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Review

Morphofunctional Peculiarities of Endocardium of the Ventricles, Main Arteries Normally and Under the Influence of Various Factors (Literature Review)

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Abstract
The article analyzes the data of literary sources about the histological and ultramicroscopic structure of the endocardium of the ventricles and arteries of various types and caliber normally, as well as under the influence of various endo- and exogenous factors. The data on changes in the structure of the endocardium and major arteries in diabetes mellitus, atherosclerosis, ischemia, hypoxia, infectious endocarditis, poisoning with heavy-density metal salts, and also in hypothyroidism, which has recently been considered as one of the main factors in the development of complications in the cardiovascular system.

Keywords
endocardium; main arteries; hypothyroidism; endo- and exogenous factors

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The endocardium is lining the heart chamber from the inside, covers the papillary muscles, tendon threads, and also forms valves. The thickness of the endocardium is greater in the left chambers of the heart, especially in the interventricular septum, as well as at the exit site of the aorta and pulmonary artery [15].

The endocardium consists of three layers: the internal endothelial, which lies on a thick basal membrane; sub-endothelial, which is formed by the loose connective tissue rich in fibroblasts; muscular-elastic layer formed by smooth myocytes, braided with elastic fibers.

The endocardium is separated from the myocardium by a subendocardial layer of loose connective tissue, which contains tiny blood vessels, nerve fibers, as well as Purkinje's fibers belonging to the conduction system of the heart. The endocardial trophy is mainly performed at the expense of blood from the chambers of the heart [5, 15, 44].

During the study of the endocardium using a scanning electron microscope, it was determined that the endocardial surface of the ventricles is represented by wavy folds in the form of roll-like elevations and depressions between them, a tree-like branching thinner than the larger, "magistral". In general, such morphological peculiarities of the endocardium provide "roughness" of its relief, designed to create the turbulence of blood flow in the cavities of the heart. With an increase in the scanning microscope exceeding $\times 1000$, it was determined that the surface of the endocardium is coated with a solid monolayer of endothelial cells, of flattened form. In some of them, there were found marginal outgrowths, perinuclear elevations, folds. Perinuclear elevations were localized in the central part of the endothelial cells, and marginal folds – unevenly and predominantly at the edges. Like the

endocardial folds, marginal protuberances, perinuclear elevations and endothelial cell folds could also be considered as manifestations of anatomic-functional peculiarities of the endocardium, aimed at providing the turbulence of blood flow in the heart cavities [6]. According to researches of the endocardium, the middle layer is represented mainly by fibrous elements of the connective tissue – collagen and elastic fibers, which are located in most cases parallel to the surface, and the surrounding amorphous substance. In the inner (deep) layer of the endocardium there are smooth myocytes and elastic fibers. The subendocardial layer contains substantially less of the elements of the connective tissue, fat cells, blood vessels, nervous elements, fibers of the cardiac conducting system [27].

The literature describes in detail the morphology of the tendon strings of the atrial-ventricular valves of the hearts of infants in the normal range. Tendon strings usually begin from the tops of the mamillary muscles and are fixed to the leaflets of atrial-ventricular valves. On the basis of the macroscopic examination of the hearts of infants, it was found that, when connected to the cusps of the valve, the tendon strings along their path branched on the strings of the first, second and third orders in a spreading or dichotomous way. Therefore, a much larger number of tendon strings was attached to the valve's cusp than was removed from the mamillary muscle [35].

The studies performed with the use of light microscopy showed that the surface of the tendon strings of the mitral and tricuspid heart valves of the infants is covered by an endocardium, which consists of a superficial layer of endothelial cells lying on the basal membrane.

The studies performed with the use of electron microscopy showed that the endothelial cells had a polygonal shape, uneven wavy edges. In the center of the cell there was one nucleus, which occupied almost the entire volume of the cell and contained a marginally located heterochromatin. Also, there were observed isolated microvilli on the lumenal surface of the cell.

During the light microscopy under the endothelium in the content of the tendon strings, a subendothelial layer of the endocardium was observed, in which the teniae of elastic fibers that looked like a loose reticulum were differentiated.

