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Morphometric parameters of the heart of domestic sheep *Ovis aries L.*, 1758

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Abstract

The cardiovascular system is one of the most critical animal systems. Its main functions are to supply organs and tissues with oxygen and nutrients and to remove metabolic products from tissues. Diseases of the cardiovascular system of animals cause significant economic damage, including reduced productivity, reproductive qualities, and the development of concomitant diseases. The prevention, diagnosis, surgery, and treatment of such pathologies are only possible by knowing the morphofunctional parameters of comparative anatomy, histology, and physiology. The heart plays a vital role in blood circulation and regulates the proper functioning and development of all organs of animal and human organisms. The study of the heart structure reveals topography features, age-related morphology, and development of this organ in domestic animals and remains relevant. The article is a fragment of the scientific developments of the Department of Normal and Pathological Morphology, Hygiene and Forensics of Polissia National University on the following topics: "Features of the morphology of the heart of domestic mammals" (state registration number 0121U108884); "Development, morphology and histochemistry of animal organs in normal and pathological conditions", state registration number 0113U000900. In the study, sexually mature clinically healthy animals (n = 5) belonging to the class Mammalia – Mammals, species *Ovis aries L*., 1758 – domestic sheep (ram) were investigated. The study aimed to evaluate the morphological structures of the heart of mature sheep using macro- and microscopic, morphometric, and statistical research methods. The heart of a sexually mature domestic sheep was subjected to anatomical dissection. Sections were stained with hematoxylin and eosin to study the cyto- and histoarchitectonics of the heart for microscopic examination of transverse striated myocardial muscle tissue, detection of cardiomyocyte cytostructure, and Heidenhain staining of histological specimens were used. The morphology of the heart in sheep has a similar organization plan, topographic location of the organ, and anatomical and histological structure. However, there are some striking species and morphological features. The heart of the domestic sheep belongs to the expanded-shortened anatomical type (according to its development index – 145.5 ± 4.02 %). According to the studies, the absolute and relative weight of the heart of mature sheep is, accordingly, 208.4 ± 9.82 g and 0.44 ± 0.007 %, and the weight without epicardial fat is 175.0 ± 8.17 g. It has been shown that the microscopic structure of the ventricles and atria of the sheep heart differ in cytometric parameters. Cardiomyocytes of the left ventricle have the most significant volume (3982.99 ± 423.96 μm^3), the smaller – of the right ventricle (2463.02 ± 318.04 μm^3). The lowest index was observed in atrial cardiomyocytes (1215.93 ± 176.94 μm^3). The volumes of cardiomyocyte nuclei in the left ventricle were (53.42 ± 5.18 μm^3) and in the right ventricle (52.85 ± 4.33 μm^3). The volume of atrial nuclei (50.16 ± 4.57 μm^3) is almost the same. Such ambiguous morphometric parameters of cardiomyocytes and their nuclei volumes are directly reflected in their nuclear-cytoplasmic ratio, which is the smallest in cardiomyocytes of the left ventricle (0.0136 ± 0.0062), larger in cardiomyocytes of the right ventricle (0.0219 ± 0.0079) and the largest (0.0430 ± 0.0096) in atrial cardiomyocytes. The obtained results of the study of the macro- and microscopic structure of the heart of domestic sheep significantly supplement the information on heart morphology in the relevant sections of comparative anatomy and histology and are a significant contribution to clinical cardiology.

Keywords: animals; cardiovascular system; functional state; macro- and micromorphology; dissection; histological preparation.

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1. Introduction

Sheep breeding as one of the livestock sectors is an integral part of the country's economic complex (Binkevych & Yatsenko, 2015; Lavruk, 2018). Goats and sheep are among the first animals domesticated by humans, which began to be tamed 8000–12000 years ago, in the Late Stone Age (Neolithic), as evidenced by fossils and rock carvings found in various parts of Europe, Asia Minor, and Central Asia. According to the zoological taxonomy, domestic goats belong to the class *Mammalia*. Domestic sheep belong to the genus *Ovis*, which, together with the genus *Sarga*, belongs to the subfamily *Caprovinae*. In the field of morphological research (as an experimental animal), the sheep can be used as a model in biomedical research and is one of the most important models of human organ systems. For example, according to statistical data, cardiovascular diseases in humans are among the most common diseases of non-communicable etiology and are the leading cause of mortality. These diseases also occur in domestic productive and carnivorous animals (Thiriet, 2019; Vatnikov et al., 2019; Iovenko & Hladii, 2021).

