



## Age features of the microscopic structure of the intestines of the budgerigar (*Melopsittacus undulatus*)

M. M. Kushch, I. Y. Lavrova, I. A. Fesenko, O. S. Miroshnikova, L. M. Liakhovich, L. L. Kushch, O. V. Byrka

State Biotechnological University, Kharkiv, Ukraine

### Article info

Received 04.05.2023  
Received in revised form  
23.05.2023  
Accepted 25.05.2023

State Biotechnological  
University,  
Alchevskiyh st., 44,  
Kharkiv, 61002, Ukraine.  
Tel.: +38-066-629-24-64.  
E-mail:  
dr.kushch@gmail.com

**Kushch, M. M., Lavrova, I. Y., Fesenko, I. A., Miroshnikova, O. S., Liakhovich, L. M., Kushch, L. L., & Byrka, O. V. (2023). Age features of the microscopic structure of the intestines of the budgerigar (*Melopsittacus undulatus*). *Regulatory Mechanisms in Biosystems*, 14(2), 304–311. doi:10.15421/022345**

Information about the morphology of the budgerigar intestines is a necessary condition for the preparation of diets for feeding, prevention and treatment of diseases of the digestive system, the state of which determines the intensity of growth and development of the bird's body. The features of the histological structure of the intestines of the budgerigar (*Melopsittacus undulatus*) of 9 ages: 1, 3, 7, 14, 21, 30, 60, 180 and 365 days of age were studied. Histological preparations were made according to the classical method with hematoxylin and eosin staining of sections, according to Mallory and Grimelius. Morphometric parameters of microstructures were determined on preparations from a transverse section of the middle section of the duodenum, jejunum, ileum and rectum. In the intestinal wall of the budgerigar, three membranes were identified: mucous, muscular and serous. Three layers were found in the mucosa: epithelial, lamina propria, and muscular lamina. The predominant type of epitheliocytes were rim enterocytes, goblet cells were found in a smaller number, the number of which increased towards the rectum, as well as enteroendocrine cells, which were located mainly in the crypts. The muscularis mucosa consists of several layers of cells of smooth muscle tissue, which delimits the lamina propria from the muscle membrane, encircles the crypts, and accompanies the blood capillaries of the villi. The submucosa was not found. The muscular coat consists of two layers formed by smooth muscle tissue: the inner circular and the outer longitudinal. The enteric nervous system is represented by two nerve plexuses: the submucosal, located between the muscularis mucosa, and the myenteric, located in the outer layer of the muscular membrane. There was a general pattern of increase in changes in most parameters with age: the diameter of the intestine, wall thickness, mucous membrane and muscle membrane, height, width and surface area of the villi, the depth of the crypts. Changes in the size of the microstructures of the intestines were asynchronous. The most intensive changes in the size of microstructures occurred in the first month after hatching, especially in the first week. They corresponded to the values of an adult bird mainly at 21–30 days of age. A decrease in the thickness of the wall, mucosa, height of the villi, and their surface area in the direction from the duodenum to the rectum was established.

**Keywords:** exotic birds; psittacine birds; digestive organs; duodenum; jejunum; ileum; rectum; histological structure.

### Introduction

Keeping different types of wild birds by humans has long been a common practice. Due to their very high exotic or genetic value, wild birds are an important commodity in trade between countries and continents. At the same time, due to the ability to act as a carrier or vector of zoonotic diseases, they pose a significant threat to humans, requiring careful monitoring by the veterinary service (Pekmezci et al., 2020; Yetismis et al., 2022; Zadavec et al., 2022; Abdullah et al., 2023). Animal welfare is a priority for accredited zoological institutions, but historically mammalian research has been the priority. Bird-focused research accounts for less than 10% of animal welfare publications in zoos and aquaria over the past ten years. At the same time, due to the lack of scientific publications on wild birds, specialists are turning to other sectors, such as agriculture, to understand the issues of their maintenance and feeding (Woods et al., 2022). But there is a significant biological difference between farm poultry and exotic birds. Agricultural bird species (Galliformes and Anseriformes) are brood birds, and non-productive bird species are nesting birds. Brood chicks are fully feathered and sighted after hatching, and after a few hours, they can feed on their own. After hatching, nestlings have no plumage at all, are often blind and need constant parental care due to the inability to feed and fly on their own.