The studies performed with the help of an electron microscope showed that in the intervals between the elastic fibers, thin single and chaotic collagen fibers were located. The fibrous components were surrounded by an amorphous component of the intercellular substance. In the intervals between collagen fibers there was a small number of fibroblastic cells. Immature fibroblasts had an elongated or oval shape, with a small number of processes. Almost all the contents of the cell was occupied by a large, oval-shaped nucleus. The cytoplasm of fibroblasts contained a large number of free ribosomes, while other organelles of general purpose were poorly developed. Mature fibroblasts contained a large, oval-shaped light nucleus, in which there was evenly finely distributed chromatin. In the cytoplasm of cells, all organelles of general purpose were visualized [26].

The aorta comes from the left ventricle of the heart. During the study of the macroanatomy of the rat aorta, the following departments typical for the person, were determined: the ascending part of the aorta, the aortic arch and the aortic descending part, with the corresponding branching for the main branches. The ascending department of the aorta – is the initial part of the aorta that emerges from the left ventricle, runs upwards and somewhat behind and is located in the pericardial stratum. Only two branches originate from the ascending department of the rats'aorta – the right and left coronary arteries, which is confirmed by the data of professional literature [25]. The aortic arch is a curved area of the vessel between the ascending and descending aorta, which intersects with the trachea in the front, and then turns back and down to the left wall of the trachea and then continues to the descending department. From the aortic arch – brachiocephalic trunk – goes to the right, to the left – the left common carotid artery and the left subclavian artery.

Brachiocephalic trunk – is a large vessel that deviates from the arch of the aorta in the upper-posterior direction, deviates to the right and at the level of the thoracic-clavicular connection branches

to the right common carotid and right subclavian arteries. The anatomy of the right and left common carotid arteries in a white rat is similar to the human.

In the preparation of the rat's aortic descending part, it is proved that it, as well as the descending part of the human aorta, is a direct extension of the arch of the aorta, divided into the thoracic and abdominal departments. In the thoracic department of the aorta directs the posterior parietal arteries, the subcostal artery, and the upper diaphragm arteries and the intestine branches – to the pericardium, esophagus, bronchi and mediastinal lymph nodes.

The similarity in the structure with the human one is observed in the abdominal aorta of a white rat, which originates from aortic aperture of the diaphragm and ends with bifurcation on the right and left common iliac arteries. Blood supply of the abdominal cavity walls is performed by a number of parietal branches, which include: lower diaphragmatic, lumbar, ilio-lumbar, mid-tail and common iliac arteries. Blood supply of the abdominal cavity organs is carried out by the visceral branches of the abdominal department of the aorta: unpaired, which include the abdominal artery, upper and lower mesenteric arteries, and paired – renal and testicular (ovarian) arteries [39].

With the help of the electron microscopy method, it was determined that the aortic wall of a white rat is constructed of three tunics – the inner, represented by the endothelial cells, the subendotelial layer and the internal elastic membrane; middle, which consists of elastic window membrane; external – adventitious. The latter one is formed by loose connective tissue with a small amount of elastic fibers, muscular cells and macrophages. The vessels of the hemomicrocirculatory bed originate from the vessels located in the adventitia, penetrate the outer third of the middle membrane and branch out between the outer and middle membranes of the aortic wall [38].

Mateshuk-Vatseba L.R., Tsytovsky M.N. [51] in their study showed the affinity of the structure of the aortic wall of the white rat and man at the ultramicroscopic level, which is also confirmed by the data of the professional literature [46]. Thus, the inner envelope, intima, is represented by endothelial and subendothelial layers, a plexus of elastic fibers. Endothelial cells, in the form of a single layer of polygonally flat cells located on the basal membrane, are characterized by variability in their shape and size, and they form two types of contacts – dense and slit-shaped.

In the ultrastructural organization of endotheliocytes there is a presence of four structural-functional zones: nuclear, organelle, peripheral and contact, as well as three surfaces: lumen, basal and contact. The nucleus is visualized in the central zone, usually containing one nucleolus. The form of nuclei is characterized by its variability, from oval to vane type, with numerous invaginations of the nuclear tunic, which in turn depends on the tension of the vascular wall. Above the nucleus there is the Golgi complex, which consists of flat bags and cisterns, large vacuoles and small vesicles. A cell center is located nearby. Elements of the granular endoplasmic reticulum, mitochondria with a light matrix and a small number of ridges, are mainly concentrated in the organelle zone. In addition, there are Weibel Palade rod-like bodies – osmophilic heterogeneous structures that contain substances (VWF factor) that are directly involved in the processes of coagulation and, according to the literature, are derivatives of the Golgi complex [46, 51].

