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Original research

Macro and microscopic structure and morphometric indices of the mature horse lungs

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Abstract. The macro- and microscopic structure of the lungs of mature horses has been studied using anatomical, histological, morphometric and statistical research methods. Morphometric estimation of lung morphological structures is given. The morphofunctional law of continuous unity and interdependence of the morphological structure and function is clearly shown in the system of the respiratory organs. Morphological researches of respiratory organs remain important and actual enough for the determination of their morphofunctional characteristic in different species. They allow diagnosing objectively the state of respiratory organs with the help of markers and criteria of morphological diagnosis. Macro- and micromorphology of lungs in sexually mature horses have characteristic anatomical features which correspond to class, age and species of animals. The presence of individual morphological features in the lung lobule structure is shown. The lung surface lobule pattern, which is formed by the stroma, is prominent in horses and has a smoother pattern compared to other domestic animals. The histological structure of the acini is formed by alveolar passages, alveolar sacs and alveoli. The alveolar tree in horses is of the shortened type, wide and vesicular in shape. Morphometric studies show that the average volume of pulmonary alveoli in clinically healthy horses is 699.8 ± 106.42 thousand μm^3. The respiratory part of the lungs in horses occupies 54.8 ± 7.4% of the total area of the lung parenchyma, and the connective tissue base occupies 45.2 ± 7.4%.

Keywords: morphology; lung histostructure; morphotopography; asymmetry coefficient; respiratory bronchioles

Макро- та мікроскопічна будова і морфометричні показники легень статевозрілого коня

Анотація. Досліджено макро- та мікроскопічну будову легень свійських статевозрілих коней за допомогою анатомічних, гістологічних, морфометричних та статистичних методів досліджень. Надано морфометричну оцінку морфологічних структур легень. У системі органів дихання наочно проявляється морфофункціональна закономірність безперервної єдності та взаємозумовленості морфологічної структури та функції. Морфологічні дослідження органів дихання наразі залишаються досить важливими і актуальними для визначення їх морфофункціональної характеристики у різних видів. Вони дозволяють об’єктивно діагностувати стан органів дихання за допомогою маркерних ознак і критеріїв морфологічної діагностики. Макро- та мікроморфологія легень у статевозрілого коня має характерні анатомічні особливості, які відповідають класу, віку та виду тварин. Показано наявність індивідуальних морфологічних особливостей у часточковій будові легень. Часточковість рисунку поверхні легень, яка утворена стромою, у коней помітна та має згладжений рисунок порівняно з іншими свійськими тваринами. Гістологічна будова ацинусів сформована альвеолярними ходами, альвеолярними мішечками та альвеолами. Альвеолярне дерево у коней укороченого типу, широке і має пухирчасту форму. Морфометричними дослідженнями виявлено, що середній об’єм легеневих альвеол у клінічно здорових коней складає 699,8 ± 106,42 тис. мкм^3. Респіраторна частина легень у коней займає 54,8 ± 7,4% від загальної площі паренхіми легень, а сполучнотканинна основа 45,2 ± 7,4%.

Ключові слова: морфологія; гістоструктура легень; морфотопографія; коефіцієнт асиметрії; респіраторні бронхіоли.

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Introduction

The main direction of the current state and prospects for successful development of animal husbandry and veterinary medicine is to improve the productive qualities of animals and prevention of infectious and non-communicable diseases (Williams et al., 2008; Johnson-Delaney & Orosz, 2011; Gutyj et al., 2017; Mylostyvyi et al., 2021; Lesyk et al., 2022). Therefore, along with organizational and economic measures, it is necessary to conduct an in-depth study of the body of productive animals in general and the morphology of organs and systems in particular (Veit & Farrell, 1978; Stravsky et al., 2020; Horalskyi et al., 2022). In a veterinarian's practice, respiratory system diseases are pretty standard (Rabeling et al., 1998; Grubor et al., 2006; Braun et al., 2018). At the same time, pathologies of pulmonary tissue most often occur (Kopytchak, 2014; Shhipakin et al., 2016), which are one of the most significant dangers to human and animal health (Lytvyn et al., 2002; Johnson & Matthay, 2010; King, 2015). Changes in inflammatory signalling underlie many processes of lung disease (Ward & Hunninghake, 1998; Bringardner et al., 2008; Provinciali et al., 2011).

Respiratory organs in humans and animals perform essential functions, the main of which is pulmonary respiration (Prokushenkova, 2009; Patwa & Shah, 2015; Radzykhovskyi et al., 2022).

The lungs are considered to be immunocompetent organs (Meyer et al., 1998; Moyron-Quiroz et al., 2004; Corbett & Kraehenbuhl, 2004). Thus, in the protection of the lungs from damage and the pathogenesis of many respiratory diseases of major importance is the pulmonary system of mononuclear phagocytes (Brogden et al., 2003; Hiemstra et al., 2016). Resistance of lung tissue to infections and exogenous and endogenous toxins largely depends on the state of the cellular component, mobilization ability, and functional reserves (Ostrovskyi, 2004; Wright, 2004).

Each lung in the majority of mammals is divided into three parts: cranial, middle, and caudal. However, the left lung has an additional lobe. Together with other domestic animals, the lungs of horses are formed by branching of bronchi of various calibres forming the bronchial tree and branching of histological structures of the respiratory section forming the alveolar tree. They are accompanied by vessels, nerves, and layers of loose connective tissue. The bronchi, in its turn, are differentiated into extrapulmonary and pulmonary. Extrapulmonary bronchi are the primary ones, and interparticle pulmonary bronchi are structures that are part of the lung parenchyma and branch out to form a bronchial tree.

The urgency of the study of the morphological component of the respiratory system in animals, in turn, is due to the significant spread and progressive growth of respiratory dysfunction at different levels of their structural organization (Kryvoruchko, 2002; Prokushenkova, 2009).

Therefore, we studied the macro-and micromorphology of lung structure and conducted its morphometric evaluation of morphological structures in mature horses, the indicators of which are morphological criteria of physiological and pathological changes in the respiratory system and are markers of pathomorphological diagnosis and disease (Yarto-Jaramillo, 2011; Nebesna & Yeroshenko, 2015; Samborska, 2021).