The cardiovascular system consists of the heart, circulatory, and lymphatic systems (Buckberg et al., 2018). The central organ of the cardiovascular system is the heart, which pumps blood into the arteries, which become smaller as they move away from the heart, turning into arterioles and capillaries that form specific networks in the organs (Onwuka et al., 2018; Mori et al., 2019).

The cardiovascular system ensures blood's continuous movement (circulation) in the animals' bodies. Blood circulation, in turn, ensures a constant supply of oxygen to the cells and tissues of the body, nutrients absorbed into the blood and lymph, and the excretion of carbon dioxide and metabolic products (Jones et al., 2014). The functional, continuous, and consistent work of the heart muscle is achieved through systole (contraction of the heart muscle) and diastole (relaxation of the heart muscle), which together form the cardiac cycle (Bessonova et al., 2016).

This system is dominant in providing respiratory, trophic, and excretory functions that ensure metabolism (Alvarado & Arce, 2016; Liu & Summe, 2019). In warm-blooded animals, the cardiovascular system is of great value in thermoregulation (Tan & Knight, 2018). The blood carries hormones, antibodies, and other physiologically active substances, which results in the activity of the immune system and hormonal regulation of processes in the body with the leading role of the nervous system (Sokulskyi et al., 2021).

Knowledge of cardiac function indicators is essential for diagnosing and determining the disease's severity and selecting treatment programs (Tian et al., 2022). There is no doubt that the comparative species and breed morphology of the organs of the cardiovascular system reveals the internal laws of their structure, features of phylogenesis and ontogenesis, and the adaptation of animals to environmental conditions of confinement with limited mobility and within farms under intense anthropogenic influence (Bhattacharjee et al., 2022).

The relevance of these problems has led to the choice of the goal and objectives of our research. Therefore, the study of the peculiarities of heart structure structure is considered a practical and essential link for the development of national morphology. This explains the fact that veterinary cardiology, which studies diseases of the heart and blood vessels of animals, as well as cardiovascular surgery, are currently among the priority areas that are actively developing in veterinary medicine (Savchuk et al., 2018; Syniachenko et al., 2018; Rykiel et al., 2020; Frąk et al., 2022; Pilz et al., 2022).

Knowledge of the morphoarchitectonics and functional state in normal and pathological conditions of the cardiovascular system is fundamental to understanding how the body is organized, how the whole organism works, and how it is affected by various pathological processes.

2. Materials and methods

In this study, sexually mature clinically healthy animals belonging to the class Mammalia – Mammals, species *Ovis aries L.*, 1758 – domestic sheep (n = 5) were investigated. The experimental animals were selected according to the principles of analogs, weight, breed, and age. Scientific research was carried out at the Department of Normal and Pathological Morphology, Hygiene, and Expertise of the Faculty of Veterinary Medicine of Polissia National University during 2019–2024. The scientific work is a fragment of the department's development: "Features of the morphology of the heart of domestic mammals" (state registration number 0121U108884); "Development, morphology and histochemistry of animal organs in normal and pathological conditions" (state registration number 0113V000900). The work began with anatomical dissection of the hearts of the studied animals. The obtained material was fixed in a 10 % solution of neutral formalin and embedded in paraffin according to the conventional method (Horalskyi et al., 2015). Paraffin sections, the thickness of which did not exceed 10–12 µm, were made on a sled microtome MS-2.

The linear parameters of the organ (height, width, and circumference) were determined by direct measurement.

The heart's absolute mass (AM) and its ventricles and atria were determined by weighing it on a RADWAG PS 6000/C/2 laboratory balance. Relative heart mass (RM) was calculated by the formula (1):

$$RM = \frac{AM}{AW} \times 100\%$$

where: AM – absolute heart mass; AW – animal weight.

