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MORPHOLOGICAL FEATURES OF THE FERAL PIGEON'S (*COLUMBA LIVIA* F. *URBANA*) DIGESTIVE SYSTEM

Kolomak I. O.

Poltava State Agrarian University, Poltava, Ukraine, e-mail: kolomak-ihor@ukr.net

Summary. Peculiarities of the morphological structure of the feral pigeon's (*Columba livia f. urbana*) digestive system have been established. In the process of evolution, the digestive system has acquired certain anatomical changes that perform adaptive mechanisms for flying and egg-laying. In pigeons, the rostral part of the skull is represented by a beak consisting of an upper bill (maxilla) and gnathotheca (mandible) part. Due to the absence of a palatal fold, the digestive tract begins with the oropharynx, which lacks lips, teeth, and gums. The gorge is present in both sexes, consists of the right and left parts, and performs the function of accumulating fodder and secreting gorge milk, which is fed to the young through regurgitation. The mucous membrane of the esophagus forms longitudinal folds. There is a large number of digestive glands in the proventriculus. The cavity of the muscular stomach contains gastroliths, which act as teeth, ensuring grinding of food mass. The small intestine consists of the duodenum and ileum, which are joined by the mesentery and form three loops. The mucous membrane is developed, represented by numerous crypts that ensure the absorption of nutrients. The large intestine is represented by the paired rectal cecum and the rectum. The mucous membrane of the thick intestine is represented by leaf-like villi. The muscle layer is the most developed, myocytes are located in circular and longitudinal directions, forming folds

Keywords: anatomy, histology, synanthropic pigeons

Introduction. The feral pigeons (*Columba livia f. urbana*) are descendants of domestic pigeons (*Columba livia* f. *domestica*) that have returned to the wild. The domestic pigeon was originally bred from the wild rock dove (*Columba livia* Gmelin, 1789), which naturally inhabits sea cliffs and mountains, and its closest relative is the hill pigeon (*Columba rupestris* Pallas, 1811). Domestic pigeons are bred for sports (racing breeds), exhibitions (refined breeds), and food (meat-type breeds) and used as objects for scientific research (Adil and Magray, 2012; Bailey et al., 1997; Kolomak and Kruchynenko, 2017; Santos et al., 2020).

The study of the birds' morphological structure deepens and supplements the data on physiological processes that occur during digestion in pigeons. Considering the longtime of evolution, depending on the habitat, pigeons adapt to external conditions. With the processes of adaptation, there are changes in the anatomical structures of the digestive system, which affect the physiological mechanisms of digestion (Bindari and Gerber, 2022; Scanes and Dridi, 2021; Klasing, 1999).

Birds tend to consume food frequently, which is associated with a shorter gut, compared to mammals. The time for digestion and absorption of nutrients is reduced, despite significant energy requirements, particularly during flying. However, the physiological mechanisms of digestion that occur in the digestive system of birds are compensated by fast enzymatic processes that ensure a high rate of substrates' decomposition and active transport of nutrients (Gugołek, Jastrzębska and Strychalski, 2016; McWhorter, Caviedes-Vidal and Karasov, 2009; Wang et al., 2020). The performed studies established the correlation features of the digestive tract's length which indicates that the birds had a 51% smaller nominal surface area of the small intestine and a 32% smaller volume of the large intestine. The short small intestine in birds reduces the time of digestion and absorption of nutrients, which is compensated by the species-specific composition of digestive enzymes. In birds, there is no compensation for the decrease in digestive and absorption capacity due to the longer retention time of food in the intestine. Partial compensatory mechanisms may be attributed to increased mucosal surface area and villous area, although this is not sufficient to compensate for the reduced nominal intestinal surface area (Hamoda and Farag, 2018; Lavin et al., 2008).

According to Price et al. (2015), birds have smaller intestines and shorter digestion time. Partial compensation of the smaller intestine occurs due to increased paracellular absorption of nutrients (Price et al., 2015; Oakley et al., 2014).