Materials and Methods

The work was performed at the Department of Normal and Pathological Morphology, Hygiene and Expertise, and the Laboratory of Pathomorphology of this department of the Faculty of Veterinary Medicine of Polissia National University. The work is a fragment of the scientific development of the department on the topic: "Development, morphology, and histochemistry of animal organs in normal and pathology" (№ state registration: 0113V000900).

Macroscopic, microscopic, morphometric, and statistical methods were used in this work. The object of the study was the lungs of clinically healthy mature horses (a domestic horse — Equus ferus caballus, Linnaeus, 1758) – Ukrainian riding horse breed, body weight 411–498 kg, (n = 6), female : male ratio was 1:1.

The work was performed in compliance with the basic provisions of good laboratory practice GLP (1981), the provisions of the "General ethical principles of animal experiments", approved by the First National Congress of Bioethics (Kyiv, 2001). The entire experimental part of the study was conducted following the requirements of international principles of the «European Convention for the Protection of Vertebrate Animals for Experimental and Other Scientific Purposes» (Strasbourg, 1986), "Rules for Working with Experimental Animals" 281 of November 1, 2000 "On measures to improve further organizational forms of work with the use of experimental animals" and the relevant Law of Ukraine "On protection of animals from cruel treatment" (№ 3447-IV of February 21, 2006, Kyiv).

Fresh lungs of the studied animals were subjected to anatomical preparation; commonly accepted methods of fixation and producing of histosections were used for histological examinations (Horalskyi et al., 2019).

The pieces of material were fixed in a 10–12% cooled solution of neutral formalin for 48 hours, followed by a step-by-step filling with a paraffin seal according to the schemes proposed in the manual (Horalskyi et al., 2019). Paraffin sections were made on a sledge microtome MS-2; their thickness did not exceed 10–12 μm.

To study the morphology of cells and tissues, histographs of lung tissue after their dewaxing were stained with hematoxylin and eosin. Stained histosections were used to study normal parenchymal organs' microscopic structure and histometric studies.

Histometric studies of the lung structural elements were carried out using light microscopy. The respiratory part and the connective tissue base of the lungs were determined on the frontal histological sections (n = 16), using an MBS-10 microscope on a unit of area that equals 5.0 mm2. The average volume of alveoli was measured by light microscopy using a "Micros" microscope (eyepiece ×8, objective ×20) with a constant tube length according to the recommendations outlined in the manual (Horalskyi et al., 2019).

Taking photos of histological sections was carried out with a microscope-mounted CAM V-200 digital video camera displaying images of histological sections on a monitor.

Digital data of morphometric studies were processed using variational statistical methods using Statistica 6.0 (StatSoft Inc., USA). We determined the arithmetic mean (M), the standard error of the arithmetic mean (m), the standard deviation (δ), the indicator of the significant difference between the arithmetic mean of two variational series according to the probability criterion (td).

Results

Lungs together with the heart in horses, as in other domestic animals, are contained in the thoracic cavity and are pale pink. In the lungs of horses, the dorsal and ventral edges are differentiated. The dorsal edge of the lungs is obtuse and adjacent to the spine. The ventral edge of the lungs is sharp and directed ventrally. Their surfaces are outlined on the lungs – rib (lateral) and diaphragmatic. The costal surface of the horse lungs is adjacent to the ribs; the diaphragmatic surface is adjacent to the diaphragm and is directed caudally.

Between the cranial and caudal lobes of the right and left lungs are interparticle surfaces, and between the right and left lungs are mediastinal surfaces adjacent to the mediastinum. They are located on each lung on the medial side. There are indentations from the aorta, esophagus, and vena cava on the same surface. Each lung in most mammals is divided into three parts: cranial, middle, and

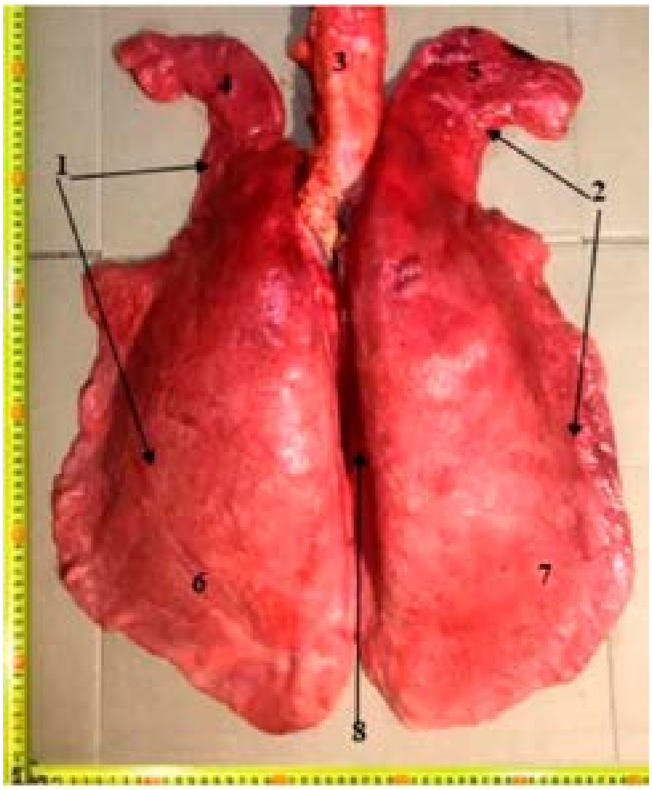

Fig. 1. The anatomical structure of the lungs of a mature horse (rib surface): 1 – left lung; 2 – right lung; 3 – trachea; 4 – left cranial part; 5 – right cranial part; 6 – left caudal part; 7 – the right caudal part; 8 – additional dorsal lobe. Macropreparation.