The heart development index (HDI) was determined by the ratio of its total height to width using the following formula (2):

$$HDI = \frac{HC}{WC} \times 100\%$$

where: HC – the height of the organ; WC – width of the organ.

To study the histological structure of the heart, the sections were stained after deparaffinization with the classical staining method – hematoxylin and eosin and the Heidenhain method. The latter method of staining allowed for better and clearer differentiation of cardiomyocytes and for the detection of cardiomyocyte junctions (insertion discs).

The stained histological sections were used for histometric studies of the structural elements of the heart wall, including measurements of cardiomyocyte length and width, the volume of cardiac cells and their nuclei, and, as a rule, the nuclear-cytoplasmic ratio.

The nuclear-cytoplasmic ratio (NCR) of cardiomyocytes was determined by the formula (3):

$$NCR = \frac{V(n)}{V(c) - V(n)}$$

where: NCR – nuclear-cytoplasmic ratio; V(n) – the volume of the nucleus; V(c) – cardiomyocyte volume.

These studies were performed by light microscopy using Micros microscopes, according to the recommendations set out in the manual (Horalskyi et al., 2015). The statistical data of the results of quantitative studies were analyzed using the Statistica 7.0 software package (StatSoft, Tulsa, USA). The difference between the digital data of the studied indicators was carried out using ANOVA, which was considered significant at $P < 0.05$ (considering the Bonferroni correction). The numerical data of the study results are presented as (mean ± standard deviation).

The research was carried out by modern methodological approaches and in compliance with relevant requirements and standards; in particular, they conform to the requirements of DSTU ISO/IEC 17025:2005 (2006), the provisions of the "General Ethical Principles for Animal Experiments" adopted by the First National Congress on Bioethics (Kyiv, 2001). Experimental studies were conducted by the provisions of the Procedure for conducting experiments and experiments on animals by scientific institutions (Nichiporuk et al., 2022), by the requirements of the international principles of the European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes (Strasbourg, 1986) (European Convention, 1986), the Rules for the Conduct of Work with Experimental Animals approved by order of the Ministry of Health of Ukraine No. 281 of 1 November 2000 "On Measures to Further Improve Organisational Forms of Work with Experimental Animals", the Helsinki Declaration for the Humane Treatment of Vertebrates and the relevant Law of Ukraine "On the Protection of Animals from Cruelty".

3. Results and discussion

Comprehensive studies of the organs of the cardiovascular system, including pure hearts, which carry out extremely vital functions in the human and animal body, ensuring metabolism, are of significant relevance (Granger, 1998; Duncker & Bache, 2008; Hnatiuk & Slabyi, 2016). Based on the research objectives, we carried out the following stages: heart dissection, description of the shape, structure, and topography, determination of the absolute and relative mass of the heart, its components, microscopic examination, and organ and cytometric parameters of the organ.

The heart is the cardiovascular system's central organ, which ensures blood flow through the vessels. According to (Storlund et al., 2021), the heart is a muscular hollow organ and is topographically and functionally the central organ of the cardiovascular system, ensuring blood circulation. The heart of mature sheep is conical, with a dilated base and a narrowed apex. The organ is located in the mediastinum of the thoracic cavity between both lungs, in the area from the third to the sixth rib on the cranial side of the diaphragm. The base of the heart has a craniodorsal direction and is located at the height of the middle of the first or second rib. The coronary sulcus divides the heart into two sections: the dorsal – atrium and the ventral – ventricle. The right and left atria and ventricles of the same name are connected by the atrial and ventricular foramen.

It should be noted that the heart has different shapes in mammals (Demus, 2015; Emam & Abugherin, 2020). In predators, the dominant shape is spherical or cone-ellipsoidal. According to the literary sources, in dogs, depending on their breed properties, ellipsoidal (43 %), cone-ellipsoidal (24 %), ellipso-circular (26 %), and spherical (7 %) shapes are found (Gómez-Torres et al., 2021; Best et al., 2022).

From the point of view of mechanics, according to studies (Shemla et al., 2021; Weiser-Bitoun et al., 2021), the heart can be considered as a mechanism consisting of two discharge pumps formed into a closed system of tubes through which fluid (blood) circulates. In this case, the pumps create a directed blood flow in the appropriate direction. According to (Storlund et al., 2021), the heart is a muscular hollow organ and is topographically and functionally the central organ of the cardiovascular system, ensuring blood circulation.

