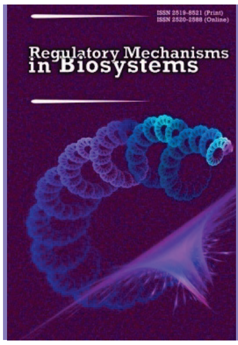

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Peculiarities of macro- and cytometric assessment of morphological structures of the domestic pig heart

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The cardiovascular system, which includes the heart, is one of the essential systems of the human and animal body. With its participation, the blood supply of the organs takes place; it promotes the outflow of lymph from the organs and its transport into the veins, and it helps to implement the functions of the organs of immune protection, endocrine, and nervous systems. The work aims to conduct a macro-, histo-, and cytomorphometric assessment of the morphological structures of the heart of the domestic pig using complex research methods (macroscopic, histological, morphometric). Functionally mature, clinically healthy animals (n = 7) of *Sus scrofa* f. *domestica* were used for the work. According to organometallic studies, the absolute weight of a pig's heart is 487.4 ± 8.12 g; the relative weight is 0.290 ± 0.004%, and the net weight of the heart is 461.4 ± 8.0 g. According to its linear dimensions, a domestic pig's heart is elongated-narrowed (conical) type, as evidenced by the heart development index of 155.1 ± 6.3%. According to the functional load of the muscle tissues of the myocardium of the heart and its separate morphological structures (ventricles and atria) when performing particular work during spontaneous rhythmic contractions, the absolute mass of the ventricles and atria is different. The enormous mass is characteristic of the left ventricle, then the right, and the smallest for the left and right atria. Therefore, the ventricles of the heart are more functionally developed, as evidenced by the ratio coefficient (1:0.79) of the mass of the ventricles to the net mass of the heart, respectively, the ratio coefficient (1:0.21) of the mass of the atria to the net mass of the heart and the ratio coefficient (1:0.27) atrial mass to ventricular mass. Cardiomyocytes of the left ventricle have the most significant volume, cardiomyocytes of the right ventricle have a smaller volume, and cardiomyocytes of the atria have the smallest volume. Their nuclear volumes have similar values, respectively, in the left ventricle – 77.16 ± 2.01 μm^3, the right ventricle – 76.02 ± 2.43 μm^3, and the atrium – 75.97 ± 3.24 μm^3, and the nuclear-cytoplasmic ratio is different from them: the smallest nuclear-cytoplasmic ratio, respectively characteristic of cardiomyocytes of the left ventricle, significantly more for cardiomyocytes of the right ventricle and significantly the most for cardiomyocytes of the atria. The scientific results of morphoarchitectonics, organo-, histo-, and cytometry of the heart of the domestic pig presented in the publication supplement the information on the morphological structure of the heart of domestic animals in the relevant sections of histology, comparative anatomy and are a significant contribution to clinical cardiology.

Keywords: *Sus scrofa* f. *domestica*; macroscopic structure; microscopic structure; myocardium; cardiomyocytes.

Introduction

An essential factor in providing the population with complete food products is the effective development of the livestock industry, which satisfies consumers with valuable food products (Bilyk et al., 2017; Borshch et al., 2020; Stadnytska et al., 2022). The state of development of this branch of agriculture is currently relevant and is considered one of the priority tasks of Ukraine's agrarian policy (Kukhar, 2013; Stravsky et al., 2020). For the successful development of the livestock industry, there must be an increase in the productive qualities of animals (Bashchenko et al., 2020; Khalak et al., 2021; Popovych & Golinka, 2021; Pepko et al., 2022; Razanova et al., 2022). Significant importance for this is given to the prevention of contagious and non-communicable diseases, for which, along with organizational and economic measures, it is necessary to conduct an in-depth study of the body of domestic and carnivorous animals at the macro- and microscopic levels (Zurbrigg et al., 2018; Radzykhovskyi et al., 2022). Therefore, an urgent task is to study the composition, structural, and functional features of the morpho-architectonics of the cardiovascular system in general and the heart in particular in productive animals, which is the basis for clinical veterinary medicine (Rykiel et al., 2020; Pilz et al., 2022). The cardiovascular system includes the central organ – the heart, arteries, veins, and intermediate vessels between them – the microcirculatory channel (arterioles, capillaries, venules) (Christoffels & Jensen, 2020; Kots et al., 2021; Raiola et al., 2023). Thanks to this, formed in the process of phylogenetic development of the cardiovascular system, a single morphofunctional complex: heart –> arteries –>arterioles –> capillaries –> venules –> veins –> heart, the primary vital functions of the body – nutrition, and breathing – are ensured (Poelmann & Gittenberger-de Groot, 2019; Bi & Zhang, 2021; Cupello et al., 2022). In addition to gas exchange, the transport of nutrients (proteins, fats, carbohydrates), salts, and water necessary for life to all organs and tissues of the body is provided, and the transport of decay products formed in tissues in the process of metabolism to excretory organs, transport of hormones to those regulated by the organs and specific substances included in the process of metabolism, etc. (Cesarovic et al., 2020; Sarah et al., 2020). The central organ of the cardiovascular system is the heart – a muscular hollow organ of the circulatory system, the primary function of which is pumping, which, with its measured contractions, pumps blood or lymph through the vessels of the body and is transferred to the cells of the body, providing nutrition and respiration of tissues. The pumping function of the heart occurs thanks to two consecutive pumps: the first (small (pulmonary) circle of blood circulation) pushes blood into the lungs, where it is saturated with oxygen and gives off carbon dioxide; the second (large (systemic) circle of blood circulation) delivers oxygen-enriched blood to all organs and tissues of the body. The pump that provides a small circle of blood circulation is located in the right half of the heart, while the pump that provides a large circle of blood circulation is in the left half of the heart (Shemla et al., 2021; Weiser-Bitoun et al., 2021).