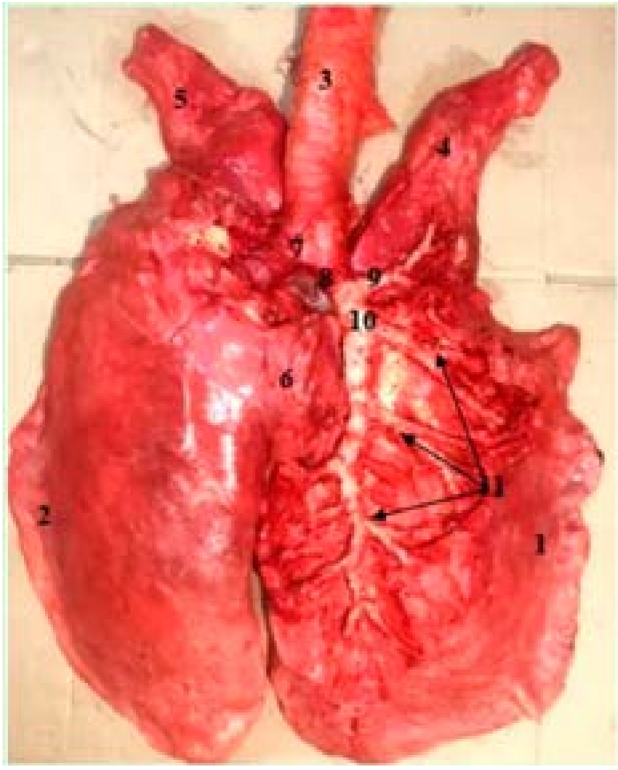

Fig. 2. Anatomical structure of the lungs of a mature horse (mediastinal surface): 1 – left lung; 2 – right lung; 3 – trachea; 4 – left cranial part; 5 – right cranial part; 5 – left caudal part; 6 – right caudal part 6 – additional part; 7 – bifurcation of the trachea; 8 – the main bronchus; 9 – cranial bronchus; 10 – caudal bronchus; 11 – branches of the caudal bronchus. Macropreparation.

caudal. In this case, the right lung has an additional part (Girfanov, 2010; Musabaeva et al., 2017; Blagojević et al., 2018). The interlobular cardiac incision divides the right and left lungs in horses into only two parts – cranial (much smaller) and caudal (large), which are separated from each other (Fig. 1). Horses do not have the average proportion of lungs as other domestic animals. In addition, in animals in the caudal lobe of the lungs (craniodorsal), we found the separation of a small area of lung tissue – the additional dorsal lobe, which had a pyramidal shape and was characteristic of one or both (right and left) lungs. On the right lung of the horse on the medial side, there is an additional lobe (Fig. 1).

The frequency of the pattern of the lung surface in horses, formed by the stroma of the lungs, is noticeable, but compared to other animals, their pattern is smoothed, so the surface of the lungs is smooth. On each lung, on its medial surface, there is a gate in the lungs, through which the main bronchus enters.

Horses' lungs, as in other domestic mammals, are formed by branches of the bronchi of different calibres that form the bronchial tree and branches of the histostructures of the respiratory department that form the alveolar tree. They are accompanied by vessels, nerves, and layers of loose connective tissue. The bronchi, in turn, are differentiated into extrapulmonary and pulmonary. Extrapulmonary bronchi, the primary and interparticle pulmonary bronchi, are structures that are part of the lung parenchyma and, branching out there, form a bronchial tree.

Branching of the bronchi of the bronchial tree of the lungs in horses occurs in the primary type. In each lung, the main bronchi, at the base of their blunt edges, are divided into large, medium, and then small, terminal bronchioles, forming a bronchial tree. At the initial stage of bronchial tree formation, the trachea of horses forms a much larger bifurcation, where it branches into two primary bronchi, which immediately (at the site of bifurcation of the trachea) in each lung, form its bifurcation, and are divided into two large bronchi – cranial and caudal. The cranial bronchus (slightly smaller in size) is closer to the cranial lobe and runs in the cranial direction, at an angle of 30–35° to the axis of the trachea, to the cranial lobe, and is characterized by a retrograde relative to the direction of the main movement. The caudal bronchus (slightly larger) goes caudally to the caudal lobe (Fig. 2).

After a specific interval, the main bronchus, which goes to the cranial lobe, is divided into two branches, branching, giving rise to segmental bronchi of different sizes (Fig. 2). The main bronchus, which goes to the caudal lobe of the lungs, in the parenchyma of each lung, branches into four dorsal and four ventral branches. The minor intraparticle bronchi branch into the pulmonary lobes, divided into terminal bronchioles, respiratory bronchioles, alveolar passages, and then alveolar sacs, forming an alveolar tree.

An essential criterion for developing an organ is the absolute mass, which directly indicates its morphofunctional maturity. At the same time, the relative lung mass of the animals we studied is directly proportional to the body weight of the animals and the absolute mass of the organ.

According to our organometry, the absolute lung mass of mature horses is 3318.1 ± 364.4 g. However, the relative lung mass of horses, which according to classical textbooks on domestic anatomy, is 1.43%, does not match the results of our studies. Thus, according to our studies, the relative lung mass in horses is much smaller and equal to 0.60 ± 0.052%. Accordingly, the absolute mass of the left lung is 1506.2 ± 60.48 g, the right – 1811.9 ± 72.92 g, while the absolute

Table – Absolute (AM) and relative mass (RM) of lung lobes of mature horses, (M ± m, n = 6)

Part of the lungs	Left lung		Right lung		Left and right lungs	
	AM (g)	RM (%)	AM (g)	RM (%)	AM (g)	RM (%)
Cranial	197.43 ± 19.2	5.95 ± 0.5	214.02 ± 24.0	6.45 ± 0.6	411.45 ± 39.6	12.40 ± 0.9
Caudial (diaphragmatic)	1308.66 ± 98.8	39.44 ± 3.6$^{\blacktriangle}$	1423.80 ± 102.7	42.91 ± 4.1$^{\blacktriangle}$	2732.46 ± 210.0	82.35 ± 7.6
Additional	–	–	174.20 ± 16.0$^{\bullet}$	5.25 ± 0.7	174.20 ± 16.0	5.25 ± 0.7
Total	1506.10 ± 60.5*	45.39 ± 4.1	1812.0 ± 62.9*	54.61 ± 5.0	3318.10 ± 364.4	100

Note: M – arithmetic mean; *m* – standard error; *$p < 0.01$, compared to the absolute mass of the left and right lungs; $^{\blacktriangle}p < 0.001$, compared to the cranial lobe; $^{\bullet}p < 0.001$, compared to the absolute mass of the caudal diaphragmatic lobe of the right lung.

mass of the cranial lobe of the left lung in horses is 197.43 ± 19.24 g; this figure in the right lungs, respectively, is equal to 214.02 ± 24.04 g (Table). The absolute mass is the caudal lobes of the lungs: in the left lung, this figure averages 1308.66 ± 98.75 g, and in the right lung – 1423.8 ± 102.71 g, respectively. The smallest is the absolute mass of the additional lobe of the right lung, which, respectively, in horses is – 174.2 ± 16.02 g. Therefore, the coefficient of asymmetry of the left lung to the right one is equal to 1:1.2 in mature horses.