The criteria of organ development, which directly indicates its morphological and functional maturity, are absolute and relative mass, linear parameters, etc. (Mits et al., 2016). Indicators of morphometric parameters not only indicate the development and morphological and functional maturity of the organ but also have cognitive value and are the basis for determining the shape and establishing comparative anatomical types of specific organs (Linask, 2003; Belimenko et al., 2021).

According to our studies, the absolute mass of the heart of mature ewes is 208.4 ± 9.82 g, and the relative mass is 0.44 ± 0.007 %, respectively. The weight of the heart without epicardial fat (net weight) is 175.0 ± 8.17 g. Heart height was 13.1 ± 0.4 cm, width was 9.0 ± 0.3 cm, and circumference was 22.2 ± 0.6 cm (Table 1).

Table 1
Linear parameters of the heart of mature sheep (M ± m, n = 5)

Parameters	Numerical values
Heart height, (cm)	13.1 ± 0.4
Heart width (cm)	9.0 ± 0.3
Heart circumference (cm)	22.2 ± 0.6
Heart development index, (%)	145.5 ± 4.02
Right ventricular wall thickness (mm)	8.04 ± 0.11
Left ventricular wall thickness (mm)	16.2 ± 0.22
Mean value of ventricular wall thickness, (mm)	12.42 ± 0.17
Right atrial wall thickness, (mm)	5.06 ± 0.07
Left atrial wall thickness, (mm)	7.05 ± 0.09
Mean value of atrial wall thickness, (mm)	6.62 ± 0.43

According to the analysis of our morphometry, in terms of linear parameters, the index of heart development of mature sheep is 145.5 ± 4.02 %, so this heart is of the expanded-shortened type (Table 1).

Macroscopic examination shows that the ventricles of the heart occupy the central part of the heart. Externally, they are separated by the interventricular subaxillary and near-cone grooves, which are combined on the cranial surface of the heart, not reaching its apex, separating the right ventricle from the left. The apex of the heart in sheep refers to the left ventricle, located to the left in the caudal direction. The heart's right ventricle, respectively, is located on the right in the cranial direction. The interventricular furrows have a similar arrangement (sub-axillary – in the caudal direction, near-cone – in the cranial direction).

The right and left atria are located at the very base of the heart, where they form bag-like protrusions - the right and left heart auricles, which in sheep are short and directed cranially and are located to the right and left, respectively, of the pulmonary artery trunk and aorta.

The most developed anatomical structures of the heart are its left and right ventricles, then the left and right atria, which correlate with linear parameters of their wall thickness and absolute and relative mass relative to the net mass of the heart (without epicardial fat) (Tables 1; 2).

We found that the wall thickness of the left ventricle was 2.01 times greater than that of the right ventricle ($P < 0.01$) and amounted to 16.2 ± 0.22 mm, and the right ventricle to 8.04 ± 0.11 mm. The atrial wall thickness was 6.62 ± 0.43 mm, in the left atrium – 7.05 ± 0.09 mm, and in the right atrium – 5.06 ± 0.07 mm (Table 1).

Table 2
Morphometry of the heart, ventricles, and atria of mature sheep (M ± m, n = 5)

Parameters	AM (g)	RM (%)
Left atrium	27.9 ± 3.31	15.94 ± 1.49
Right atrium	11.2 ± 2.02	6.4 ± 0.82
Right and left atrium (along)	39.1 ± 4.64	22.34 ± 2.02
Left ventricle	90.3 ± 5. 21	51.6 ± 3.06
Right ventricle	45.6 ± 3.04	26.06 ± 1.32
Left and right ventricles (along)	135.9 ± 7.16	77.66 ± 4.36
Net heart mass without apical fat	175.0 ± 8.17	100
Ventricular mass to heart mass ratio	1 : 0.78	
Atrial mass to heart mass ratio	1 : 0.22	
The ratio of atrial myocardial mass to ventricular myocardial mass	1 : 0.29	

With such linear parameters of the heart components, the average weight of the left atrium is 27.9 ± 3.31 g (15.94 ± 1.49 %), and the average weight of the right atrium relative to the left is significantly (P < 0.01) 2.5 times less. It equals 11.2 ± 2.02 g (6.4 ± 0.82 %). The average weight of the atria of the sheep heart is 39.1 ± 4.64 g (22.34 ± 2.02 %) (Table 2).