Specialized transport structures of the endothelial cell are mainly concentrated in the peripheral zone. These are, first of all, micropinocyte vesicles and transendothelial channels. According to literary sources, pinocytic vesicles play an active role in the accumulation and transport of low density lipoprotein and fibrinogen in the inner membrane of the vessel. In turn, accumulated low density lipoproteins are subject to oxidation processes with free radicals produced by the endothelial cells themselves. Such modified lipoproteins are captured by macrophages and converted into foam cells, that is the latter ones are the typical feature of the atherosclerotic plaque [51, 19, 31, 10, 49].

When studying the luminal surface of the endothelial cell, the attention is drawn to its division into three layers: para-plasmolemmotic or glycocalyx, plasmolemma and submembranous (cortical). There are micro-outgrowths, folds and microvilli.

According to literary references, the lumenal surface plays an important role in the reception and selection of transportable compounds, regulation of transport properties of the surface of the endothelial cell, and also defines a change in its configuration [51, 31, 10, 48].

The basal membrane of the endothelium of the aorta of the white rat is thinner, sometimes it is intermittent, in the form of lattice-like pores, penta- and hexa-shaped. The main component of the electron-dense layer of the basal membrane is type IV collagen, glycoproteins and heparinsulphate-containing proteoglycans.

The sub-endothelial layer is constructed of loose connective tissue, rich in smooth myocytes, macrophages, lymphocytes and fibroblasts. It takes up to 20% of the wall thickness of the vessel. According to the specialised literature data, in the intercellular substance of the aortic membrane, there is a significant amount of glycosaminoglycans and phospholipids [51, 24, 47, 52, 50].

The inner elastic membrane is located deeper than the sub-endothelial layer. It looks like a massive plexus with longitudinal and circular orientation of layers of elastic fibers.

Elastic window membranes represent the average membrane of the aortic wall. Due to the dense contacts of elastic window membranes with collagen and elastic fibers, a single, so-called elastic frame with elastic fibers of other membranes is formed.

There are three types of elastic membranes: homogeneous, fibrous and mixed [24, 46]. Homogenous and mixed types of elastic membranes consisting of homogeneous and several fibrous layers are present in the middle tunic of the aortic wall of a white rat. For elastic window membranes there is a principle, so to speak, two-vector contact, when, on the one hand, elastic fibers are firmly inweaved into elastic membranes, and on the other – longitudinally directed elastic fibers surround smooth smooth myocytes from all sides. In relation to elastic membranes, smooth myocytes are oblique. Collagen fibers in the intermembrane space create a ”case” around the elastic window-like membranes, and also connect the adjacent window membranes. The above-described peculiarities of the structure of the medial membrane of the aortic wall contribute to the greater elasticity of the vascular wall and soften the pressure of blood flow [46].

There are elastic window-like membranes, collagen and elastic fibers, smooth myocytes immersed into an amorphous substance rich in glycosaminoglycans. The cytoplasm of smooth myocytes contains numerous intermediate filaments, which are constructed from the vimentin protein, unlike other vessels. According to scientists, such peculiarities of the protein composition of smooth myocytes are associated with a small isotonic shortening, unlike other vessels that are involved in redistribution of blood, smooth myocytes of which contract more significantly [24, 50]. The protein composition of the latter ones includes vimentin and desmin [48].

The outer shell is constructed of loose connective tissue with longitudinally orientated elastic and collagen fibers. This type of structure determines the strength of the vascular wall and prevents it from overdistension [51].

The performed studies of the structure of the renal arteries in the rat in norm have established that their intima is formed by a layer of flat polygonal, extracted in the length endothelial cells, the middle membrane is represented by circularly located smooth myocytes and elastic fibers, the ratio of which varies with the decrease of the artery caliber – the content of elastic fibers decreases and the number of smooth myocytes increases. The inner and slightly thinner outer elastic membranes are clearly expressed in the renal arteries and their branches. Adventitia is represented by a connective tissue [4].