The absolute mass of the left lung is 2.20 times smaller ($p < 0.01$) and the right lung is 1.83 times smaller ($p < 0.01$) compared to the absolute total mass of both lungs of a mature horse.

At the same time, the relative mass of the caudal diaphragmatic lobe of the left and right lungs is 6.63 times ($p < 0.001$) and 6.65 times ($p < 0.001$) greater compared to the cranial lobe, respectively (Table). Meanwhile, the relative mass of the caudal diaphragmatic lobe of the right lung tends to increase when compared to the left lung. The absolute mass of the additional right lung lobe is 8.17 times less ($p < 0.001$) than the absolute mass of the caudal diaphragmatic lobe (Table).

According to the organometry, the total length of the lungs in horses is 61.50 ± 6.32 cm, width – 48.44 ± 4.14 cm, and thickness – 9.60 ± 1.10 cm. For the right lung, these indices are 61.84 ± 6.39 cm; 23.90 ±1.42 cm and 9.64 ±1.48 cm, respectively, but to the left lung – 60.35 ± 6.96 cm; 23.51 ± 1.44 cm, and 9.10 ± 1.37 cm, respectively. At the same time, the ratio of the total lung length to their width in horses is 1.27:1, so the lungs in horses belong to the narrowed-elongated type.

Microscopically, the horse's lungs are formed by the branches of the bronchi, the stroma of the lungs, and the branches of the respiratory lungs (Fig. 3), which form the alveolar tree.

The structural basis of horses` lungs is pyramidal or conical lobes, which form the stroma of the lungs. Part of the structure of the particles is acini, covered with a thin layer of connective tissue. The microscopic structure of acini is formed by alveolar passages, alveolar sacs, and alveoli (Fig. 4).

Lung bronchi have different sizes, depending on their morphofunctional features. Bronchi are divided into extrapulmonary (main and interlobular) and pulmonary (are part of the lung parenchyma), where they branch and form the bronchial tree. The bronchi have three membranes: mucous, fibrocartilage, and adventitia.

The primary bronchi of the lungs have the largest diameter. Compared with the middle and small bronchi, their membranes are pronounced and have a similar microscopic structure as in the trachea. Thus, their mucous membrane is formed by epithelial, own, muscle plates, and submucosal basis (Fig. 5).

The microscopic structure of the epithelial plate is represented by a single layer of multilayered ciliated epithelium, the epitheliocytes of which are located on its basement membrane. In the mucous membrane of its plate, which is formed mainly by loose fibrous connective tissue, is lymphoid tissue in the form of clusters (Fig. 5).

The muscular plate of the mucous membrane is formed by bundles of smooth muscle cells that form circular, longitudinal layers so that the muscular plate of the membrane of such bronchi does not form internal folds, as in large, medium, and small bronchi (Fig. 5).

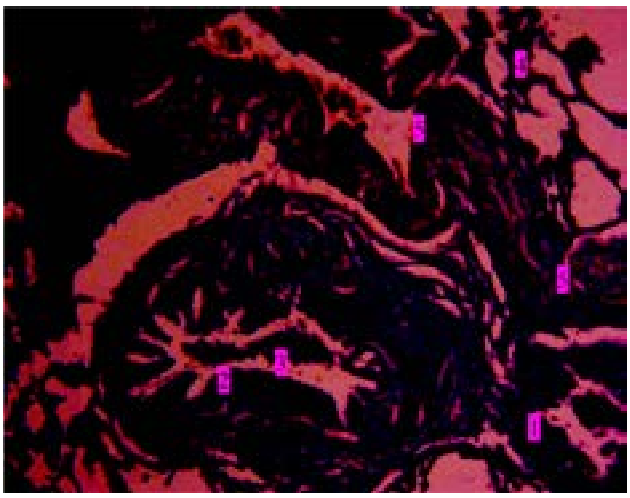

Fig. 3. Fragment of the histological structure of the lungs of a mature horse: 1 – respiratory bronchiole; 2 – small bronchus; 3 – bronchial lumen; 4 – alveoli; 5 – connective tissue stroma. *Hematoxylin–eosin*, ×280.

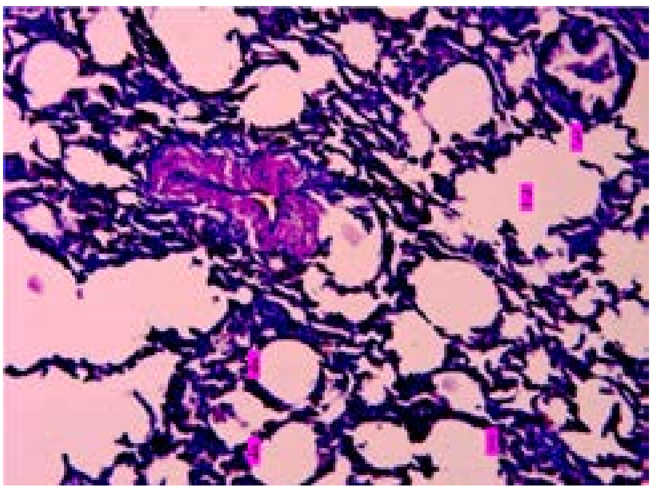

Fig. 4. Fragment of the histological structure of the lungs of a mature horse: 1 – respiratory part; b – alveolar course; 3 – alveolar sac; 4 – alveoli. *Hematoxylin–eosin*, ×280.

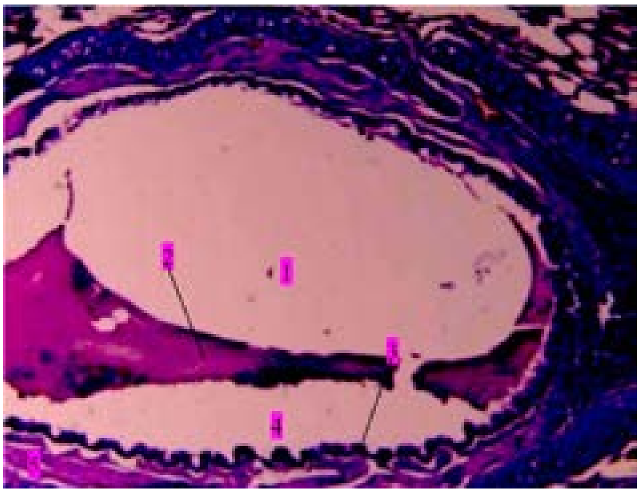

Fig. 5. A histological structure of the mature horse`s main lung bronchus: 1 – bronchial lumen; 2 – epithelial plate; 3 – muscle plate; 4 – fibrous-cartilaginous shell; 5 – alveoli. *Hematoxylin–eosin*, ×280.