Therefore, the study of the morphoarchitectonics of the heart is of great importance in morphology, the indicators of which are morphological criteria of physiological and pathological changes in the cardiovascular system and can be used in vital clinical diagnosis, ultrasound diagnosis, and pathomorphological diagnosis related to the pathology of the cardiovascular system.

That is why we conducted a macro- and cytometric evaluation of the morphological structures of the hearts of pigs, the indicators of which characterize the dynamics of the development and construction of the cardiovascular system in general and the heart in particular and are morphological criteria of physiological and pathological changes in the cardiovascular system.

Materials and methods

The scientific research was conducted in compliance with the general rules of laboratory practice GLP (1981), the provisions of the "General Ethical Principles of Animal Experiments", which were adopted by the first National Congress on Bioethics (Kyiv, 2001). Experimental studies were carried out following the requirements of the international principles of the "European Convention for the Protection of Vertebrate Animals Used in Experiments and for Other Scientific Purposes" (Strasbourg, 1986) (European Convention, 1986), "Rules for Conducting Work on the Use of Experimental Animals", approved by order Ministry of Health No. 281 dated 1.12. 2000 "On measures to further improve organizational forms of work using experimental animals" and the corresponding Law of Ukraine "On the Protection of Animals from Cruelty" (No. 3447-IV dated February 21, 2006, Kyiv) (Law of Ukraine No. 3447-IV, 2006, February; Mishalov et al., 2007).

The research material was the heart of physiologically mature, clinically healthy animals of the *Sus scrofa* f. *domestica* Linnaeus, 1758. Experimental animals (n = 7) were selected according to the principle of analogs, considering breed characteristics, weight categories, and age of animals. The research stages were anatomical preparation of the organ, determination, and description of the shape of the heart, morphotopography, study of the macroscopic structure and organometry (absolute mass (AM), relative mass (RM), linear measurements of the heart and its components), histological studies of the heart structure and determination of cytometric parameters of cardiomyocytes.

For macroscopic studies and conducting organometry (determining the shape of the heart, absolute and relative mass, circumference, height, width, and thickness of the heart and its components), the heart was prepared from the chest cavity together with the pericardium.

The absolute weight of the heart, its ventricles, and atria was determined by weighing on a laboratory scale of the brand "RADWAG" PS 6000/C/2 (Poland). The relative weight of the heart was determined by the ratio of its absolute weight and the animal's weight. Determination of the heart's height, width, and circumference was carried out by direct measurement. The heart development index (HDI) was determined by the total height-to-width ratio using appropriate calculations.

Histological studies were performed according to the methodology for generally accepted methods of fixation and production of histological sections (Horalskyi et al., 2019). For this, pieces of the heart were fixed in a 10–12 percent cooled aqueous solution of neutral formalin for 24 hours or more; then, the material was embedded in paraffin according to the schemes described in the manual by Horalskyi et al. (2019). Paraffin sections, the thickness of which did not exceed 10–12 µm, were made on a sled microtome (MS-2). After deparaffinization, the sections were stained with hematoxylin and eosin staining (Diapath, Italy, 2020) and the Heidenhain method, which made it possible to differentiate contractile myocytes (cardiomyocytes), thanks to the identification of places of connections (insertion disks) of cardiomyocytes between themselves. The prepared tissue preparations were used for cytometric studies (measurement of the length and width of cardiomyocytes, determination of the volume of cardiomyocytes, their nuclei, and the nuclear-cytoplasmic ratio). Histological and cytometric studies were performed under light microscopy, using microscopes "Micros" (Austria, 2012) and MBS-10 (Micromed, Russia, 1998), according to the recommendations proposed in the manual (Horalskyi et al., 2019).

The length and width of cardiomyocytes and their nuclei were measured using a microscope eyepiece ruler.

The formula determined the volume of cardiomyocytes: $V_k = 3.14 \times (B/2)^2 \times A$, where: V_k is the volume of a cardiomyocyte; B – width (diameter) of cardiomyocyte; B/2 – cardiomyocyte radius; A is the length of the cardiomyocyte.

The following formula was used to determine the volume of cardiomyocyte nuclei: $V = P/6 \times A \times B^2$, where V is the volume of cardiomyocyte nuclei; P – 3.14; A is the length of cardiomyocyte nuclei; B is the width of cardiomyocyte nuclei.

Determination of the nuclear-cytoplasmic ratio of cardiomyocytes was carried out according to the following calculations:

$$\text{nuclear} - \text{cytoplasmic ratio} = \frac{\text{core volume}}{\text{cardiomyocyte volume} - \text{nucleus volume}}$$

The terminology of the structural parts of the organ is presented following the provisions of the International Veterinary Histological Nomenclature and the International Veterinary Anatomical Nomenclature.