The literature sourses describe the morphology of the walls of the carotid arteries of rabbits. Their inner elastic membrane has a folded structure. On the inner side of the vessel, the nuclei of the endothelial cells of round or oval form located at approximately the same distance from each other, adhere to the indicated membrane. In the middle membrane of the artery there is a large number of rugulose membranes that form the vessel's frame. Between them there are several rows of smooth myocytes that have a slanted direction in relation

to elastic membranes. The inner and outer elastic membranes are clearly visualized. Adventitia contains a small amount of elastic and collagen fibers [2, 14, 21, 18].

The endothelium lining the inner surface of the vessels and the endocardium is an autocrine, paracrine and endocrine organ that controls the entire blood circulation system, participates in the regulation of vascular tone, hemostasis, immune response, migration of blood cells to the vascular wall, synthesis of inflammatory factors and their inhibitors, performs barrier functions.

Endothelium produces a large number of biologically active substances that regulate the function of the heart and blood vessels. All substances that are synthesized by endothelial cells can be divided into four groups:

1. Factors affecting the tone of the smooth muscles of the vessels:
    - constitutors: endothelin, angiotensin II, thromboxane A_2;
    - dilators: nitric oxide (NO), prostacyclin (PGI_2), endothelial depolarization factor (EDHF).
2. Haemostatic factors:
    - prothrombogenic – platelet growth factor (PDGF), plasminogen activator inhibitor, Willebrand factor, angiotensin IV, endothelin-1;
    - antithrombogenic – nitric oxide (NO), tissue plasminogen activator, prostacyclin (PGI_2).
3. Factors influencing growth and proliferation:
    - stimulants – endothelin-1, angiotensin II, superoxide radicals;
    - inhibitors – nitric oxide (NO), prostacyclin (PGI_2), C-natriuretic peptide.
4. Factors influencing inflammation:
    - stimulants – tumor necrosis factor-*a* (FNP-*a*), superoxide radicals;
    - inhibitors – nitric oxide (NO), C-natriuretic peptide [8].

It is known that the endothelium secretes the so-called "large" proendothelin, from which under the influence of the endothelin-transforming enzyme three isomers are formed: endothelin-1, endothelin-2, endothelin-3. The most active isomer is endothelin-1. And the vasoactive effect of endothelin-1 is determined by its concentration. Thus, at low levels of the peptide, its vasodilating effect is associated with the excitation of endothelin receptors of type B, and at high levels, vasoconstriction occurs due to excitation of receptors of type A. The main effect of the endothelin is in the release of calcium, which is accompanied by the contraction of smooth myocytes in vessels, which as a result can lead to their hyperplasia [45].

Endothelin-1 is formed predominantly in endothelial cells, but unlike other endothelins, it can be synthesized in smooth myocytes of vessels, neurons, astrocytes, endometrium, hepatocytes, mesangiocytes, mammary glands, mast cells. Synthesis of endothelin is stimulated by thrombin, adrenaline, angiotensin, interleukin-1 and various growth factors.

Endothelin-1 concentration has a prognostic value in ischemic heart disease, in particular, in acute myocardial infarction, heart rhythm disorder, pulmonary and systemic hypertension, and is a marker for endothelial function and coronary atherosclerosis [8].

Nitrogen oxide (NO) is of great importance for the maintaining of adequate blood flow, which is synthesized by the endothelium. Formation of NO occurs with the participation of NO-synthase, which converts L-arginine into NO – an unstable hormone with a half-life in a few seconds. NO is a major stimulant for the formation of cyclic 3.5-guanosine monophosphate (cGMP). By increasing the amount of cGMP, it reduces the calcium content in platelets and smooth muscles.