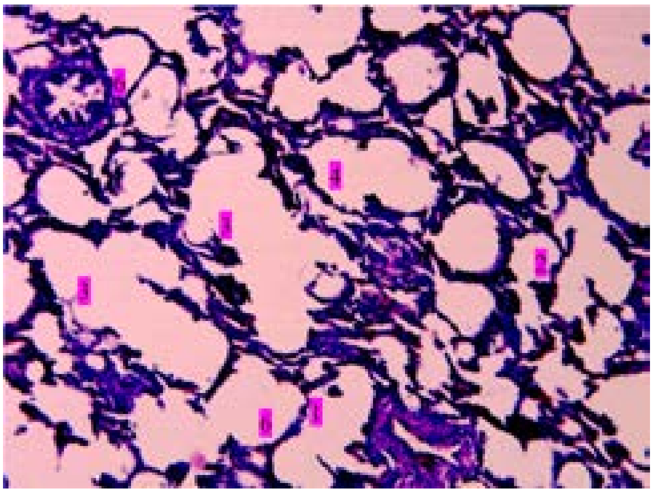

Fig. 6. Fragment of the histological structure of the lungs of a mature horse: 1 – respiratory bronchiole; 2 – alveolar sacs; 3 – large alveoli; 4 – middle alveolus; 5 – small alveoli; 6 – interalveolar membranes. *Hematoxylin–eosin*, ×280.

The submucosal base of such bronchi is formed by loose connective tissue where the end sections of the bronchial glands are located. However, compared to other species of animals we studied; bronchial glands are found in small quantities. Collagen fibres are also found in the submucosal membrane.

The microscopic structure of the fibrocartilage of the main bronchi has specific features – their cartilaginous tissue is continuous, and has the form of rings along the entire perimeter of the fibrocartilaginous membrane (Fig. 5).

The adventitial membrane of the main bronchi is formed by a thin layer of loose fibrous connective tissue.

Morphologically, the wall of the large bronchi has a similar structure to that of the main bronchi. However, the rings of the cartilage of the fibrocartilage shell do not have a continuous structure but are formed by separate, pronounced, large cartilaginous plates (Fig. 6).

The mucous membrane of the middle bronchial wall is covered with a single layer of multilayered respiratory epithelium, and the muscular plate of the mucous membrane forms distinct folds. The fibrous-cartilaginous shell of the middle bronchi contains only individual cartilaginous islands of small size, which are formed by hyaline cartilaginous tissue.

In the study of the wall of the small bronchi, as in other experimental animals, it is formed only by the mucous membrane and adventitia. The muscular plate of the corresponding bronchi is clearly expressed, thanks to which the inner wall of the mucous membrane forms pronounced folds. In addition, cartilaginous islets in the walls of the small bronchi are not detected.

The lung parenchyma's terminal (terminal) bronchioles are formed by a thin wall, similar to the small bronchi, which is thinner, and its muscular plate, formed by smooth myocytes, which are in the form of a network, no longer forms folds. Around the bronchi of various calibres, bronchial arteries are found.

The histological structure of the respiratory part of the lungs of horses, represented by the alveolar tree (respiratory bronchioles, alveolar passages, alveolar sacs), in the walls is alveoli. Such histostructures form the lungs' structural and functional unit – the pulmonary acinus. In microscopic structures, the walls of respiratory bronchioles are similar to the walls of terminal bronchioles. At the same time, there are no ciliated cells in the epithelial cells of the plate.

Alveoli in the form of vesicles are interconnected by interalveolar membranes formed by delicate layers of loose connective tissue in which numerous elastic fibres are found. The inner wall of the alveoli is built of alveocytes located on the basement membrane. The lungs' alveoli have different sizes-small, medium and large (Fig. 6).

The alveolar tree in horses is shortened and wide and has a bubble shape. Alveolar bronchioles are poorly differentiated. Due to the expansion, the alveolar sacs are vast with smoothed alveoli. According to morphometric studies, clinically healthy horses' average lung alveolar volume is 699.8 ± 106.42 thousand μm^3. The respiratory (respiratory) part of the lungs in horses occupies 54.8 ± 7.4% of the total area of the lung parenchyma, connective tissue base, 45.2 ± 7.4%.

Discussion

It is known that the components of systems and their organs in animals can be differentiated depending on lifestyle and the total load on the body, including the respiratory system, namely the lungs, the variability of which is not only of general biological interest but is important in the study of morphophysiological environmental conditions (Tschernko et al., 1998; Lafortunaet al., 2003; Franklin et al., 2012).

At the same time, the morphological study of the lungs of different species of animals showed the presence of individual morphofunctional features in the lobular structure of the lungs (Franklin et al., 2012). Thus, in bats, the left lung is not divided into lobes, and in mink and sable, the left lung is divided into only two lobes – cranial and caudal (Girfanov & Sitdikov, 2010; Chirkova et al., 2017). Some foreign morphologists believe that in mammals, the lobular structure of the lungs is natural and has no species characteristics (Duncker, 2004).

In most vertebrates, the lungs have five lobes: one lobe in the left lung and 4 in the right (cranial, medial, caudal, and accessory lobes) (Hyde et al., 2009; Reczyńska et al., 2018). However, in the descriptive structure of the lung lobes, there is another terminological name for the presence of 5 lobes in the right lung (additional, divided into intermediate and diaphragmatic) (Treuting et al., 2011).

The division of the lungs of domestic mammals into individually expressed lobes is directly dependent on the structure of the thoracic cavity and the characteristics of animals and individual physiological characteristics of animals, and the physiological load on the body. Thus, there are only two lobes in the left lung of horses – cranial and caudal; in the right lung, three lobes – cranial, caudal, and additional.