The budgerigar (*Melopsittacus undulatus* Shaw, 1805), a species of the parrot subfamily (Psittacidae), the only member of the genus *Melopsit-*

*tacus*, is the most favoured exotic bird at home, however, research on their diet is limited and the nutritional requirements of nestlings are not well understood (Comejo et al., 2021). Poor nutrition and digestive diseases are a major problem and a common cause of death in captive parrots (Donatti et al., 2014). In addition, the conditions of cellular maintenance significantly affect the health of parrots, which, together with the food factor, has a negative impact. The most common health disorder observed by budgerigar owners in Germany was obesity, found in 26.4% of survey respondents (Wickermann & Krautwald-Junghanns, 2021). The number of publications on diseases of the digestive organs of budgerigars has been increasing in recent years, which indicates the severity of the problem. Research covers diseases of many digestive organs: beak deformity due to malnutrition (Demir & Gerbaga, 2021), metaplasia of squamous epithelium in the beak, esophagus, tumour of the sublingual salivary glands (Hollmann, 1990), catarrhal proventriculitis (Tsai, 1992), parrot proventricular dilatation disease (Rossi et al., 2018; Hoppes & Shivaprasad, 2020), proventriculus carcinoma (Wildmann et al., 2022), avian yeast infection of the stomach, which is caused by *Macrorhabdus ornithogaster*, which colonizes the isthmus of the proventriculus and ventricle (Fulton & Mani, 2020; Baron et al., 2021), enteritis (Baker, 1987), hepatitis, lipidosis, and focal hepatic necrosis (Baker, 1980; Beaufrière et al., 2019), pancreatitis (Barazorda et al., 2022).

The gut is the main organ that has been studied to evaluate the effects of diet on animals (Lilburn & Loeffler, 2015). A powerful digestive appa-

ratus reduces the risk of diseases of infectious and non-infectious etiologies by preventing the entry of pathogens into the internal environment of the animal body (Williams & Athrey, 2020). The parameters of the intestine, indicating its morphofunctional state, are such morphometric indicators as the height of the villi and the depth of the crypts, their density, and the area of the suction surface (Alshamy et al., 2018). Correlative relationships have been established between these indicators and the degree of absorption of dietary nutrients and, ultimately, the growth rate of birds (Gehart & Clevers, 2019; Ravindran & Abdollahi, 2021).

The fragmentary, insignificant and sometimes contradictory amount of data in the scientific literature on the patterns of the microscopic structure of the parrot intestine indicates the insufficient development of this issue of age-related morphology, and the prevalence of diseases of the digestive system indicates the relevance of such studies. The aim of the study was to determine the features of the microscopic structure of the intestines of the budgerigar during the first year of the postnatal period of ontogenesis.

## Material and methods

The parrots were kept and handled in accordance with the European Convention for the Protection of Vertebrate Animals used for Research and other Scientific Purposes (Strasbourg, 1986). The study protocol was approved by the Bioethics Commission of the Faculty of Veterinary Medicine of the State Biotechnological University (Kharkiv, Ukraine). During the experiment, the birds were clinically healthy. The parrots were kept in spacious cages, where they constantly had the opportunity to fly and had fresh air. The parrots were fed a diet that was a mixture of grains, which included yellow, white and red millet, oats, canary and sunflower seeds, as well as dried fruits and vegetables. The food constantly contained sand. Once a week, a boiled grated chicken egg was added to the diet as a protein feed. Water and food were always fresh, free and always available. After the chicks hatched, female parrots were independently fed with "goiter milk", older ones – from the goiter with soaked grains. No preventive vaccinations and antiparasitic treatments were performed for the birds.

The birds were withdrawn from the experiment by gradual overdose of ether for anesthesia. The material for research was taken from budgerigars (*Melopsittacus undulatus*) of 9 age groups: 1, 3, 7, 14, 21, 60, 180, and also 365 days old ( $n = 5$ ). Pieces of the middle section of four intestines – duodenum, jejunum, ileum and rectum were fixed in 8% neutral formalin solution. After dehydration in alcohols of increasing concentration, the material was embedded in paraffin. For the preparation of preparations, histological sections were stained with hematoxylin and eosin by Mallory's technique, with silver nitrate by Bolshevsky's technique. The total population of enteroendocrine cells was found in the argyrophilic reaction using the Grimelius technique.

Morphometric parameters of microstructures were determined on cross sections of the intestines using the ToupView program (ToupTek, China) and a scoring grid. The study of histological preparations and the preparation of micro photos were performed using a Jenamed 2 microscope (Carl Zeiss Jena, Germany). The surface area of the villus was calculated by determining its height and width (Iji et al., 2001). Density of villi and crypts was determined in terms of 1 mm of mucosal length. When characterizing changes in the morphometric parameters of the intestines of parrots, they were always compared with the previous age. For a comparative assessment of the development of individual intestines, such a parameter as the average age indicator (AAI) was used. AAI of each intestinal structure was determined as the arithmetic mean of 9 of its age indicators. The data were analyzed in Biostat LE 7.3. (AnalystSoft Inc., 2020) soft-ware. The data are presented in the tables as  $x \pm SD$  (mean  $\pm$  standard deviation). Differences between the values in different age groups were determined using the Tukey test, where the differences were considered reliable at  $P < 0.05$  (with taking into account Bonferroni correction).