Taking into account the existing data of the digestive system's studies, it should be noted that the study of digestion in pigeons has not been investigated enough. Thus, a review of the digestive system's anatomical structure will provide a comprehensive representation of the physiological processes occurring in the body, and a histological analysis of the digestive system organs' structure will complement the existing morphological data.

The aim of the study was investigate morphological features of the feral pigeon's digestive system.

Material and methods. The morphological study of 25 feral pigeons caught in the city of Poltava involved the pathoanatomical study of cadavers, performed according to the Shore method, as well as the selection of pathological material (small and large intestines, liver) for the manufacture of histologic specimens (Scanes and Pierzchala-Koziec, 2014).

Manufacturing of histologic specimens was carried out of selected organs from the digestive tract of pigeons. Fixation of the material was carried out in a 10% aqueous solution of neutral formalin. At the next stage, samples were washed in distilled water, and dehydrated, and the pathological material was embedded in paraffin. Histological sections with a thickness of 7–10 μm were made of the produced compacted paraffin blocks on the MPS-2 type sledge microtome.

Staining of histologic specimens was carried out with hematoxylin and eosin, which involved the process of deparaffinization in xylene, washing in distilled water, staining with Ehrlich's hematoxylin, washing in distilled water, dehydrating, staining with a 1% aqueous solution of eosin. Afterward, the histologic specimen was clarified in xylene and covered with a coverslip glass.

Stained histological sections were examined using a MICROmed XS-5520 light microscope with magnifications of $\times 40$, $\times 100$, $\times 400$, and $\times 800$. The material for the illustrations was photographed using a MICROmed microscope with 5 Mpix attachment.

Experiments on animals were conducted following the recommendations of the 'European Convention for the Protection of Vertebrate Animals Used for Experimental and Other Scientific Purposes' (CE, 1986) and Council Directive 2010/63/EU (CEC, 2010), and in accordance with Art. 26 of the Law of Ukraine No. 3447-IV of 21.02.2006 'About protection of animals from cruel treatment' (VRU, 2006) and basic bioethical principles (Simmonds, 2017). The research program was reviewed and approved by the Bioethics Committee of the Poltava State Agrarian University under the current procedure.

Results. In the process of evolution, the anatomical structure of the pigeon's digestive tract has acquired adaptive changes associated with the ability to fly. The digestive system includes the intestines (small and large), stomach (glandular and muscular), and a system of digestive glands (Fig. 1).