The caudal lobe of the lungs in horses is formed by merging the cranial and middle lobes into one and therefore is called cardio-diaphragmatic (Zelenevsky & Zelenevsky, 2014). According to our data, this particle is caudal (diaphragmatic). The interparticle notches between the middle and caudal lobes in the right and left lungs are absent. Their surface is adjacent to the diaphragm, so we propose calling the heart-diaphragmatic lobe – diaphragmatic (caudal). In rabbits, the relatively narrow trachea is divided into two primary bronchi, which in turn - into bronchioles, thus forming a respiratory tree (Keir & Page, 2008). In pigs, terminal bronchioles are relatively long and are divided into 2 or 3 short bronchioles; the latter are divided into alveoli (Zhang et al., 2021).

According to our study, the alveolar tree in horses is shortened and wide and has a bubble shape. It should be noted that the morphological structure of the lungs is different (Horalskyi et al., 2020). Thus, the right lung in mammals is slightly larger than the left because the heart is shifted to the left; therefore, a characteristic feature of the lung structure of mammals is their pronounced asymmetry, which manifests itself in different sizes, ambiguous absolute mass of right and left lungs, their position and ambiguous shape of their particles. depending on the functional load (Ramchandi et al., 2001; Chaturvedi & Lee, 2005; İlgun et al., 2014). The size ratios of left to right lungs are 1.21:1 in horses, 1.38:1 in cattle, 1.35:1 in pigs, and 1.32:1 in dogs.

Prokushenkova (2009) showed a natural tendency to the prevalence of the right lung mass of dogs of the neonatal period, which is explained by the peculiarities of their structure and topography. The coefficient of lung asymmetry in day-old puppies is maximum and is 1.60, while with age, it gradually decreases, reaching 1.36 in 20-day-old animals. This is due to the formation of gas exchange and intensive growth and development of the respiratory system, inherent in all animals in the neonatal period.

Some scientists regard the manifestation of lung asymmetry in domestic mammals as a genetic trait; others argue that asymmetry is associated with the asymmetric position of the heart and other organs in the thoracic cavity and depending on the intensity of their gas exchange function, which manifested itself in the evolutionary development of animals. The most pronounced asymmetry of all mammals is present in small rodents (rats, guinea pigs, hamsters) in which the left lung is not divided into lobes, and the right has four lobes (Petrenko, 2013).

According to our study, the coefficient of asymmetry of the left lung to the right in horses is 1: 1.2, and this is due to the displacement of the heart and aorta in the left half of the thoracic cavity. These data are consistent with the results of other scientists, who indicate that the volume of the left lung in mammals, compared with the right, is reduced by the heart by two-thirds to the left (Tkachenko et al., 2010).

The microscopic structure of the lungs in horses is similar to that in bovines (Veit & Farrell, 1978). However, according to the results of our research, the structure of the alveolar tree in horses is shortened, wide and has a bubble shape when compared to domestic mammals. Alveolar bronchioles are poorly differentiated. The alveolar sacs are wide with flattened alveoli due to the expansion of the alveolar tree. The sphincters of the alveoli (muscular elements of the alveolar tree) are very poorly developed, which is consistent with the results (Zelenevsky & Zelenevsky, 2014; Shhipakin et al., 2016).

Conclusions

The lungs of mature horses have species-specific differences that must be considered in the morphological criteria of physiological and pathological changes. The horses` lungs have a partial structure and the left lung is slightly smaller than the right one; the asymmetry factor is 1:1.2.

The total length of the lungs in horses is 61.50 ± 6.32, width – 48.44 ± 4.14, and thickness – 9.60 ± 1.10 cm. The ratio of the total length of the lungs to their width in horses is 1.27:1; therefore, the lungs of horses belong to the narrowed-elongated type.

Based on the analysis of morphometric indices, it was found that the connective tissue stroma is 45.2 ± 7.4%. It is formed by loose connective tissue and contains elastic fibres, blood and lymphatic vessels. Respiratory parenchyma of the lungs is 54.8 ± 7.4% and it is formed by respiratory bronchioles, alveolar ducts and alveolar sacs, in the walls of which alveoli are located. Lung alveoli have different sizes: small, medium and large. Their average volume is 699.8±106.4 thousand μm^3.

Further research plans an ultramicroscopic examination of lung tissue in structural parts of the heart (ventricles, atria) in domestic animals.

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References

Blagojević, M., Božičković, I., Ušćebrka, G., Lozanče, O., Đorđević, M., Zorić, Z., & Nešić, I. (2018). Anatomical and histological characteristics of the lungs in the ground squirrel (Spermophilus citellus). Acta Veterinaria Hungarica, 66(2), 165–176.

Braun, U., Gerspach, C., & Brammertz, C. (2018). The frequency of abnormal ultrasonographic findings in the lungs of 129 calves with bronchopneumonia. Schweizer Archiv fur Tierheilkunde, 160(12), 737–741.

Bringardner, B. D., Baran, C. P., Eubank, T. D., & Marsh, C. B. (2008). The role of inflammation in the pathogenesis of idiopathic pulmonary fibrosis. Antioxidants & redox signaling, 10(2), 287–301.

Brogden, K. A., Ackermann, M., McCray, P. B., & Tack, B. F. (2003). Antimicrobial peptides in animals and their role in host defences. International Journal of Antimicrobial Agents, 22(5), 465–478.

Chaturvedi, A., & Lee, Z. (2005). Three-dimensional segmentation and skeletonization to build an airway tree data structure for small animals. Physics in Medicine and Biology, 50(7), 1405–1419.

Chirkova, E. N., Zavaleeva, S. M., Sadykova, N. N., & Chernoprudova, P. V. (2017). Morphological features of the structure of the lungs and heart of Brandt's bat (MyotisBrandtii). Bulletin of the Orenburg State University, 6(206), 90–93 (in Russian).

Corbett, M., & Kraehenbuhl, J.-P. (2004). Lung immunity: necessity is the mother of induction. Nature Medicine, 10(9), 904–905.

Duncker, H. R. (2004). Vertebrate lungs: structure, topography and mechanics: A comparative perspective of the progressive integration of respiratory system, locomotor apparatus and ontogenetic development. Respiratory Physiology & Neurobiology, 144, 111–124.

Franklin, S. H., Van Erck-Westergren, E., & Bayly, W. M. (2012). Respiratory responses to exercise in the horse. Equine Veterinary Journal, 44(6), 726–732.