The numerical values of the morphometric study of structural elements in the heart are shown in Table 2. Thus, the mass of the left ventricle is the largest and amounts to 90.3 ± 5. 21 g (51.6 ± 3.06 %), the mass of the right ventricle is intermediate and equals 45.6 ± 3.04 g (26.06 ± 1.32 %), the average mass of both ventricles is 135.9 ± 7.16 g (77.66 ± 4.36 %). Thus, the mass of the ventricles of the sheep heart is significantly (P < 0.001) 3.5 times higher than the mass of the atria. Accordingly, the ratio of the mass of the ventricles of the heart of a mature sheep to its net (without epicardial fat) mass is 1 : 0.78, the ratio of the mass of the atria to its net mass is 1 : 0.22, and the ratio of the mass of the atrial myocardium to the mass of the ventricular myocardium is 1 : 0.29.

The wall of the sheep heart is formed by the inner (endocardium), middle (myocardium), and outer (epicardium) membranes. The myocardium, a muscular membrane, is the main structural component of the ventricular and atrial heart wall.

The analysis of hematoxylin and eosin-stained histological specimens of the myocardium of the left and right ventricular walls of the heart shows five layers: the outer and inner layers (whose muscle fibers have an oblique longitudinal direction), then the outer and inner deeper layers and the deepest layer, whose fibers have a figure-eight direction.

Two layers of muscular membrane form the myocardial structure of the atrial wall: the outer (common to both atria) and the deep. The cardiac muscle fibres of the outer layer of the myocardium are located in a transverse direction from the right to the left heart auricle. The muscle fibres of the deep myocardial layer of the right and left atria are located in the longitudinal direction. However, circular bundles of muscle fibers were found in the area of the myocardial venous orifices.

The histoarchitecture of the myocardium of the ventricular and atrial heart wall is formed by cardiac striated muscle tissue, which is represented by cardiomyocytes and intermuscular layers of loose fibrous connective tissue with the presence of blood and lymphatic vessels and nerves (Figs. 1, 2).

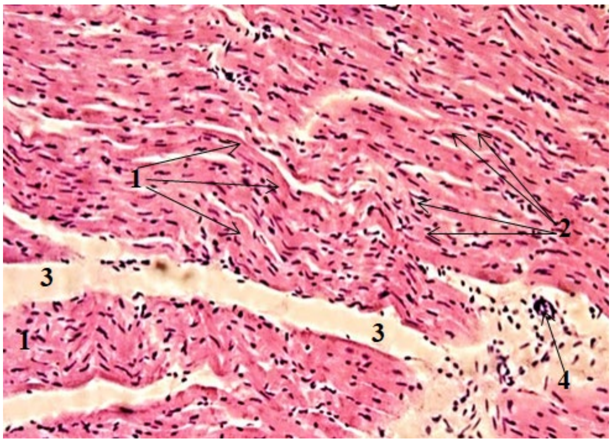

Fig. 1. Fragment of the histological structure of the myocardium of the left ventricle of the heart of a mature sheep: 1 – muscle fibres (longitudinal section); 2 – nuclei; 3 – intermuscular connective tissue; 4 – microcirculatory vessel. Hematoxylin and eosin staining. x 120

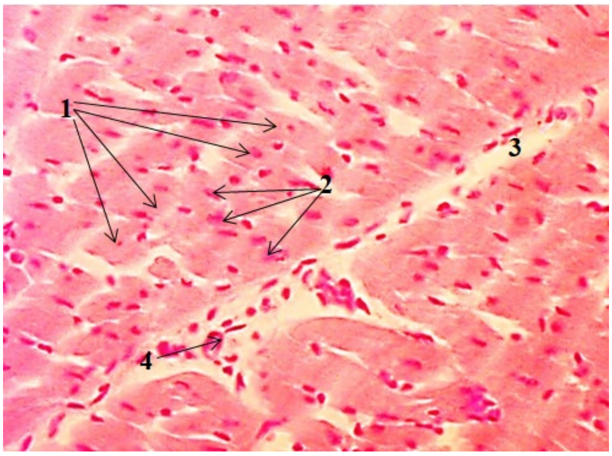

Fig. 2. Fragment of the histological structure of the myocardium of the left ventricle of the heart of a mature sheep: 1 – muscle fibres (transverse section); 2 – nuclei; 3 – intermuscular connective tissue; 4 – microcirculatory vessel. Hematoxylin and eosin staining. x 280