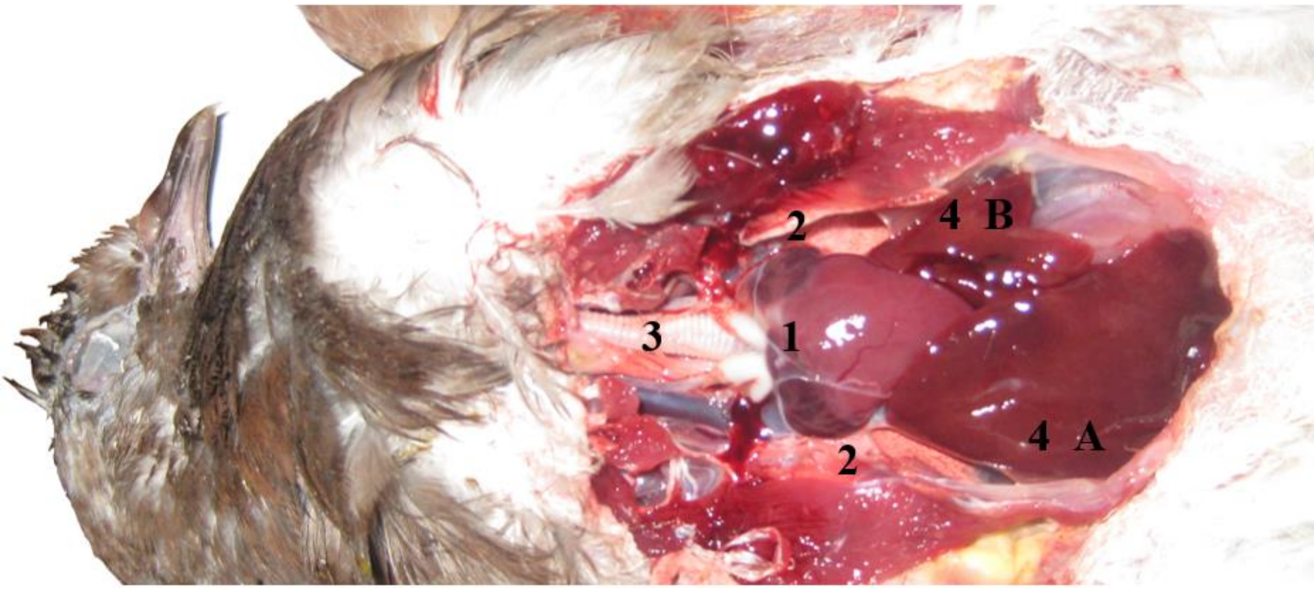

Figure 1. General view of the thoracic-abdominal cavity internal organs of the feral pigeon: 1 — heart, 2 — lungs, 3 — trachea, 4 — liver (A — right part, B — left part).

The digestive system begins with the oropharynx since the palatal fold separating the oral cavity and pharynx is absent in pigeons. The oropharynx lacks lips, teeth, and gums. The rostral part of the skull is represented by the beak, which provides the entrance to the oropharynx and consists of two parts: maxillar and mandibular. The distal part of the oropharynx is represented by the buccal cavity, which passes into the pharynx. At the bottom of the buccal cavity, there is the tongue.

The submucosal layer of the oropharynx's mucous membrane contains numerous salivary glands that secrete saliva through ducts. Depending on their localization, they can be divided into sublingual, maxillar, and mandibular. Saliva permeates the feed lump and provides ramollissement during swallowing, which is accomplished through rostrocaudal movements.

The alimentary canal is built according to the general type of tubular organs' structure, which determines the presence of mucous, muscular, and serous membranes.

The pharynx passes into the esophagus, which forms an ampoule-shaped diverticulum — a goiter, in which food accumulates, is processed by digestive enzymes, and the initial stages of enzymatic digestion take place. In pigeons, the goiter is a highly differentiated organ consisting of two lateral parts.

In both sexes, a secret is formed — 'bird's milk', which is fed to the young with the help of regurgitation. Depending on the section of the esophagus, the cervical part will be covered with adventitia, unlike the thoracic part, where the outer layer is represented by a serous membrane.

Analyzing the histological structure of different alimentary canal sections, each of the membranes, depending on the localization, will have certain variations in the structure due to the functional significance of the small and large intestine sections.

Histological examination of the esophagus established that the mucous membrane forms longitudinal folds, the apical part of which is covered with a multilayered flat partially keratinized epithelium. The submucous base is represented by an irregular connective tissue in which there are blood, lymphatic vessels, and nerve fibers. A large number of glands and secretory goblet cells producing mucus were found. The muscle membrane is represented by several layers of myocytes, located in a circular and longitudinal orientation. The muscle layer of the esophagus cranial part, to the diverticulum, is more developed, due to constant rostrocaudal movements during swallowing. Anatomically, the goiter divides the esophagus into a cervical part, up to the entrance into the oesophagus, directly into the oesophagus, and the thoracic part, which starts from the exit from the oesophagus and ends at the entrance to the glandular stomach. From the esophagus, the feed mass enters the differentiated stomach. In case when the stomach is full, food accumulates in the goiter, in the absence of fodder mass in the stomach, the fodder lump is directed directly to the stomach. The stomach of pigeons is highly differentiated and consists of glandular and muscular parts, between which there is an isthmus. The glandular stomach, which is located more cranially than the muscular stomach, contains a large number of digestive glands, the secretion of which permeates the fodder lump and provides enzymatic digestion. The muscular stomach is represented by highly developed muscle tissue, which provides mechanical digestion of feed.

The cavity of the muscle stomach is covered with cuticles and has cranial and caudal diverticulum-like extensions that form the blind gastric pouches. Exit from the stomach is carried out through the pyloric sphincter.

Between the proventriculus and the stomach, on the right side, there is a spleen, which has an elongated and rounded shape.