A CAM V–200 video camera (InterMed, China, 2017) mounted in a microscope was used to photograph the microscopic structure of the heart. Digital data were processed using the variational statistical method on a personal computer using the Statistica 7 program (StatSoft Inc., USA). The work gives the average arithmetic values and the error of the average arithmetic value x ± SD (mean ± standard deviation), which are presented in the tables. We used Tukey's test to compare the mean parameters between indicators, where differences were considered statistically significant at $P < 0.05$ for all data (Horalskyi et al., 2019).

Results

The heart of a pig is relatively large in size, elliptical-conical in shape, which is given to it by an expanded base and a pointed (narrowed) top (Fig. 1). The heart is contained in the pericardial sac (pericardium) – an external connective tissue membrane (dense sac) that surrounds the heart from all sides. On the surface of the heart, there are well-defined external interventricular grooves (right and left), and inside, a thick, impenetrable muscular wall (septum) separates the ventricles from each other, as well as the atria and blood vessels into the left and right halves, which are not connected (Fig. 1).

In the area of the transition of the interventricular groove from the cranial to the caudal direction, closer to the right edge of the pig's heart, there is a heart notch. Each half of the heart from the outside, by the coronal groove, which is across the heart, closer to its base, is divided (left and right) into two connected chambers – a thin-walled atrium and a thick-walled ventricle, which are separated from each other by a flap valve that ensures the movement of blood in only one direction – from the atrium to the ventricle. The right and left atria are located at the most extended base of the organ. There, they form bag-like protrusions – large and well-defined heart ears of the same name (Fig. 1). The latter are topographically located in the cranial direction and are located to the right and left, concerning the trunk of the pulmonary arteries and the aorta.

Our organometric studies of the heart of sexually mature pigs established that the absolute weight of the heart is 487.4 g, and the relative weight is 0.29%. The weight of the heart without epicardial fat (net weight) is 461.4 g. According to research, the height of the heart of a sexually mature pig is 15.9 ± 0.1 cm, the width at the base is 10.3 ± 0.1 cm, the circumference is 26.5 ± 0.1 cm, while the pig heart development index is 155.1 ± 6.3%; therefore their heart is elongated-narrowed (cone-like) type (Fig. 1; Table 1).

According to the results of the morphometry of the anatomical structures of the heart, the left and right ventricles are more voluminous in absolute mass. The smallest values of the absolute mass belong to the left and right atria. According to the morphometric analysis conducted by us, such quantitative absolute indicators of the components of the heart (ventricles and atria) of the pig are correlated with the linear measurements of their wall thickness and, accordingly, with their absolute mass and relative mass, concerning the absolute mass of the heart. The most developed anatomical structures of the heart are its left and right ventricles, then the left and right atrium, which correlate with linear indicators (diameters) of the thickness of their walls and the absolute and relative mass of the ventricles and atria concerning the net mass of the heart (Tables 1 and 2). Thus, the wall of the left ventricle of a pig (26.7 ± 0.51 mm) is almost two times thicker than the right ventricle (14.4 ± 0.3 mm), the wall of which in a pig is thin-walled and less distinctly flattened. The thickness of the atrial wall is the smallest: RA – 6.02 ± 0.04 mm, LA – 7.81 ± 0.06 mm (Table 1).