CGRP, activating cGMP-dependent proteinase, creates conditions for the opening of numerous potassium and calcium channels. Particularly important role is played by proteins – K-Ca^{2+}-channels. The opening of these channels for potassium leads to the relaxation of smooth myocytes due to the release of potassium and calcium from the mus-

cles in repolarisation. Activation of channels K-Ca^{2+}, whose density on membranes is very large, is the main mechanism of NO action. Therefore, the ultimate NO effect – is anti-aggregating, anticoagulating and vasodilating. NO also forestalls the growth and migration of smooth myocytes in vessels, inhibits the migration of monocytes and the synthesis of collagen in the vascular wall, inhibits the synthesis of adhesive molecules and oxidation of LDL, prevents the development of vascular spasm. Nitric oxide acts as a neurotransmitter, a translator of nerve impulses, participates in memory mechanisms, provides a bactericidal effect [23].

The vascular wall is an integral functional structure that undergoes remodeling in response to hemodynamic changes in various physiological and pathological conditions [32]. Thus, the literature describes the morphological changes in the aortic wall [17, 30], the femoral artery [13], the arterial bed of the lower limb [37, 12], coronary [33], carotid [2, 14, 18, 21], renal arteries [3] in the development of various pathological conditions.

One of the most common diseases that leads to the development of cardiovascular complications is diabetes mellitus [38]. In an experiment in rats, it has been shown that the first manifestations of angiopathy in the structures of the aortic wall and its parts of the HMCB are detected in the course of two weeks of the streptotsotocin-induced diabetes. The development of atherosclerotic changes in the vascular wall is characteristic for the DM, primarily due to the excessive penetration of the endothelium of plasma proteins, which contains low density lipoprotein and their accumulation in the subendothelial space. In addition, there is a selective capture by the inner tunic of vessels of monocytes. This process is accelerated in hyperlipidemia. Hemodynamic pressure causes damage to the endothelial lining, and above all – of its glycocalyx. In the early stages of the experimental DM, there are initial processes of destruction of glycocalyx, expansion of inter-endothelial spaces, increased intima permeability for lipoproteins, proliferation of intimocytes. In the later stages of the experimental DM (after 6 and 8 weeks of the experiment), in the wall of the aorta, the phenomena of progression of atherosclerotic changes increase [38].

According to WHO, cardiovascular and cerebrovascular diseases occupy the first place in the structure of the general morbidity of the population and cause not less than one third of deaths in the world. Researchers believe that the reason for such unfavorable situation is the increase in the spread of risk factors, among which they distinguish dislipoproteinemia. It is revealed that the so-called atherogenic triad, which is characterized by an increase in the level of very low density lipoproteins and the associated increase in triglycerides and low cholesterol level of low density lipoproteins and low cholesterol levels of high density lipoprotein, is of great importance. Violation of the metabolism of the lipid profile of the sblood erum is the main cause of the development of the atherosclerotic process, which is characterized by a specific damage of the arteries in the form of damage and development of endothelial dysfunction, accumulation of lipids in the wall of the vessels, enlargement of the connective tissue, hypertrophy of the smooth muscle cells, formation of atherosclerotic plaques, i.e., it causes pathological changes of the functional state and morphological remodeling of cardiac vessels. In experimental dislipoproteinemia, signs of marked remodeling of arteries of small and medium caliber, which manifest themselves in the form of thickening of their walls and narrowing of the lumen, are noted. More pronounced morphological changes were found in vessels of small caliber [43].

In the modeling of atherosclerosis in laboratory animals, it was found that intima of coronary arteries in rats normally contains dendritic cells. There is also a complex system of interconnection of dendritic cells with other cells, which is realized by means of processes. Specific changes characteristic of atherosclerosis were observed beginning from the 12^{th} week of the experiment in the form of thickening of intima due to the significant number of lipid drops and lymphocytic-hystiocytic infiltration, which corresponded to the stage of lipoidosis. The phenomena of liposclerosis were noted during the 18-20 weeks of the experiment. The number of dendritic cells increased in parallel with the progression of atherosclerotic lesions. There was noted

the redistribution of cellular populations in intima, depending on the stage of atherosclerosis [33].

In the experimental hypercholesterolemia, the wall of the aorta is thickened due to swelling and sclerosis. Endothelium is swollen, sometimes it is desquamated. Elastic membranes are thinned, slightly straightened, their contours are unclear. Between the fibers there is the pronounced proliferation of smooth muscular cells and connective tissue cells with the pronounced nuclei polymorphism. Part of the nuclei is of a round, irregular shape; there is the phenomenon of "vertical arrangement of nuclei", i.e., perpendicular to the inner surface of the aorta. In adventitia, the phenomenon of chronic inflammation with perivascular location of round-cell infiltration. Infiltration under conditions of inflammation consists mainly of macrophages and lymphoid elements. Some macrophages migrate into the elastic layer, located between fibers. Elastic fibers are thinned, transparent, straightened [17].