Girfanov, A. I. (2010). Morphology of the bronchial tree of the lungs in sable. Scientific notes of the Kazan State Academy of Veterinary Medicine N. E. Bauman, 204(1), 75–78 (in Russian).

Girfanov, A. I., & Sitdikov, R. I. (2010). The structure of the bronchial tree in the American mink. Scientific notes of the Kazan State Academy of Veterinary Medicine. N. E. Bauman, 1, 205–208 (in Russian).

Grubor, B., Meyerholz, D. K., & Ackermann, M. R. (2006). Collectins and Cationic Antimicrobial Peptides of the Respiratory Epithelia. Veterinary Pathology, 43(5), 595–612.

Gutyj, B., Grymak, Y., Drach, M., Bilyk, O., Matsjuk, O., Magrelo, N., Zmiya, M., & Katsaraba, O. (2017). The impact of endogenous intoxication on biochemical indicators of the blood of pregnant cows. Regulatory Mechanisms in Biosystems, 8(3), 438–443.
Hiemstra, P. S., Amatngalim, G. D., van der Does, A. M., & Taube, C. (2016). Antimicrobial peptides and innate lung defenses: role in infectious and noninfectious lung diseases and therapeutic applications. Chest, 149(2), 545–551.
Horalskyi, L. P., Khomych, V. T., & Kononskyi O. I. (2019) Osnovy histolohichnoi tekhniky i morfofunktsionalni metody doslidzhennia u normi ta pry patolohii [Fundamentals of histological technique and morphofunctional research methods in normal and pathological conditions] Polissia, Zhytomyr (in Ukrainian).
Horalskyi, L. P., Ragulya, M. R., Glukhova, N. M., Sokulskiy, I. M., Kolesnik, N. L., Dunaievska, O. F., Gutyj, B. V., & Goralska, I. Y. (2022). Morphology and specifics of morphometry of lungs and myocardium of heart ventricles of cattle, sheep and horses. Regulatory Mechanisms in Biosystems, 13(1), 53–59.
Horalskyi, L., Hlukhova, N., & Sokulskyi, I. (2020). Morphological traits of rabbit lung. Scientific Horizons, 08(93), 180–188. (in Ukrainian).
Hyde, D. M., Hamid, Q., & Irvin, C. G. (2009). Anatomy, pathology, and physiology of the tracheobronchial tree: Emphasis on the distal airways. Journal of Allergy and Clinical Immunology, 124(6), 72–77.
İlgun, R., Yoldas, A., Kuru, N., & Özkan, Z. E. (2014). Macroscopic Anatomy of the Lower Respiratory System in Mole rats (Spalax leucodon). Anatomia, Histologia, Embryologia, 43(6), 474–481.
Johnson, E. R., & Matthay, M. A. (2010). Acute Lung Injury: Epidemiology, Pathogenesis, and Treatment. Journal of Aerosol Medicine and Pulmonary Drug Delivery, 23(4), 243–252.
Johnson-Delaney, C. A., & Orosz, S. E. (2011). Rabbit Respiratory System: Clinical Anatomy, Physiology and Disease. Veterinary Clinics of North America: Exotic Animal Practice, 14(2), 257–266.
Keir, S. D., Spina, D., Douglas, G., Herd, C., & Page, C. P. (2011). Airway responsiveness in an allergic rabbit model. Journal of Pharmacological and Toxicological Methods, 64(2), 187–195.
Keir, S., & Page, C. (2008). The rabbit as a model to study asthma and other lung diseases. Pulmonary Pharmacology & Therapeutics, 21(5), 721–730.
King, P. T. (2015). Inflammation in chronic obstructive pulmonary disease and its role in cardiovascular disease and lung cancer. Clinical and Translational Medicine, 4(1). Portico. 68.
Kopytchak, I. R. (2014). Morfofunktsionalni zminy v leheniakh pry izolovanii ta poiednanii travmakh. Shpytalna Khirurhiia. Zhurnal imeni L. Ya. Kovalchuka, 1, 36–40.
Kryvoruchko, O. H. (2002). Vikovi i reaktyvni osoblyvosti limfoidnykh utvoren lehen: Avtoref. ... kand. biol. nauk. 14.03.09 – histolohiia, tsytolohiia, embriolohiia. Kyiv (in Ukrainian).
Lafortuna, C. L., Saibene, F., Albertini, M., & Clement, M. G. (2003). The regulation of respiratory resistance in exercising horses. European Journal of Applied Physiology, 90(3–4), 396–404.
Lesyk, Y. V., Dychok-Niedzielska, A. Z., Boiko, O. V., Honchar, O. F., Bashchenko, M. I., Kovalchuk, I. I., & Gutyj, B. V. (2022). Hematological and biochemical parameters and resistance of the organism of mother rabbits receiving sulphur compounds. Regulatory Mechanisms in Biosystems, 13(1), 60–66.
Lytvyn, V. P., Oliinyk, L. V., Korniienko, L. Ye., Yarchuk, B. M., Dombrovskyi, O. B., & Korniienko, L. M. (2002). Faktorni khvoroby silskohospodarskykh tvaryn: monohrafiia. Bila Tserkva: Bilotserkivskyi derzhavnyi ahrarnyi universytet (in Ukrainian).
Meyer, K. C., Rosenthal, N. S., Soergel, P., & Peterson, K. (1998). Neutrophils and low-grade inflammation in the seemingly normal aging human lung. Mechanisms of Ageing and Development, 104(2), 169–181.
Moyron-Quiroz, J. E., Rangel-Moreno, J., Kusser, K., Hartson, L., Sprague, F., Goodrich, S., Woodland, D. L., Lund, F. E., & Randall, T. D. (2004). Role of inducible bronchus associated lymphoid tissue (iBALT) in respiratory immunity. Nature Medicine, 10(9), 927–934.
Musabaeva, L. L., Seitov, M. S., & Parshina, T. Y. (2017). Comparative aspects of the morphology of the heart and lungs of the hare and the domestic rabbit (milk age). Almanac of Young Science, 4, 32–35 (in Russian).
Mylostyvyi, R., Lesnovskay, O., Karlova, L., Khmeleva, O., Kalinichenko, O., Orishchuk, O., Tsap, S., Begma, N., Cherniy, N., Gutyj, B., & Izhboldina, O. (2021). Brown Swiss cows are more heat resistant than Holstein cows under hot summer conditions of the continental climate of Ukraine. Journal of Animal Behaviour and Biometeorology, 9(4), 2134.
Mylostyvyi, R., Sejian, V., Izhboldina, O., Kalinichenko, O., Karlova, L., Lesnovskay, O., Begma, N., Marenkov, O., Lykhach, V., Midyk, S., Cherniy, N., Gutyj, B., & Hoffmann, G. (2021). Changes in the spectrum of free fatty acids in blood serum of dairy cows during a prolonged summer heat wave. Animals, 11(12), 3391.
Nebesna, Z. M., & Yeroshenko, H. A. (2015). Histolohichni ta histokhimichni zminy lehen pry eksperymentalnii termichnii travmi [Histological and histochemical changes of the lungs in experimental thermal trauma]. World of Medicine and Biology, 2(49), 106–109 (in Ukrainian).
Ostrovskyi, M. M. (2004). Rol system surfaktantu lehen ta interleikiniv v protsesi formuvannia zatiazhnoho perebihu pnevmonii. Ukrainskyi Pulmonolohichnyi Zhurnal, 2, 23–25 (in Ukrainian).
Patwa, A., & Shah, A. (2015). Anatomy and physiology of respiratory system relevant to anaesthesia. Indian Journal of Anaesthesia, 59(9), 533.
Petrenko, V. M. (2013). Anatomy of the lungs in a white rat. International Journal of Applied and Basic Research, 10(3), 414–417 (in Russian).
Prokushenkova, O. H. (2009). Morfolohiia lehen tsutseniat sobak Neonatalnoho periodu. Naukovyi visnyk Lvivskoho natsionalnoho universytetu veterynarnoi medytsyny ta biotekhnolohii imeni S. Z. Gzhytskoho, 11(2), 244–247 (in Ukrainian).
Provinciali, M., Cardelli, M., & Marchegiani, F. (2011). Inflammation, chronic obstructive pulmonary disease and aging. Current Opinion in Pulmonary Medicine, 17(1), 3–10.
Rabeling, B., Rehage, J., Döpfer, D., & Scholz, H. (1998). Ultrasonographic findings in calves with respiratory disease. The Veterinary Record, 143(17), 468–471.
Radzykhovskyi, M., Sokulskiy, I., Dyshkant, O., Antoniuk, A., Gutyj, B., & Sachuk, R. (2022). Experimental study of tropism of cultivated canine parvovirus in the immunogenesis organs of puppies. Regulatory Mechanisms in Biosystems, 13(3), 241–246.
Ramchandani, R., Bates, J. H. T., Shen, X., Suki, B., & Tepper, R. S. (2001). Airway branching morphology of mature and immature rabbit lungs. Journal of Applied Physiology, 90(4), 1584–1592.
Reczyńska, K., Tharkar, P., Kim, S. Y., Wang, Y., Pamuła, E., Chan, H.-K., & Chrzanowski, W. (2018). Animal models of smoke inhalation injury and related acute and chronic lung diseases. Advanced Drug Delivery Reviews, 123, 107–134.
Samborska, I. A. (2021). Comparative characteristics of histological changes in lung tissue in rats of different ages under conditions of hyperhomocysteinemia. Reports of Vinnytsia National Medical University, 25(2), 196–199. (in Ukrainian).