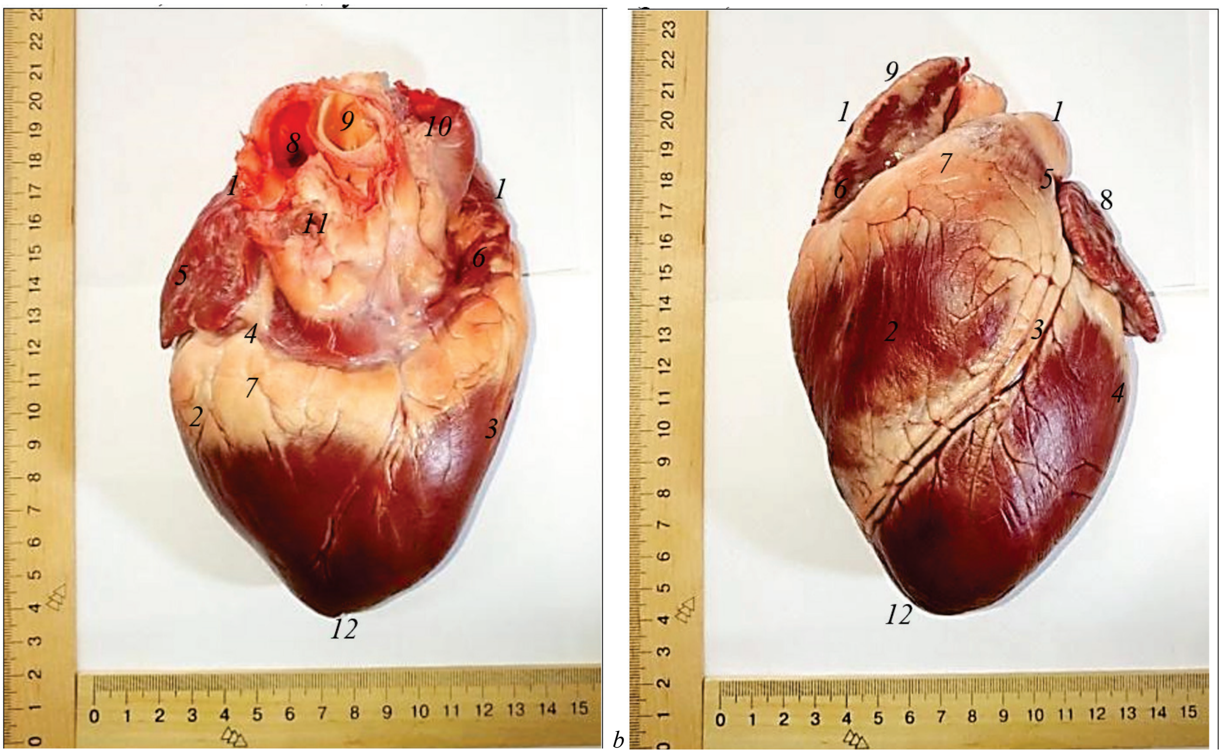

Fig. 1. Macroscopic structure of the heart of a sexually mature pig: *a* – caudal projection: *1* – heart base; *2* – left ventricle; *3* – right ventricle; *4* – left atrium; *5* – left auricle; *6* – right auricle; *7* – subepicardial fat; *8* – pulmonary artery; *9* – aorta; *10* – caudal vena cava; *11* – pulmonary veins; *12* – apex of the heart; *b* – right side: *1* – heart base; *2* – left ventricle; *3* – axillary interventricular groove; *4* – right ventricle; *5* – right atrium; *6* – left atrium; *7* – subepicardial fat; *8* – right auricle; *9* – left auricle; *12* – top of the heart

Table 1
Linear parameters of the heart of a pig (x ± SD, n = 7)

Indicator	Numeric values
Heart height, cm	15.9 ± 0.1
Heart width, cm	10.3 ± 0.1
Heart circumference, cm	26.5 ± 0.1
Cardiac development index, %	155 ± 6
Average value of ventricular wall thickness, mm	20.6 ± 0.2
Left ventricular wall thickness, mm	26.7 ± 0.5
Right ventricular wall thickness, mm	14.4 ± 0.3
Average value of atrial wall thickness, mm	6.9 ± 0.1
Left atrial wall thickness, mm	7.8 ± 0.1
Right atrial wall thickness, mm	6.0 ± 0.0

Such a significant ($P < 0.01$) difference is explained by the fact that the right ventricle of the heart participates in the small circle and the left ventricle, respectively, in the large circle of blood circulation, where the blood in animals, which enters the aorta from the left side of the heart, is significantly below the high systolic pressure “upper” pressure – 120–130 mm Hg. Art., depending on the type of animals.

The linear parameters of the ventricles' wall and the heart's atria correlate with their weight. Moreover, there is a specific dependence between the thickness of the walls of the ventricles and atria and their absolute and relative mass, which emphasizes the connection between the linear dimensions of the heart and its absolute mass. According to our research, the difference between the absolute mass of the left atrium (59.6 ± 2.2 g; 12.9 ± 0.1%) and the absolute mass of the right atrium (38.1 ± 1.9 g; 8.26 ± 0.11%) is 21.5 g. At the same time, the average mass of the atria of the pig heart is 97.7 ± 5.5 g (21.2 ± 2.0%). The most enormous absolute mass is observed in the left ventricle, which withstands the most significant loads in the heart. At the same time, the difference between the absolute mass of the left ventricle (250 ± 5; 54.4 ± 3.2%) and the absolute mass of the right ventricle (113 ± 4 g; 24.5 ± 1.6%) is the largest and is equal to 138.1 g.

Table 2
Morphometry of the heart, ventricles and atria of pigs (x ± SD, n = 7)

Indicators	Absolute mass, g	Relative mass, %
Heart	487 ± 8	0.29 ± 0.00
Left atrium	59.6 ± 2.2	12.9 ± 0.1
Right atrium	38.1 ± 1.9	8.3 ± 0.1
Right and left atrium (together)	97.7 ± 5.5	21.2 ± 2.0
Left ventricle	251 ± 5	54.4 ± 3.2
Right ventricle	113 ± 4	24.5 ± 1.6
Left and right ventricles (together)	364 ± 11	78.8 ± 5.9
Heart weight (without apical fat)	461 ± 8	100
The coefficient of the ratio of the mass of the ventricles to the net mass of the heart	1:0.79	
The coefficient of the ratio of the mass of the atria to the net mass of the heart	1:0.21	
The ratio of the mass of the atria to the mass of the ventricles	1:0.27	

The average absolute mass of both ventricles is 364 ± 11 g. Given this, the absolute mass of the ventricles is 3.7 times significantly ($P < 0.001$) more than the absolute mass of the atria. And from this, the coefficient of the ratio of the absolute mass of the ventricles of the heart of a pig to the absolute mass of the heart without epicardial fat is equal to 1:0.79, respectively, the ratio of the absolute mass of the atria is equal to 1:0.21. At the same time, the ratio of the atrial myocardium's absolute mass to the ventricular myocardium's absolute mass is 1:0.27 (Table 2).

