrils. Membrane structures of the endoplasmic network are observed in the central areas of the cell, where the lamellar complex, ribosomes, and polysomes are located. Micropinocytic vesicles are often found.

Myofibrils occupy most of the cytoplasm, except for the perinuclear zone and the most peripheral areas of the cell. They are located along the length of the myocyte without a strict orientation. Adjacent smooth muscle cells are separated from each other by elastic membranes and layers of connective tissue, whose collagen and elastic fibers form a well-defined framework for these cells.

Contacts between them can be quite complex and are established by means of marginal cytoplasmic protrusions that pass through the basement membrane of both cells to the surface of adjacent cells, where, in particular, corresponding indentations are formed.

These connections are formed by the plasma membranes of muscle cells and the basal processes of endothelial cells, which are adjacent to the surface of the myocyte with their expanded part.

The plasma membrane of smooth muscle cells often has osmiophilic formations that are relatively evenly

distributed around the periphery of the myocyte. In some places, it can be seen that these bodies are in close contact with myofibrils.

The fibrous elements of connective tissue in the muscle membrane are represented by separate collagen fibers and microfilaments in the spaces between the basement membranes.

Myoendothelial contacts in arterioles are not pronounced due to the presence of a well-defined basement membrane of the endothelium, which clearly separates the inner layer of the arteriole from the middle and muscular layers, and are a random finding in those areas where the elastic membrane is almost completely absent (transition of arterioles into terminal branches).

As arterioles branch and become smaller, their walls become thinner and the lumen narrower. In small arterioles, the inner and outer elastic membranes become very thin or may be absent. The number of layers of smooth muscle cells decreases to one, and their size also decreases.

The outer layer of small arterioles is super thin and is mostly made up of delicate bundles of collagen fibers.

Meanwhile, the wall of the arteriole can be really close to the basement membrane and the basal labyrinth of the ependyma. True capillaries are located nearby. A layer of epithelium covers the bulging surface of the villi where the arterioles pass through the marginal zone.

Morphometric data indicate rapid growth in the diameter of the arterioles of the vascular plexus of the third ventricle in newborns and a sharp decrease in its diameter by early childhood, which cannot be said about the diameter of the arterioles in the vascular plexuses of the fourth and lateral ventricles. Further, the arterioles of the third ventricle lag behind in diameter until adulthood, when their diameters equal those of the arterioles of the vascular plexuses of the lateral and fourth ventricles. With the onset of old age and senility, their diameter decreases sharply.

The diameter of the arterioles of the vascular plexuses of the lateral ventricles gradually increases until early childhood, followed by a sharp increase until adolescence and reaching a maximum in adulthood. The arterioles of the vascular plexuses of the fourth ventricle repeat the diameters of those of the lateral ventricles in their development, but with the smallest values.

There is also a sharp increase in their diameters during adolescence and a sharp decrease in old age.

This is obviously associated with age-related and sclerotic phenomena that occur in the walls of blood vessels.

The diameter of the precapillaries of the vascular plexus of the fourth ventricle lags behind the diameter of the precapillaries of the third and lateral ventricles until infancy.

From early childhood to late childhood, there is a noticeable rapid increase in their diameter. Then, their diameter decreases again in adulthood. During these periods, the smallest diameter remains in the precapillaries of the vascular plexus of the third ventricle.

In children during their first year of life, there is mainly an intensive process of differentiation and growth of the diameters of the vessels of the vascular plexus of the cerebral ventricle.

At the same time, qualitative changes in the vessels also occur. In the vascular plexus, the ependymal epithelium is represented by columnar ependymocytes. The height of the cells varies from 15 (cubic cells) to 30 μm (prismatic).

Most ependymocytes (Fig. 2) have cilia. In terms of their structure and configuration, they are true epithelial cells.

Both the endothelium of the vascular plexus and the epithelium of the ventricles are elements of the blood-cerebrospinal fluid barrier.

The cytoplasm of the epithelial cell contains a large number of round or oval-shaped mitochondria. The endoplasmic reticulum is well developed, and a moderate number of electron-dense vesicles occupy the apical part of the cell cytoplasm. The cytomembrane of the apical part contains numerous microvilli in the form of finger-like protrusions.

This refers to the aforementioned cilia that form the cell border of the apical surface of ependymocytes, as well as the richly branched processes on their basal surface: together they form the so-called labyrinth, because the cell processes branch in the basement membrane and form a system of gaps between the processes filled with lipoproteins. A wide layer of the basal labyrinth is in contact with the connective tissue cells of the soft membrane and with the basement membrane of the blood capillaries.

DISCUSSION

In the literature, the vascular plexus is defined as a special vascular organ of the central nervous system that develops from the pia mater.