Shhipakin, M. V., Prusakov, A. V., Barteneva, Ju. Ju., Virunen, S. V., & Andreev, K. A. (2016). Morfologija bronhial'nogo dreva u sobak porody taksa. Aktual'nye Voprosy Veterinarnoj Biologii, 2(30), 10–12 (in Russian).

Stravsky, Ya. S., Boltyk, N. P., Sachuk, R. M., Serheyev, V. I., & Rushchynska, T. M. (2020). The content of total protein and protein fractions in cows during pregnancy and their diagnostic value. Scientific Messenger of Lviv National University of Veterinary Medicine and Biotechnologies. Series: Veterinary Sciences, 22(99), 198–202.

Tkachenko, L. V., Konovalov, V. K., Tyutyunnikov, S. V., Malofeev, Yu. M., Leshchenko, V. A., & Bryukhanov, A. V. (2010). Normal topography of the lungs of a mature rabbit. Bulletin of the Altai State Agrarian University, 8(70), 55–60 (in Russian).

Treuting, P. M., Dintzis, S. M., Liggitt, D., & Frevert, C. W. (2011). Comparative anatomy and histology: a mouse and human atlas. Academic Press.

Tschernko, E. M., Gruber, E. M., Jaksch, P., Jandrasits, O., Jantsch, U., Brack, T., Lahrmann, H., Klepetko, W., & Wanke, T. (1998). Ventilatory mechanics and gas exchange during exercise before and after lung volume reduction surgery. American Journal of Respiratory and Critical Care Medicine, 158(5), 1424–1431.

Veit, H. P., & Farrell, R. L. (1978). The anatomy and physiology of the bovine respiratory system relating to pulmonary disease. The Cornell Veterinarian, 68(4), 555–581.

Ward, P. A., & Hunninghake, G. W. (1998). Lung inflammation and fibrosis. American Journal of Respiratory and Critical Care Medicine, 157(4), 123–129.

Williams, K. J., Derksen, F. J., de Feijter-Rupp, H., Pannirselvam, R. R., Steel, C. M., & Robinson, N. E. (2008). Regional pulmonary veno-occlusion: a newly identified lesion of equine exercise-induced pulmonary hemorrhage. Veterinary Pathology, 45(3), 316–326.

Wright, J. R. (2004). Host defense functions of pulmonary surfactant. Neonatology, 85(4), 326–332.

Yarto-Jaramillo, E. (2011). Respiratory system anatomy, physiology, and disease: Guinea pigs and chinchillas. The veterinary clinics of North America. Exotic Animal Practice, 14(2), 339.

Zelenevsky, N. V., & Zelenevsky, K. N. (2014). Anatomy of animals. Lan, St. Petersburg. Moscow. Krasnodar (in Russian).

Zhang, L., Zhu, J., Wang, H., Xia, J., Liu, P., Chen, F., Jiang, H., Miao, Q., Wu, W., Zhang, L., Luo, L., Jiang, X., Bai, Y., Sun, C., Chen, D., & Zhang, X. (2021). A high-resolution cell atlas of the domestic pig lung and an online platform for exploring lung single-cell data. Journal of Genetics and Genomics, 48(5), 411–425.