In the experiment on white rats it was found that hypercholesterolemia causes significant changes in the structure of the femoral artery wall. There is a thinning, and in some places a complete absence of glycocalyx endothelial cells on the surface; an increase of the micropinocytic vesicles in their cytoplasm, indicating the activation of endo- and transcytosis; destruction and detachment of individual endothelial cells; stratification, loosening and swelling of the sub-endothelial layer, the inner elastic membrane and the muscular membrane; accumulation of foam cells in intima and extracellular cholesterol deposits [13].

The pathomorphological picture of the arterial bed of the lower extremity in atherosclerosis is characterized by the presence of circular and segmental atherosclerotic plaques, which, depending on the localization, can create a picture of obstruction or simulate the patency of the artery in the presence of organized blood clots with recanalisation in their lumen. Morphologically there is a reduplication of the internal elastic membrane, mononuclear infiltration of the vascular wall, medial hypertrophy [37]. Histologically, the instability of the atherosclerotic plaque is characterized by desquamation of the endothelium, rupture, calcinosis, hemorrhage, inflammatory infiltration, neovascularization and vasa vasorum changes [12].

Hypofunction of the thyroid gland is considered as an additional risk factor for cardiovascular diseases, as it is associated with the development of atherogenic dyslipidemia, diastolic arterial hypertension, myocardial remodeling, which, in turn, are the predictors of arrhythmic complications, sudden cardiac death, and heart failure.

Nowadays, much attention in the study of the pathogenesis of ischemic heart disease is paid to the endothelial dysfunction, as the earliest phase of the vascular wall damage. Endothelin-1 – is an important marker of endothelial dysfunction, which has a distinct mitogenic activity with respect to smooth vascular myocytes, is capable of activating the expression of adhesive molecules, stimulating proliferation and cell migration into subintimal layers of vessels. Endothelin-1 has been proved to induce molecular mechanisms causing hypertrophy of the heart muscle, including growth programs at the genetic level. Endothelin-1 is capable of suppressing fibrinolysis by reducing the release of tissue plasminogen activator by the endothelium, increasing the permeability of the vascular wall for lipids, which facilitates the further development of atherosclerosis and coronary thrombosis. Endothelial dysfunction leads to the production of cytokines, kinins, monoamines and other biologically active substances that are responsible for the development and progression of heart failure.

It has been proved that in patients with autoimmune thyroiditis and hypothyroidism, the presence of systemic inflammation of low activity causes the development of endothelial dysfunction and oxidative stress [22]. The thickening of the intima-media carotid artery complex in women with obesity and autoimmune thyroiditis has been demonstrated, which confirms the important role of hypothyroidism in the progression of atherosclerotic vascular injury [29].

It has been determined that in patients with subclinical hypothyroidism, endothelial dysfunction occurs against the background of dyslipidemia, hyperhomocysteinemia and chronic low-grade inflammation [1, 20].

Cardiac symptoms play a leading role in the clinical picture of hypothyroidism. Their set is designated as "myxedematous (hypothyroid) heart". Hypofunction of the thyroid gland affects both the properties of the contractile myocardium and the functional state of the cardiac conduction system. In experiments on white immature rats, it has been shown that the main pathogenetic mechanism of sinus bradycardia in hypothyroidism is the activation of vagal effects on the synoarthrial node due to the high ability of the hypothyroid heart to synthesize acetylcholine and accumulate it in presynaptic vesicles [40].