Transverse striated muscle fibres are made up of cardiac myocytes (cardiomyocytes) that perceive colour differently (Fig. 2). Cardiac myocytes in the myocardium form a network of thin and thicker striated muscle fibres, between which there is a gap space filled with intermuscular connective tissue (Figs. 2, 3). The parallel myocardial muscle fibres, formed by cardiomyocytes, are interconnected by anastomoses and form a mesh-like structure, forming a single contractile system of the heart.

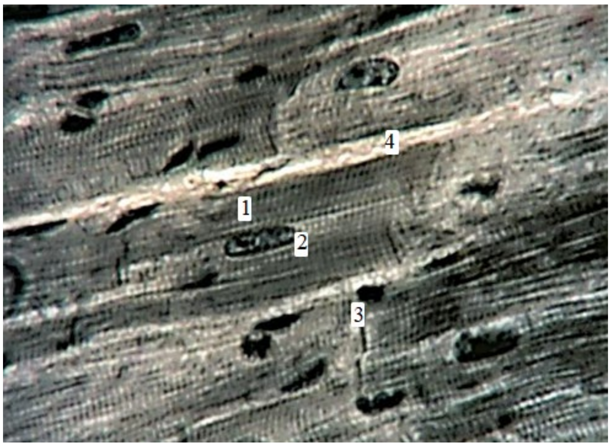

Fig. 3. Fragment of the histological structure of the myocardium of a mature sheep's left ventricle of the heart: 1 – cardiomyocytes; 2 – cardiomyocyte nuclei; 3 – insertion discs; 4 – intermuscular connective tissue. Staining by Heidenhain method. x 600

When staining histological specimens using the Heidenhain method, Cardiomyocytes in the fiber structure are arranged in a chain, interconnected by insertion discs (Figs. 3, 4). When histological sections are stained with hematoxylin and eosin, cardiomyocytes in the cardiac muscle tissue form histological structures similar to the muscle fibres of somatic muscle tissue, this interconnection of cardiomyocytes into muscle fibres represented by insertion discs provides a support function for the contractile elements of cardiac cells (myofilaments). It ensures a unified contraction of the myocardium, thus forming a functional syncytium.

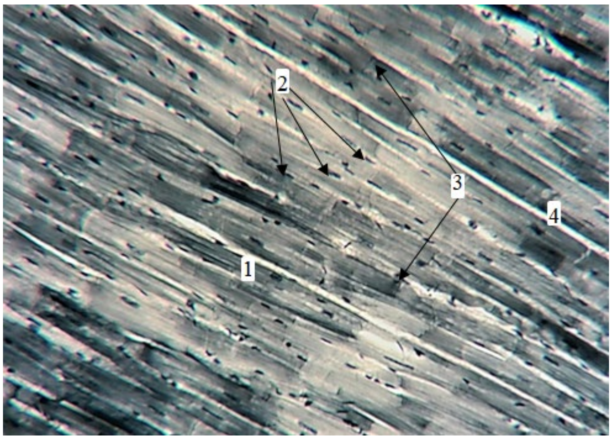

Fig. 4. Fragment of the histological structure of the myocardium of a mature sheep's left ventricle of the heart: 1 – cardiomyocytes; 2 – cardiomyocyte nuclei; 3 – insertion discs; 4 – intermuscular connective tissue. Staining by Heidenhain method. x 280

Light microscopy of histopreparations stained by the Heidenhain method shows cardiomyocytes in the longitudinal section as dark stripes, rectangular (Fig. 4), and in the transverse section as rounded (Fig. 5), so their shape is cylindrical.