According to textbooks [1, 7], the tela chorioidea of the fourth ventricle is represented by a triangular section of the soft meninges covered with epithelium and penetrating the transverse fissure of the cerebellum. The base of the triangle points upward and forward, and the apex points backward toward the posterior end of the fourth ventricle. It is attached to the lower lateral edges of the rhomboid fossa and to the edge of the inferior cerebral velum. The vascular plexus of the fourth ventricle is enclosed between two layers

of the base: the upper and lower, facing the ventricle cavity. The latter has villous formations along the entire length of the base. They end in a thickening at the back. Through the median aperture, the processes of the plexus emerge onto the lower surface of the cerebellar vermis. Similar vascular plexuses deviate laterally, where they thin and enter the subarachnoid space through the lateral apertures.

The vascular plexus is an unpaired continuation of the soft meninges, forming a villous covering of the ventricle and a vascular protrusion covered by the ependyma. The vascular base is triangular in shape and located between the ventral surface of the corpus callosum, the fornix, and the dorsal surface of the diencephalon. Its protrusion extends into the sagittal fissure between the optic thalamus and is connected to the vascular plexuses of the lateral ventricles. The structure of the vascular base of the third ventricle includes a duplication of the soft meninges. One of its layers first extends forward as the upper layer along the lower surface of the corpus callosum. In the area of the interventricular openings, it turns back and follows as the lower layer to the rear, where it fuses with the ependymal plate of the third ventricle, covering most of the dorsal surface of the thalamus on both sides. Between these two layers of the vascular covering, in loose connective tissue, there are two internal and unpaired veins of the brain. On the lower layer of the covering, there are villi, which are designated as components of the vascular plexus.

The vascular plexus of the third ventricle participates in the formation of the vascular plexuses of the lateral ventricles, directing villous protrusions with a huge number of blood vessels into the cavities of the lateral ventricles. These formations are the vascular plexuses of the lateral ventricles. They are located in the central part and in the lower horn of each lateral ventricle.

They are located in the central part and in the lower horn of each lateral ventricle.

The plexuses cover the upper surface of the optic thalamus and part of the vault that is not fused with the corpus callosum. The main mass of the vascular plexus is located in the lateral horn and forms a thickening at the level of the central part of the lateral ventricle – the glomus. Here, the vascular plexus is located above the hippocampus, covering it.

The vascular plexuses of the lateral ventricles of the human brain communicate with the plexus of the third ventricle through the interventricular openings [10, 11, 12].

They vary greatly in size and shape, and their outgrowths form additional villi on the surface of the vascular plexuses.

The vascular plexuses of the cerebral ventricles receive the necessary amount of blood from two main systems: 1) through special branches of the internal carotid artery and 2) the basilar artery.

The vascular plexus and vascular base of the fourth ventricle are supplied with blood by branches of the posterior inferior cerebellar artery. Branches from the anterior inferior cerebellar artery, posterior spinal artery, and sometimes the vertebral artery also enter the vascular plexus of the fourth ventricle.

Blood flows into the vascular plexus of the lateral ventricles from the anterior choroidal artery and the choroidal branches of the posterior cerebral artery. They penetrate through the pedicle of the vascular plexus along the lateral and medial edges, then divide into arterioles that spread along the entire length of the vascular plexus.

The anterior choroidal artery branches off from the internal carotid artery and, penetrating the lower horn of the lateral ventricle, occupies the outer edge of the lateral vascular plexus, supplying two-thirds of the plexus and the ependyma covering the posterior part of the caudate nucleus. Along its path, the anterior choroidal artery gives rise to numerous arterial branches that penetrate the thickness of the plexus in parallel. They anastomose with each other and with the branches of the posterior choroidal artery, simultaneously supplying the vascular base of the third ventricle [13].

According to some authors [14], it can also branch directly from the bifurcation of the internal carotid artery (10%) or from the posterior communicating artery (20%) in some cases. In such variants of the anterior villous artery, aneurysms often occur [15], which require surgical intervention to prevent rupture of the aneurysm [16, 17] or various types of complications [18, 19] in the form of ischemic or infarct manifestations.

The posterior villous artery branches off from the posterior cerebral artery, the outer branch of which penetrates the vascular plexus of the lateral ventricle along the inner edge and gives 4-5 pairs of branches, running parallel in the thickness of the plexus. They anastomose with the branches of the anterior choroidal artery, supplying blood mainly to the villi of the racemose part of the plexus.

The arteries of the vascular plexuses of the cerebral ventricles anastomose with each other, forming loops. Arterioles and then capillaries branch off from each of the arteries.

The microcirculatory bed of the plexuses has a complex structure and is inextricably linked to the peculiarities of the macroscopic and microscopic organization of these organs. The essential components of this system are arterioles, precapillaries, capillaries, postcapillaries, venules, and an undifferentiated vascular-capillary network. Some capillaries are directly adjacent to the

choroidal epithelium – these are functional capillaries, while others do not come into contact with epithelial cells and do not form villi—these are trophic capillaries. Capillaries with a wide lumen are the main capillaries, while narrow, short capillaries are the connectives of wide, loop-shaped capillary vessels.