One of the most important etiological factors that have a pronounced damaging effect on the endothelium of the heart and blood vessels, are considered stressful situations of different genesis. It is proved that the damaging effect of any stress factor on the heart is accompanied by lipolysis activation, increased free fatty acids, degradation of membrane phospholipids with accumulation of their isoforms, and also – intracellular accumulation of two-chain forms of fatty acids and acetyl-coenzyme. It was determined that the consequence of acute emotional-pain stress is the damage to the endocardium, which is accompanied by desquamation of individual endothelial cells. In addition to increasing the process of desquamation of endothelial cells of the endocardium in conditions of stress reaction, morphometric indices of changes in their nuclei have been determined. In parallel with this, there is a change of the nuclei shape: the number of ellipsoids is reduced, the number of spindle-shaped nuclei and irregular nuclei increases. One day after acute stressful effects in the endothelium there are changes that, on the one hand, indicate an increase in destructive processes (hyperchromicity of the nuclei, signs of karyopicnosis and carriolysis), on the other hand, it is a sign of the adaptation of these cells (change in the form of nuclei) to the influence of the pathogenic factor [16].

The literature contains data on structural changes in the heart and blood vessels and in other pathological conditions. In particular, the peculiarities of the structural rearrangement of the arterial wall under conditions of cold factor influence are described in detail. Thus, at the height of the cold factor and during the 1st, 3rd day of the posthypotermic period, the edema and partial destruction of the individual cellular and extracellular elements of the arterial wall are observed, which gradually undergo dystrophic changes of the structural components of the vascular wall at later stages of the study [34].

The experimental study of morphological changes in the wall of the aorta after blood loss showed that the chest and abdominal parts of the aorta differ from each other by morphometric parameters, which determines various conditions of hemodynamics in them in critical states of the organism. Hypertrophy of the middle tunic of the abdominal part of ther aorta due to thickening of the smooth muscle layers testifies to the processes of remodeling in the vascular wall, which after massive blood loss is accompanied by a decrease in the number of elastic membranes and the expression of collagen-containing structures. For the thoracic part of the aorta, such changes are manifested by a decrease in the area of the middle membrane, a significant thickening of adventitia, and a sharp decrease in the coefficients of throughput ability, which may be an compensatory mechanism that allows effective blood supply of the brain and lungs in the long terms after massive blood loss [30].

The literature contains data on the morphological state of the aorta in the fetuses and newborns who have undergone chronic intrauterine hypoxia. Experimental study on laboratory rats of WAG showed a deterioration of endothelial trophy, resulting in a thickening of the basal membrane by intima, which leads to a change in the ratio of nucleus and cytoplasm of cells, flatten of endothelial cells, dystrophic processes followed by their desquamation. Under the influence of chronic hypoxia, the density of the placement of smooth myocytes decreases sharply, which may lead to a decrease in the contractile capacity of the vascular wall. Chronic intrauterine hypoxia stimulates the increase of the number of elastic fibers, thereby altering their correlation with collagen fibers. This fact could be regarded as a consequence of increased production of endothelial cells fibronectin, laminin, elastin or activation of proteins responsible for the formation of fibers

of the first type under such conditions [9].

Modern morphological science considers the kidney as the main organ for providing homeostasis of an organism, therefore it is advisable to thoroughly study the structural rearrangement of its vascular bed as the main factor of ensuring the full functioning of the organ in pathological conditions. Structural changes in the vascular bed of the kidneys under the conditions of stenosis of the renal artery and acute general peritonitis were studied in detail [3]. With the progression of acute general peritonitis, morphological reactions were observed at almost all levels of the branching of the vessels of the studied organ. The morphological study of the renal vessels showed folding up to the "ruffled shape" of the inner elastic membrane and thickening of the muscular membrane with simultaneous narrowing of the lumen. Along with this, edematous phenomena were observed in the structural elements of the vascular wall, which were manifested as enlightenment of the cytoplasm of smooth myocytes and swelling of the nuclei of the endothelium with their protrusion into the lumen of the arteries in the form of a "palisade-type fence". Stenting of the renal artery is accompanied by vascular reactions of constrictor character, which have a progressive nature and develop against the background of venous plethora [3].

In recent years, in the environment there is an increase in the content of heavy metal salts, which adversely affect the various organs and systems of the organism. At the same time, heart and blood vessels are damaged too. Therefore, many researchers pay attention to the peculiarities of the structural rearrangement of the cardiovascular system under the action of heavy metal salts. Thus, due to the action of cesium chloride in histological agents of the myocardium, dystrophic changes of cardiomyocytes, mostly vacuolated dystrophy, have been determined. Throughout the sections there is an uneven thickening of the endocardial membrane. In the subendothelial layer there are areas with a significant accumulation of red blood cells [7].