The sarcolemma, sarcoplasm, myofibrils, and nuclei are differentiated in cardiomyocytes with this histological structure. They have distinct transverse (due to myofibrils) and longitudinal (due to the presence of actin and myosin proteins) striations.

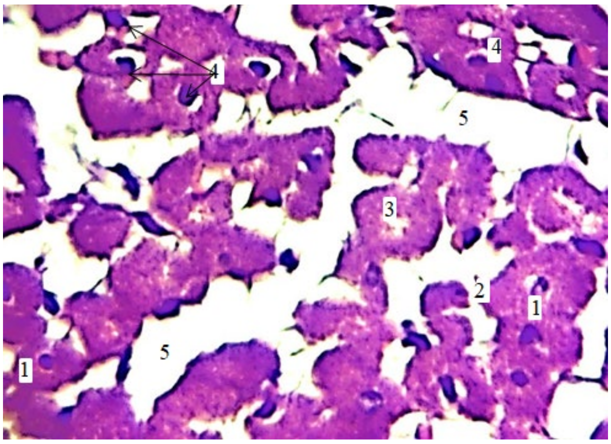

Fig. 5. Fragment of the histological structure of the transverse section of the myocardium of the right ventricle of the heart of a mature sheep: 1 – cardiomyocytes (transverse section); 2 – sarcolemma; 3 – sarcoplasm; 4 – cardiomyocyte nuclei; 5 – intermuscular connective tissue. Hematoxylin and eosin. x 400

In modern morphology, morphometric methods of research are widely used, which make it possible to establish the relationship and interdependence of quantitative changes in individual structures of the animal body, quantitative and relative characteristics of specific morphological components at different stages of ontological and phylogenetic development of animals and different functional states of a particular animal body system, depending on their species characteristics, etc.

According to the analysis of literature sources (Demus, 2015; Slabyi et al., 2017) and our research results, the sheep heart's microscopic structure and atrial and ventricular histoarchitecture have a similar structure. However, it differs in histological and cytometric parameters, which make it possible to establish even minor changes in the microscopic structure at the tissue and cellular levels, depending on their functional load. Thus, according to the results of our histometry, cardiomyocytes that form muscle fibres, depending on their morphotopography (right, left ventricles, atria), are characterised by ambiguous cytometric parameters (Table 3).

At the same time, the quantitative indicators of contractile myocytes of the left ventricle of the sheep heart myocardium are greater than those in the right ventricle: the average length of cardiomyocytes of the left ventricle is significantly ($P < 0.05$) is 1.27 times greater than that of the right ventricle and is equal to 62.92 ± 1.84 µm, the width of cardiomyocytes, respectively ($P < 0.05$) is 1.13 times more significant and is 8.98 ± 0.64 µm (Table 3).

We found similar morphometric characteristics when calculating the volume of cardiomyocytes: the most significant volume of cardiomyocytes is characteristic of the left ventricle (3982.99 ± 423.96 μm^3), the volume of cardiomyocytes of the right ventricle, compared with the left, is significantly ($P < 0.05$) less by 1.62 times and is equal to 2463.02 ± 318.04 μm^3 (Table 3).

The ambiguous morphometric parameters of the volumes of cardiomyocytes and their nuclei in the right and left ventricles of the heart, which we found, lead to different nuclear-cytoplasmic ratios: the lowest nuclear-cytoplasmic ratio is characteristic of cardiomyocytes of the left ventricle (0.0136 ± 0.0062) and significantly ($P < 0.01$) in 1.61 times was higher for right ventricular cardiomyocytes (0.0219 ±

0.0079), indicating morphological and functional activity of left ventricular cardiomyocytes (Table 3).

The minor cytometric parameters (length, width, volume) were characteristic of atrial cardiomyocytes, in which the nuclear-cytoplasmic ratio relative to that of left and right ventricular cardiomyocytes was significantly ($P < 0.001$) 3.16 and 1.96 times ($P < 0.01$) higher and equaled 0.0430 ± 0.0096 (Table 3). Such cytometric parameters of cardiomyocytes indicated a lower morphological and functional load of atrial contractile myocytes than ventricular cardiomyocytes. After all, the most morphofunctional active and mature somatic cells are those characterized by a low nuclear-cytoplasmic ratio index, and conversely, cells with a high nuclear-cytoplasmic ratio are less functionally active (Anderson & Ho, 2002; Hnatyuk et al., 2016). We attribute the different cyto- and karyometric parameters of ventricular and atrial cardiomyocytes to the morphological and functional activity of the heart: the atria receive blood returning to the heart from the body of animals, and the ventricles pump blood from the heart to the body, thus carrying the most significant load.