The liver consists of the right and left parts (Figs 1 and 2A), where the right part is much larger. The left part is not divided, and the gall bladder is absent. Bile moves along the paired hepatic-intestinal duct, the right duct opens into the ascending part of the duodenum, and the left hepatic-intestinal duct, together with the pancreatic duct, opens into the proximal part of the duodenum.

The liver parenchyma is represented by hepatic lobes consisting of hepatocytes (Fig. 2B), which are located radially from the central hepatic vein. Sinusoidal spaces stand out between the beams of hepatocytes. The connective tissue separating the liver lobes is weakly expressed.

The mucous membrane of the glandular stomach is overlayed with a single-layered prismatic glandular epithelium containing mucocytes that produce a mucous secretion. The transition zone leading to the muscle stomach does not have glands and separates the glandular and muscle stomach.

The cavity of the muscular stomach contains gastroliths involved in the mechanical grinding of fodder clods (cereal crops), acting as teeth, that are absent. The cuticle lining the muscular stomach is a product of the digestive glands of the gastric mucosa and performs a protective function for the mucous and muscular membranes.

From the pyloric part of the stomach, through the pyloric sphincter, the small intestine opens, consisting of the duodenum and ileum. The small intestine of an adult pigeon forms three loops, where the first and the third ones are short, having a cone-like shape with outer centripetal and inner centrifugal parts, collected by the mesentery. The small intestine contains numerous protrusions that can be traced macroscopically (Fig. 3), which increase the absorption area.

Duodenum and ileum are characterized by a developed mucous membrane (Fig. 4), which contains numerous villi (crypts), which are processes of the mucous membrane. The central part of the crypts is formed by connective tissue.

The proper mucous plate of the mucous membrane contains blood and lymphatic capillaries, as well as individual lymphoid clusters that form Peyer's plaques (Fig. 5).

On the outside, crypts are covered with a single-layer prismatic epithelium with numerous inclusions of goblet cells. The muscle layer is represented by myocytes oriented in the circular and longitudinal direction, in some areas, a morphological connection between the muscle layer and myocytes located at the base of the crypts can be traced.

The large intestine is represented by paired rectal appendages (Fig. 6), located on the border of the ileum and rectum.

In the mucous membrane of the large intestine, circular folds are replaced by simple tubular crypts (Fig. 7). The mucous membrane of the rectum has branched leaf-like villi (Fig. 8), which ensure reabsorption. The apical surface is covered with a single-layer prismatic epithelium alternating with glandular goblet cells. The lamina of the mucous membrane is represented by a layer of collagen fibers and a system of lymphatic vessels.