Prolonged action of cadmium chloride on the body leads to a significant damage of all parts of the microhemocirculatory bed of the ventricles of the heart. In this case, the structural reconstruction of it is characterized by narrowing of the lumen of arterioles, precapillaries and capillaries, and the expansion of postcapillaries and venules, it is most pronounced in the left ventricle and in animals with low resistance to hypoxia [28].

The most serious and widespread diseases of the cardiovascular system include the acquired heart defects. Important place in morphogenesis of defects belongs to rheumatic heart disease, infectious endocarditis, dystrophic changes, ischemic heart disease. Violations in this case are related to the morphological changes of the valves, namely, with the structural reorganization of the endothelium and connective tissue components of the valvular apparatus of the heart [35].

Morphological changes of heart valves affected by infectious endocarditis, in macroscopic examination, were manifested by local edema and hyperemia of tissues with the destruction of valvular edges with vegetations on them. In case of the damage of the central parts of the valves, they usually had long aneurysmic protrusions. At the aortic valve, they were turned towards the left ventricle, at the mitral one – towards the left atrium. This suggests that in the formation of the aneurysm of the valves, a significant role is played by factors of hemodynamic effect. The peaks of these aneurysms were hyperemic, sometimes destroyed and covered with more or less abundant vegetations, which in many areas spread to the base of aneurysms with the transition to a fibrous ring.

In the microscopic study of preparations obtained from the valve tissue, attention was drawn to swelling and large areas of necrosis, whose peripheral layers usually differed in basophilia due to the large amount of nuclear detritus that progressed gradually to leukocyte infiltrates, which consisted predominantly of neutrophils. The pyogenic layer was often interrupted by a necrosis that stretched out of its edges [36].

An important sign of all types of acquired heart defects of inflammatory and non-inflammatory genesis is the damage of the endothelium of the heart valves, which, at the light-optical level, is manifested by exfoliation, edema and lysis of the en-

dothelial cells, and at the submicroscopic level – by the thinning of the peripheral regions of the endothelial cells, the partial destruction of their plasmolemma, the appearance of vacuoles with myelin-like structures in the cytoplasm, deformation of the nucleus with the thickening of the nuclear membrane, as well as the destruction or induration and homogenization of the basal membrane, with which the endothelial cells sometimes lost contact [35, 36].

Conclusions

Thus, the analysis of literature data suggests that the problem of morphofunctional changes in the endocardium of the ventricles and arteries of different types and caliber is topical today due to the progressive prevalence of cardiovascular diseases. In parallel with this, it is known about the increase of the frequency of iodine deficiency and hypothyroidism [41].

Thyroid dysfunction is associated with increased cardiovascular morbidity and mortality. Moreover, the changes in cardiovascular system have already been determined at the stage of subclinical hypothyroidism [11]. An early effect of hypothyroidism of the thyroid gland is the development of diastolic arterial hypertension, a prerequisite for which is the growth of the total peripheral vascular resistance. Diastolic hypertension in hypothyroidism is quite common phenomenon and, according to the literature data, it is diagnosed in 15-28%, which is, in comparison, three times higher than in the euthyroid population. The strategic anatomical position of the endothelium between the circulating bloodstream and the smooth vascular myocytes determines its ability to perceive hemodynamic and humoral blood signals. Probable causes of a vasodilating function during hypothyroidism are: a decrease in the generation of vasodilating substances and/or resistance to them by vascular smooth muscular cells, distortion of compensatory vasodilating effects of the endothelium. Under conditions of hypothyroidism of the thyroid gland, a number of interconnected pathogenetic mechanisms that cause the development of endothelial dysfunction are realized. Evidence of this is the development of dyslipidemia, which is a structural-functional background for atherogenesis, a decrease in the activity of the NO-dependent component of vasodilating vascular endothelium effects, and also the excessive production of oxygen and lipid radicals against the background of suppression of enzymes of antiradical and antiperoxide action and, consequently, the development of oxidative stress [42].

In view of the above-mentioned, we consider it promising to research further in this direction.

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