The microscopic structure of the wall of the myocardium is formed by cardiac muscle fibers, which are formed by contractile (typical) cells – cardiomyocytes. The latter has a rectangular shape on a longitudinal section and a rounded shape on a transverse section (Fig. 2b). Between the muscle fibers, there are layers of loose connective tissue (intermuscular connective tissue), where a significant number of blood vessels and nerves are located (Fig. 2a). Muscle fibers (cardiomyocytes) have different lengths and widths: the most extensive length (64.08 ± 2.02 μm) and width (11.04 ± 0.13 μm) are typical for left ventricular cardiomyocytes, the smallest for atrial cardiomyocytes, 55.49 ± 1.98 and 8.25 ± 0.18 μm, respectively (Fig. 3a; Table 1). In some places, the muscle fibers of the myocardium connect with the help of anastomoses (Fig. 2c), forming a mesh-like structure visible on the longitudinal section of the muscle tissue. This myocardium structure contributes to the rapid and simultaneous contraction of the heart muscle. When staining histopreparations of the myocardium of the pig heart according to the Heidenhain method, the sarcoplasm of cardiomyocytes is seen to contain a well-defined uniform parietal striation (Fig. 3b). Such striations are formed as a result of the alternation of actin and myosin proteins, which together form a complex protein of muscle fibers (actomyosin) – actomyosin complex (actomyosin system), which is a component of contractile (typical) cells - cardiomyocytes, determining their contractile ability.

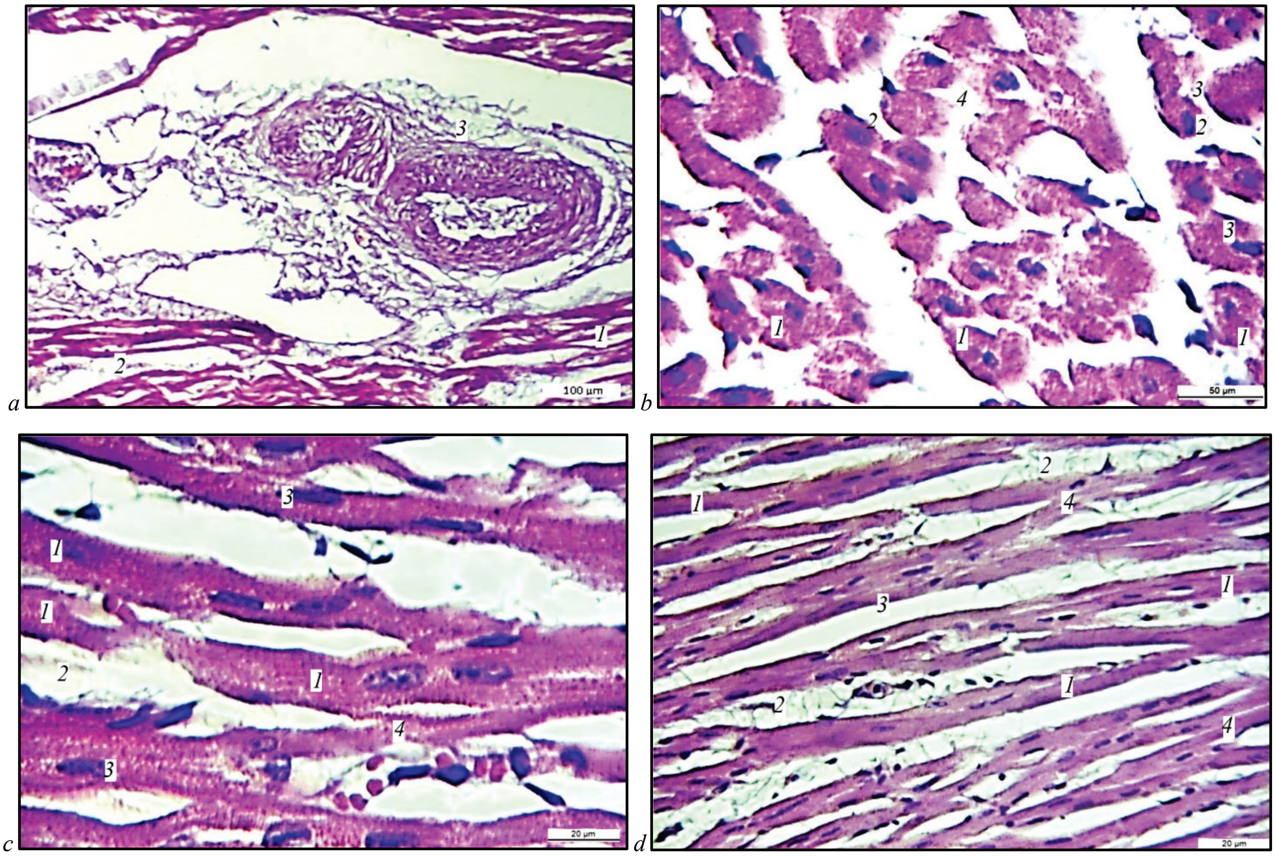

Fig. 2. Microscopic structure of the myocardium: *a* – the left ventricle of the heart of a pig: *1* – muscle fibers; *2* – intermuscular connective tissue; *3* – blood vessels; *b* – the left ventricle of the heart of a pig (transverse section): *1* – cardiomyocytes of a rounded shape; *2* – nuclei; *3* – sarcoplasm; *4* – intermuscular connective tissue; *c* – the right ventricle of the heart of a pig: *1* – muscle fibers; *2* – intermuscular connective tissue; *3* – nuclei of muscle fibers; *4* – anastomoses; *d* – the left ventricle of the heart of a pig: *a* – muscle fibers in the form of a mesh-like structure; *b* – intermuscular connective tissue; *c* – nuclei of muscle fibers; *d* – anastomoses; hematoxylin and eosin