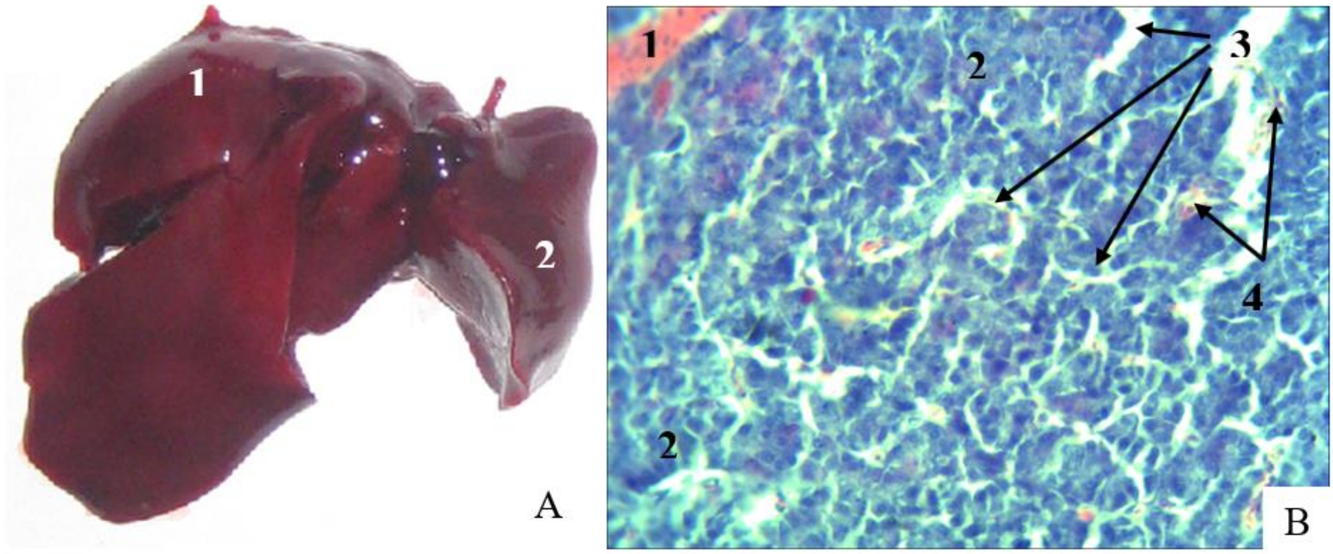

Figure 2. Macroscopic structure of pigeon liver: A1 — right part, A2 — left part; B — fragment of the liver histological structure: 1 — blood vessels, 2 — hepatocytes, 3 — sinusoidal spaces, 4 — bile ducts. Hematoxylin and eosin, × 400.

Figure 3. Fragment of the pigeon duodenum: 1 — protrusion of the duodenum, 2 — flexure of the duodenum.

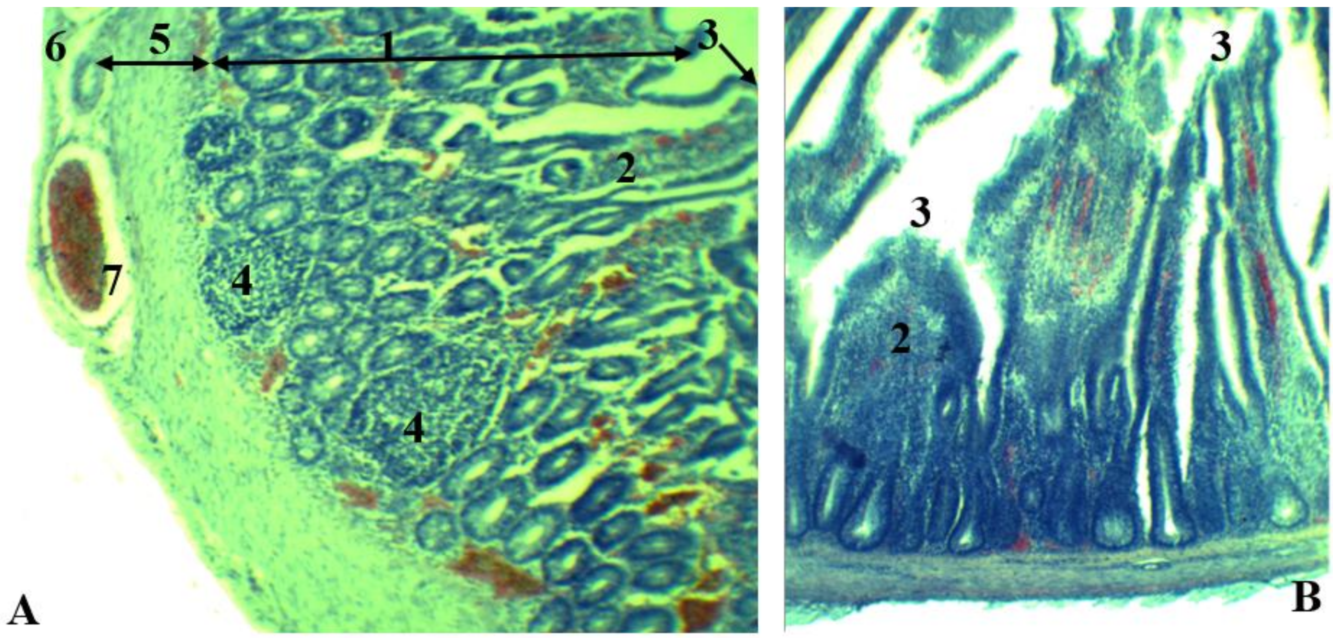

Figure 4. Fragment of a histologic specimen of the pigeon ileum: A, B: 1 — mucous membrane, 2 — intestinal crypts, 3 — apical surface of intestinal villi, 4 — accumulation of lymphoid cells, 5 — muscular membrane, 6 — serous membrane, 7 — blood vessels. Hematoxylin and eosin, × 100 (A), × 400 (B).