Blood from the capillaries collects in the venules and veins of the plexuses, then in the internal cerebral veins, which are located between the layers of the third ventricle, and from there into the great cerebral vein, forming a unique drainage system [20, 21]. Until now, researchers have focused on studying the blood supply and innervation of the blood vessels of the brain and its membranes, without taking into account the vascular plexuses, despite the fact that they are derivatives of the soft meninges and an integral part of the brain components, morphologically and functionally connected to them.

Knowledge of individual anatomical variations in the blood supply system of vascular plexuses may be particularly important in neurosurgery.

We have established that the density of the capillary bed per 1 mm^2 of the vascular plexus area varies significantly: the largest number of capillaries are found in the vascular plexuses of the lateral ventricles, and the smallest per 1 mm^2 in the plexus of the fourth ventricle. The microcirculatory bed of the plexus makes up most of its volume and basically determines its functions.

The vessels have a tortuous course, forming loops along their path, especially at the edges of the plexus. The arches and tortuosity of the capillaries not only change the direction of blood flow, but also the force of the pulse, which once again points to the important role of precapillaries in peripheral vascular resistance. Along the course and at the points of division of the arterioles, clusters of smooth muscle cells have been identified, the presence of which has been reported earlier by a number of authors [14, 22, 23].

It can be assumed that the presence of smooth muscle couplings has some effect on the regulation of blood volume in the vascular plexus.

It is believed that the strategic position of precapillary sphincters determines their participation in the selective distribution of blood between the metabolic links of the microcirculatory bed. The contraction of smooth muscle cells throughout the precapillaries allows individual capillary links to be shut off. In this way, the amount of blood flowing to different parts of the capillary network of the plexus is regulated. Muscle sphincters regulate blood flow in the microcirculatory bed.

It is an indisputable fact that vascular motor reactions occur as a result of myocyte excitation, which can be achieved by direct or indirect exposure to various metabolites, neurotransmitters, or other vasoactive substances. Myoendothelial connections serve as pathways for conducting excitation from the endothelium to the myocytes.

The action of these factors is directed and cumulative and is superimposed on the spontaneous activity of myocytes, whose sensitivity and rhythm of work in different parts of the vascular system are not the same. In this way, blood factors act on the vascular wall.

We have established that the arterioles and venules of the vascular plexuses of the lateral, third, and fourth ventricles are characterized by typical features of their wall structure: monolayer endothelial cells varying in length and thickness, with a well-defined basement membrane throughout. It separates a layer of myocytes with a circular arrangement. No noticeable differences in the structure of these cells were found.

Their unequal number and localization indicate a repeated functional load performed by these cells in the processes of hemodynamic regulation in vascular plexuses.

The ultrastructural organization of myocytes in the muscle layer of arteries and arterioles, with the presence of special contacts between myocytes, can ensure a synchronous generalized response of the vessel to irritation even from a small group of cells. Myoendothelial contacts serve to conduct excitation from the endothelium to the myocytes of the intima. These connections between the inner and middle layers facilitate the action of biologically active substances in the blood on the vascular wall through their reception by receptor proteins of endothelial cells.

The outer layer of arterioles is made up of loose connective tissue, which contains fibroblasts and collagen fibers.

In precapillary arterioles, the distance between smooth muscle cells increases. The nuclei of endothelial cells in precapillary arterioles and capillaries protrude into the lumen of the vessel, causing it to narrow. This is extremely important in regulating blood flow.

Studies show that the contacting surfaces of two adjacent endothelial cells are highly diverse, complex, and dynamic in their organization. They can range from simple, tile-like overlaps of endothelial cells to complex structures formed by the invagination of one cell surface into another or interdigitating insertions of cytoplasmic processes of adjacent endothelial cells.

The complex organization and heterogeneity of intercellular connections between endothelial cells of the arteries of the vascular plexuses of the ventricles of the brain make it likely that these contacts perform a variety of functions.

Thus, as a result of this study of the vascular plexuses of the cerebral ventricles, along with typical morphological features, characteristics of organ specificity were identified.

CONCLUSSIONS

The basis of the vascular plexuses of the cerebral ventricles is formed by a set of blood vessels, ranging from muscular arteries to capillaries. The microcirculatory bed is adapted to its connective tissue environment and is closely functionally related to the epithelium of the vascular organ. Capillaries with polar arrangement of fenestrated endothelial cells on the side of the vascular plexus epithelium predominate, indicating their active transport function and participation in the function of the blood-cerebrospinal fluid barrier as part of the blood-brain barrier. Microvessels undergo changes during ontogenesis that correlate with changes in the plexus itself, which occur simultaneously with the development of the brain and reflect the functional loads of the vascular plexus.

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CONFLICT OF INTEREST
The Authors declare no conflict of interest

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