Two protein filaments, actin (thin) and myosin (thicker), form sarcomeres, which combine to form myofibrils. The latter is located in the sarcoplasm of contractile cells (cardiomyocytes) in a specific order, thus forming their longitudinal striation (Fig. 3c, 3d). The nuclei of cardiomyocytes, located in the center of the sarcoplasm, are most intensively stained. The nuclei were oval or elongated in shape. Nucleoli and grains of different sizes were found in the karyoplasm; nuclear chromatin was uniformly located in the karyoplasm.

According to cytomorphometry, the average indicators of the volume of cardiomyocytes of the left ventricle of the pig heart were 6130 ± 922 μm^3. Meanwhile, the volume of cardiomyocytes of the myocardium of the right ventricle in a pig was 3794 ± 489 μm^3), lower than those in the left ventricle. The average indicators of the volume of the cardiomyocytes of the atria of the pig heart myocardium were the smallest (2964 ± 412 μm^3), respectively, 2.07 times smaller, compared to such indicators of the cardiomyocytes of the left ventricle and by 1.3 – with the cardiomyocytes of the right ventricle (Table 3).

The indicators of the volume of the core of cardiomyocytes of the LV, RV, and atria have similar values, which are 77.16 ± 2.01, 76.02 ± 2.43, and 75.9 ± 3.2 μm^3, respectively (Table 3). Based on the average indicators of the volume of cardiomyocytes and their nuclei, it was established that the nuclear-cytoplasmic ratio in cardiomyocytes of the left ventricle is the smallest at 0.0127 ± 0.0056. Meanwhile, the nuclear-cytoplasmic ratio of cardiomyocytes of the right ventricle (0.0204 ± 0.0068) is 1.60 times greater than that of the left ventricle. The most significant value of the nuclear-cytoplasmic ratio is typical for atrial cardiomyocytes and, accordingly, is equal to 0.0263 ± 0.0097; thus, this indicator is 2.07 times higher compared to left ventricular cardiomyocytes and 1.29 times higher than right ventricular cardiomyocytes (Table 3).

Discussion

The heart is a hollow fibromuscular organ; thanks to the work of its contractile myocytes, continuous blood circulation occurs. Topographically, the heart is located in the chest cavity between the right and left lungs, cranial to the diaphragm, and slightly shifted to the left of the median plane. Its expanded base is at the level of the shoulder joint (at the level of the middle of the first rib) and is directed dorsocranially and to the right. The pointed apex of the heart is located in the 5–6th intercostal space, near the sternum in the junction of the 7th rib with its cartilage. It is directed ventrocaudally and to the left, not reaching the diaphragm and sternum, which are connected by diaphragmatic-pericardial and sternopericardial ligaments. The cranial edge of the heart lies at the level of the third, and the caudal edge at the level of the sixth rib. The wall of the heart is made up of the endocardium (inner lining of the heart), myocardium (middle muscular lining), and epicardium (outer lining of the heart). The endocardium is formed from endothelial, subendothelial, muscle-elastic, and connective tissue layers. The endothelial layer of the endocardium is located on the basement membrane; the subendothelial layer is formed by a large number of poorly differentiated cells, the muscle-elastic layer is represented by smooth muscle cells, the connective tissue layer is formed by fibrous connective tissue formed by thick collagen, elastic and reticular fibers. The outer shell of the heart (epicardium) is formed by fibrous connective tissue, which is covered with mesothelium.