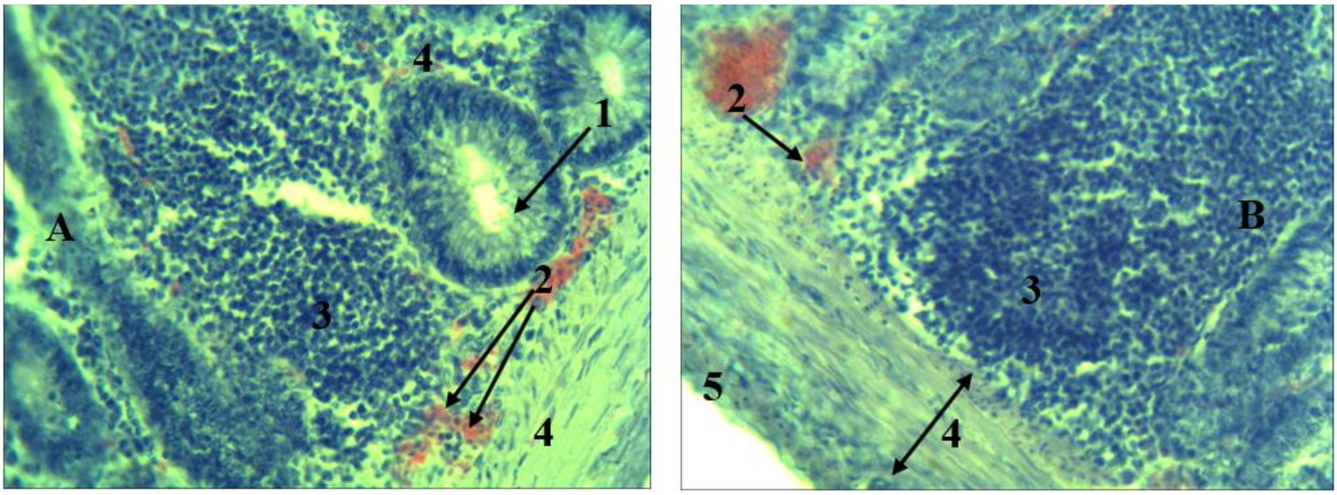

Figure 5. Fragment of a histologic specimen of the small intestine: A, B: 1 — intestinal crypts in cross-section, 2 — blood vessels of the mucosa and submucosa, 3 — accumulation of lymphoid cells, 4 — muscular membrane, 5 — serous membrane. Hematoxylin and eosin, × 400.

Figure 6. Section of the large intestine with paired blind appendages.