Table 3
Histometric parameters of sheep cardiomyocytes (M ± m, n=5)

Parameters	Cardiomyocyte length (μm)	Width of cardio-myocytes (μm)	Cardiomyocyte volume (μm^3)	The volume of cardiomyocyte nuclei (μm^3)	NCR
Left ventricle	62.92 ± 1.84	8.98 ± 0.64	3982.99 ± 423.96	53.42 ± 5.18	0.0136 ± 0.0062
Right ventricle	49.52 ± 1.62*	7.96 ± 0.56*	2463.02 ± 318.04*	52.85 ± 4.33	0.0219 ± 0.0079**
Atrium	42.04 ± 1.27**	6. 07± 0.38*	1215.93 ± 176.94**	50.16 ± 4.57	0.0430 ± 0.0096***

Notes: * $P < 0.05$; ** – $P < 0.01$; *** – $P < 0.001$ compared with the left ventricle

Thus, our studies have shown that the morphological structure of the sheep heart myocardium has macro- and histoarchitectonics similar to other mammals but differs in morphometric parameters.

4. Conclusions

With linear parameters of the heart: height – 13.1 ± 0.4 cm; width – 9.0 ± 0.3 cm, and circumference – 22.2 ± 0.6 cm, the index of heart development is 145.5 ± 4.02 %, so the heart in sheep is of the expanded-shortened type.

Morphological studies have shown that the most developed components of the heart are the ventricles: left and right, then the atria: left and right. Thus, the mass of the left ventricle is the largest and amounts to 90.3 ± 5. 21 g (51.6 ± 3.06 %), and the mass of the right ventricle is 45.6 ± 3.04 g (26.06 ± 1.32 %). The average weight of both ventricles was 135.9 ± 7.16 g (77.66 ± 4.36 %).

The average weight of the left atrium was 27.9 ± 3.31 g (15.94 ± 1.49 %), the average weight of the right atrium relative to the left atrium was significantly ($P < 0.01$) 2.5 times less and was 11.2 ± 2.02 g (6.4 ± 0.82 %), the average weight of both atria was 39.1 ± 4.64 g (22.34 ± 2.02 %). The ratio of the mass of the ventricles of the sheep heart to its net weight is 1: 0.78. The ratio of atrial mass is 1 : 0.22. The ratio of atrial myocardial mass to ventricular myocardial mass is 1 : 0.29.

The microscopic structure of the ventricles and atria of the sheep heart has similar histoarchitectonics but differs in cytometric parameters, depending on their morphological and functional load. Thus, the cardiomyocytes of the left ventricle have a larger volume (3982.99 ± 423.96 μm^3), the right ventricle has a smaller volume (2463.02 ± 318.04 μm^3), and the atrial cardiomyocytes have the smallest volume (1215.93 ± 176.94 μm^3). Almost the same indicators characterize the volumes of cardiomyocyte nuclei in the heart chambers: in the left ventricle – 53.42 ± 5.18 μm^3; in the right ventricle – 52.85 ± 4.33 μm^3; in the atria – 0.16 ± 4.57 μm^3. The lowest nuclear-cytoplasmic ratio in cardiomyocytes was observed in the left ventricle (0.0136 ± 0.0062), significantly higher ($P < 0.01$) – in cardiomyocytes of the right ventricle (0.0219 ± 0.0079) and significantly higher ($P < 0.001$) in atrial cardiomyocytes (0.0430 ± 0.0096). The relevant indicators are associated with the characteristics of myocardial muscle tissue capable of spontaneous rhythmic contractions.

Prospects for further research are to conduct a species-specific morphological study of the heart of domestic animals of the class Mammals – *Mammalia.*

Conflict of interest

The authors declare that no conflict of interest exists.

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