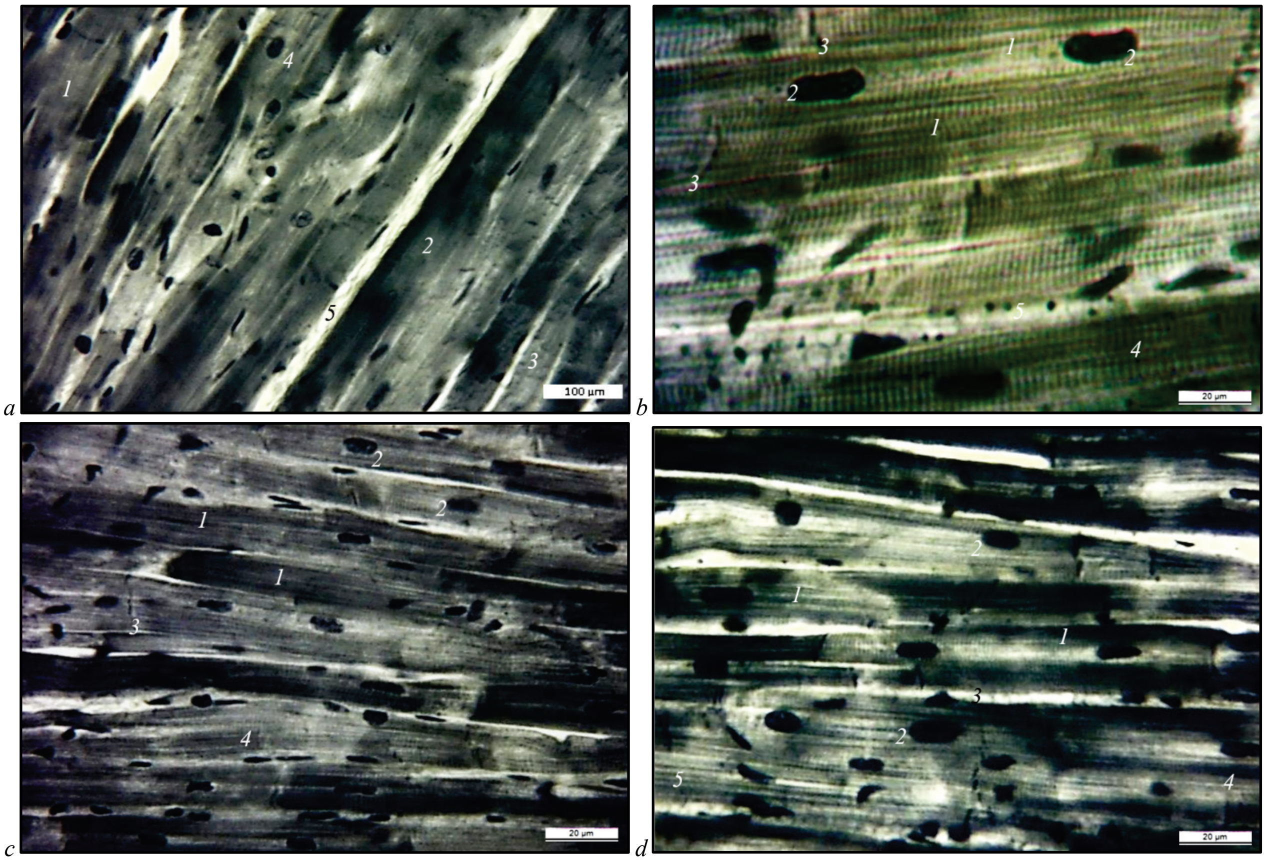

Fig. 3. Microscopic structure of myocardium: *a* – pig left ventricle: *1* – thick muscle fiber; *2* – muscle fiber of medium thickness; *3* – muscle fiber of small thickness; *4* – nuclei of cardiomyocytes; *5* – intermuscular connective tissue; *b* – left ventricle of a pig heart: *1* – cardiomyocytes; *2* – nuclei of cardiomyocytes; *3* – insert discs; *4* – transverse banding; *5* – intermuscular connective tissue; *c* – the right ventricle of the heart of a pig: *1* – cardiomyocytes; *2* – nuclei of cardiomyocytes; *3* – insert discs; *4* – longitudinal striation; *d* – left ventricle of pig heart: *1* – cardiomyocytes; *2* – nuclei of cardiomyocytes; *3* – insert discs; *4* – longitudinal striation; dyeing according to the Heidenhain method

Table 3
Histometric parameters of pig cardiomyocytes (x ± SD, n = 7)

Indicator	Length of cardiomyocytes, µm	Cardiomyocyte width, µm	Volume of cardiomyocytes, µm^3	The volume of cardiomyocyte nuclei, µm^3	Nuclear-cytoplasmic relationship
Left ventricle	64.1 ± 2.0^c	11.0 ± 0.1^c	6131 ± 922^c	77.2 ± 2.0^b	0.0127 ± 0.0056^a
Right ventricle	59.2 ± 2.1^b	9.0 ± 0.1^b	3795 ± 490^b	76.0 ± 2.4^a	0.0204 ± 0.0068^b
Auricle	55.5 ± 2.0^a	8.3 ± 0.2^a	2964 ± 412^a	75.9 ± 3.2^a	0.0263 ± 0.0097^c

Note: letters indicate significant differences between values within a bar (P < 0.05) by Tukey's test.

The middle membrane (myocardium) is the base of the wall of the heart, its ventricles, and atria. The wall of the myocardium of the heart's ventricles consists of outer and inner (the muscle fibers of which have an oblique-longitudinal direction) layers, outer and inner deeper layers, and the deepest layer, the fibers of which have a figure-of-eight direction. Two layers, outer and deep, form the myocardium of the atrial wall. The first (external) is common to both atria; their muscle fibers have a transverse direction from the right to the left auricle. The muscle fibers of the second (deep) layer of the myocardium of the right atrium and left atrium are located in the longitudinal direction. In addition, circular bundles of muscle fibers are found in the venous openings of the myocardium.

The ventricles occupy the central lower part of the heart, separated by the interventricular axillary and biconical furrows. The latter are combined on the cranial surface of the heart, not reaching its apex, separating the right ventricle from the left ventricle. The narrowed apex of the heart refers to the left ventricle, which is located to the left in the caudal direction. The right ventricle is located on the right in the cranial direction. Interventricular furrows have a similar location: axillary – in the caudal; near-conical – in cranial directions. In the upper third, the left and right ventricles of the heart are more pronounced, more voluminous, and taper cone-like towards the apex (Fig. 1). Similar studies of the macrostructure of the structural components of the heart of animals agree with the results (Crick et al., 1998).