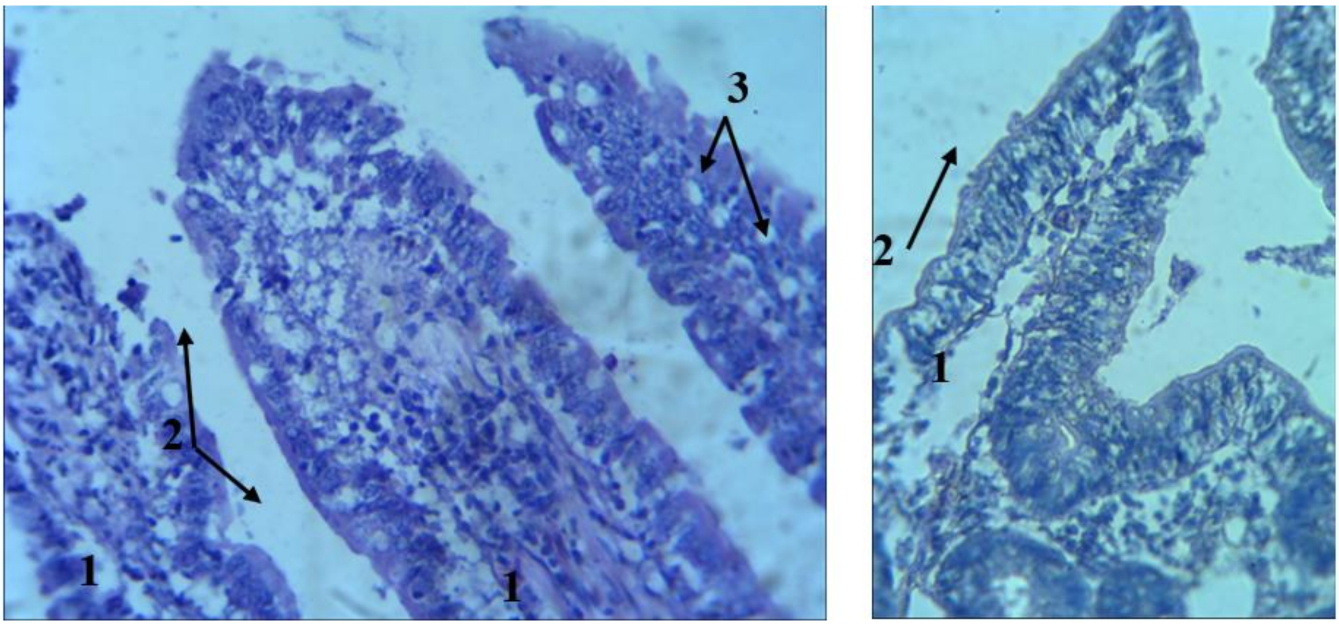

Figure 7. Fragment of a histologic specimen of the large intestine's proximal part: 1 — villi of the mucous membrane, 2 — single-layer prismatic epithelium, 3 — goblet cells. Hematoxylin and eosin, × 400.

The muscle layer is the most developed. Myocytes form longitudinal folds and are located in the circular and longitudinal direction the main function is to provide elastic movements. From the outside, the large intestine is covered with a serous membrane, which is a thin layer of simple flat epithelium with flattened nuclei.

The rectum is similar in structure to the small intestine. It was found that the muscular layer of the rectum was much more developed, in contrast to the small intestine, which has a more pronounced mucous membrane.

The cloaca has a complexly differentiated structure, where the rectum opens into the cranial part — the coprodeum, and the urogenital ducts (urodeum) open into the medial part. The caudal part (proctodeum) ensures the removal of waste products through a sphincter that opens to the outside.

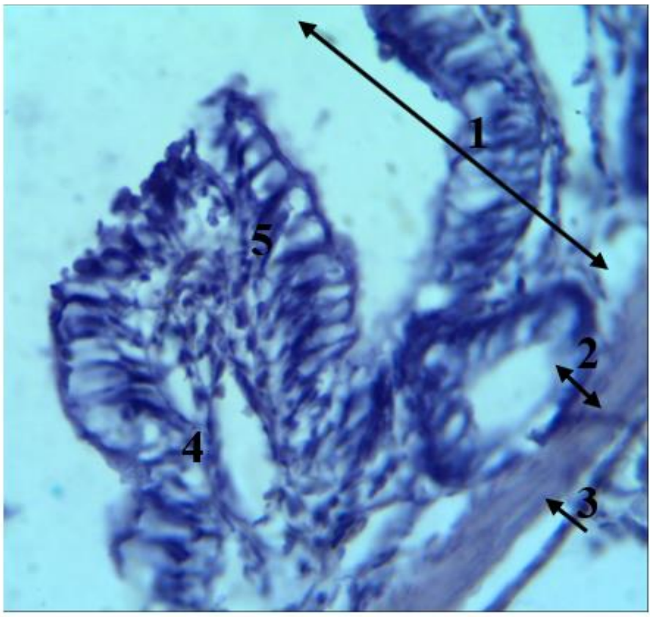

Figure 8. Fragment of a histologic specimen of a large intestine: 1 — mucous membrane, 2 — muscular membrane, 3 — serous membrane, 4 — leaf-like villi of the large intestine, 5 — single-layer prismatic epithelium, 6 — goblet cells. Hematoxylin and eosin, × 400.

Discussion. Most of the evolutionary processes that transform the anatomical structures of the birds' digestive tract are associated with the ability to fly and the process of egg-laying (Klasing, 1999).

In pigeons, the digestive tract is shorter compared to the digestive tube of mammals, which is indicated by the studies of most scientists.

Because the main way of moving birds is flight, which requires significant energy costs, the search for compensatory mechanisms that ensure sufficient energy accumulation for birds is underway (Lavin et al., 2008; Oakley et al., 2014).

According to Lavin et al. (2008), birds have an increased surface area of the intestinal mucosa, which is provided by a larger area of intestinal villi. Similar conclusions were reached by Oakley et al. (2014), who proved that flying birds and bats are under selective pressure to reduce the size and weight of the intestines they carry.

Our morphological studies indicate the presence of numerous protrusions in the small intestine, which increase the area of absorption due to the developed mucous membrane.

In the gastrointestinal tract of pigeons, proteins are split using a mixture of proteases (pepsin, trypsin, and chymotrypsin) to obtain a protein hydrolysate, which is subsequently absorbed in the small and partially large intestine (Price et al., 2015). According to other data, due to the large number of nerve fibers located in the digestive tract, enhanced functional regulation of the pigeon's intestine is carried out, which is a key role in the compensatory mechanisms of the reduced digestive tract (Hamdi et al., 2013; Ratnayani et al., 2019; Scanes and Pierzchala-Koziec, 2014).

In the alimentary canal of pigeons, lymphatic tissue is organized in the submucosa of its proper membrane in the form of diffusely located lymphatic tissue and lymphoid follicles. The epithelium in the intestines has lymphocytic infiltration with the formation of lymphoepithelium. Lymph nodes are located not only in the submucosa itself but also in the muscular and serous membranes of the intestines.

The small intestine contains numerous protrusions that can be traced macroscopically, which increase the area of absorption.

The duodenum and ileum are characterized by a developed mucous membrane containing numerous villi (crypts), which are processes of the mucous membrane. Development of the mucous membrane depending on age. Thus, Ratnayani et al. (2019), Klasing (1999), and Price et al. (2015) proved that the layers of the mucous membrane were most developed in mature pigeons, compared to young ones (Lee, Kil and Sul, 2017; Nasrin et al., 2012).

Conclusions. The digestive tract of the feral pigeon (*Columba livia f. urbana*) begins with the oropharynx, which lacks the palatal fold, lips, teeth, and gums. The rostral part of the skull is represented by a beak. The mucous membrane of the oropharynx contains numerous salivary glands that ensure the permeation of the fodder lump. In the wild, fodder is accumulated and processed with digestive enzymes, and both sexes produce a secret — 'bird's milk', which is fed to the young through regurgitation.

The mucous membrane of the esophagus forms longitudinal folds, the apical part of which is covered with a multilayered flat keratinized epithelium. Blood, lymphatic vessels, and nerve fibers are located in the submucosa. The muscle membrane is represented by several layers of myocytes, located in a circular and longitudinal orientation.

The proventriculus contains a large number of digestive glands, and the cavity of the muscular stomach contains gastroliths, which act as teeth. The small intestine consists of the duodenum and ileum, which are joined by the mesentery to form three loops. The mucous membrane is developed and contains numerous crypts, the central part of which is formed by connective tissue. The outer crypts are covered with a single-layered prismatic epithelium with numerous inclusions of exocrine cells.

The liver consists of the right and left parts, whereas the right part is much larger. The left part is not divided, and the gall bladder is absent. Bile moves along the hepatic-intestinal ducts and opens into the duodenum.

The large intestine is represented by the paired rectal cecum and the rectum. In the mucous membrane of the large intestine, circular folds are replaced by leaf-like villi. The apical surface is covered with a single-layer prismatic epithelium alternating with glandular goblet cells. The muscle layer is the most developed, myocytes form longitudinal folds located in circular and longitudinal directions.

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