One of the indicators of the functional state of organs, their systems, and the body as a whole is the study of their absolute and relative mass, which is essential in clinical and preventive medicine (Mits et al., 2016). The results of numerous studies (Hushchyn, 2021) show that the indicators of the absolute mass and relative mass of the heart directly depend on the age, species, and breed of the animal, as well as on the work performed by the animal. Thus, according to S. K. Rudyk and V. T. Khomych, the heart weight of a newborn animal is 0.76% of its body weight (Rudyk, 2004). In pigs, these indicators are 307.2–334.3 g and 0.28–

0.30%, respectively, in horses – 2150–4300 g and 0.58–0.60% (Bertho & Gagnon, 1964; Rudyk, 2004), in cattle – 1300–2400 g and 0.35–0.40% (Demus, 2015). The weight of the heart is also affected by the size of the animals, which is characteristic mainly for dogs: absolute – 72.4 g in small to 154.0 g in large breeds, relative weight, respectively – from 1.30% to 0.59% (Gómez-Torres et al., 2021; Best et al., 2022). The weight of the heart is more significant in males than in females (in bulls – 0.50%, in cows – 0.42%). With increased physical exertion, the weight of the heart rises (Rudyk, 2004).

Criteria for the functional state of organs and their systems are linear dimensions (length, width, thickness, circumference), which can be used to determine the shape of organs, their development index, etc. (Mits et al., 2016). The shape of the heart is individual and depends on age, gender, body structure, state of health, and other factors. The measure of elongation (factor) of the shape of the heart is the ratio of its largest longitudinal (height) and transverse (width at the base) linear dimensions (Linask, 2003; Shevchenko, 2018).

According to species, breed characteristics, age, different forms of the morphological structure of the heart are distinguished in domestic animals of the mammal class: narrowed-elongated (cattle), narrowed-shortened (rabbits), widened-shortened (horses), round-oval (dogs) (Emam & Abugherin, 2020). In dogs, the heart shape (depending on breed characteristics) can be elliptical in 43% of cases), conical-elliptical in 24%, elliptical-spherical in 26%, and spherical in 7% of cases. In cattle, the shape of the heart is conical, elongated-narrowed and expanded-shortened. Analyzing literary sources, it can be noted that pigs are characterized by three main heart types: elongated-narrowed (cone-shaped), shortened (relatively narrowed), extended-shortened (triangular) (Rudyk, 2004; Garg et al., 2013; Shah et al., 2022).

It should be noted that the structural organization of cardiomyocytes of the myocardium is a critically important factor in the coordinated contractile function of the heart. Due to the functioning of the pulmonary blood circulation, immediately after the birth of the animal, the relative load on the left and right ventricles changes significantly, which is subsequently reflected in the cytoarchitectonics of cardiomyocytes and their morphometric indicators (Zhang et al., 2013).

When analyzing the processes of nuclear-cytoplasmic ratio formation in cardiomyocytes of the heart myocardium, specific features of the nuclear-cytoplasmic ratio of cardiomyocytes of heart histostructures were established, depending on their functional load (Anderson & Ho, 2002; Horalskyi et al., 2023). Thus, according to our studies, the lowest index of the nuclear-cytoplasmic ratio is typical for cardiomyocytes of the left ventricle. This is not a coincidence, but an objective reality, according to data (Hnatyuk et al., 2016). The most functionally active cells are those characterized by a low nuclear-cytoplasmic ratio, and conversely, cells with a high index of nuclear-cytoplasmic ratio are less functionally active.

This is because a large (somatic) circle of blood circulation begins from the left ventricle, where, thanks to the work of contractile (typical) cardiomyocytes through a closed system of vessels to organs and animals, arterial blood flows, where gas exchange processes take place in the capillaries. Therefore, the LA of the heart functions as a pressure pump. On the contrary, the LA of the heart, one of the four chambers in which the small (pulmonary) circle of blood circulation begins, where, owing to the work of contractile cardiomyocytes, venous blood proceeds to the lungs. Therefore, the LA functions as a volume pump. At the same time, the LA and RA close a small circle of blood circulation, and the LA and RA close a large circle of blood circulation. Therefore, atrial cardiomyocytes have significantly smaller volumes than those of the left and right ventricles and are characterized by a high nuclear-cytoplasmic ratio index.

Conclusion

The absolute weight of the heart of a domestic pig (*Sus domestica*) is 487.4 ± 8.1 g, the relative weight is 0.290 ± 0.004%, and the weight of the heart without epicardial fat is 461.4 ± 8.0 g. According to linear measurements (height 15.9 ± 0.1 cm, width – 10.30 ± 0.06 cm, circumference – 26.5 ± 0.1 cm), the domestic pig heart development index is 155.1 ± 6.3%, therefore the heart is of the elongated-narrowed (cone-like) type. Depending on the functional load, the left and right ventricles have the most significant mass, followed by the left and right atria. The volumes of the nuclei of cardiomyocytes in the left ventricle and the right ventricle and the volumes of the nuclei of cardiomyocytes in the atria have similar values, but the nuclear-cytoplasmic ratio is different. The smallest nuclear-cytoplasmic ratio is characteristic of cardiomyocytes of the left ventricle, there is a significantly greater nuclear-cytoplasmic ratio of cardiomyocytes of the right ventricle, and, accordingly, the most significant nuclear-cytoplasmic ratio is characteristic of atrial cardiomyocytes, depending on the functional load of myocardial muscle tissue, during spontaneous rhythmic abbreviations.

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