## Results

In the composition of the intestines of the budgerigar, the duodenum is anatomically distinguished, containing in its loop the pancreas, jejunum and ileum, the border between which was Meckel's diverticulum, as well

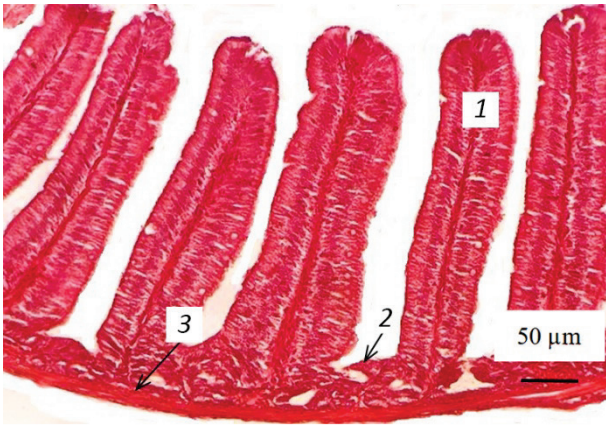
as the rectum. Microscopically, three membranes were identified in the intestinal wall: mucous, muscular, and serous. Three layers were found in the mucosa: epithelial, lamina propria, and muscular lamina. We did not find the submucosa in the wall of different intestines of the parrots in all the studied age periods. Thin layers of loose connective tissue were found between the muscularis mucosa of the mucous membrane and the muscular membrane only around the elements of the submucosal nerve plexus – nerve ganglions and bundles of nerve fibers.

The characteristic structure of the intestinal mucosa of the budgerigar is the villi – a protrusion of the lamina propria, covered with an epithelial layer, on transverse sections having a finger-shaped shape and crypts (Lieberkuhn's glands) – the immersion of the epithelium into the lamina propria (Fig. 1–3). The lamina propria is formed by loose fibrous connective tissue, in which individual fibroblasts were found in chicks of 1–3 days of age; amorphous substance predominated in the composition of the intercellular substance. In older parrots, fibroblast cells and other cells of loose connective tissue, as well as collagen and elastic fibers, were found in it in a significantly larger amount. In addition to fibroblasts, it contained leukocytes in a smaller amount, which were dominated by lymphocytes, as well as tissue basophils. A blood capillary passes along the villus to its apex, containing shaped blood cells and accompanied by 1–3 narrow chains of smooth muscle cells (Fig. 4). In the intestinal mucosa of older parrots, blood vessels were found in greater numbers, mainly arterioles and venules. In the composition of the mucosal lamina propria, both between the crypts and within the villi, small accumulations of lymphoid tissue, both diffuse fields and lymphoid nodules, were sometimes found. In the epithelial layer of the villi and crypts, border enterocytes, goblet cells, and enteroendocrine cells were found. The predominant type of epithelial cells were border enterocytes with a distinct border at the apical pole formed by microvilli. Goblet cells were found in a much smaller number, the number of which increased in the direction from the duodenum. Enteroendocrine cells were located mainly in the crypts and were distinguished by the presence of secretory inclusions at the basal pole (Fig. 5). The crypts are very short; their width was somewhat less than their depth, which gave them a hemispherical shape. Under the crypts, there is a muscular plate of the mucosa, represented by one–three layers of smooth muscle cells, which had a longitudinal direction of location, and encircled the crypts with one layer.

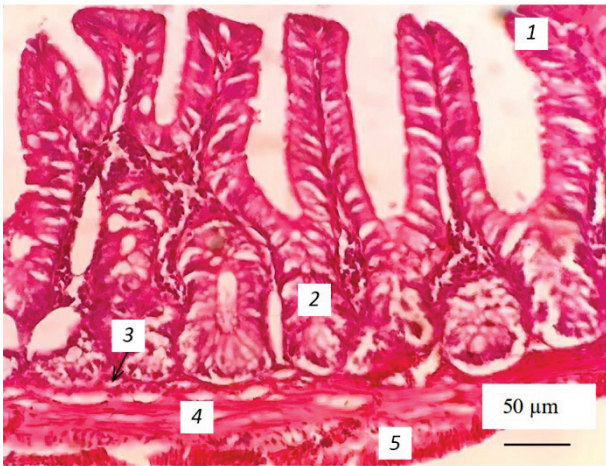
In the muscular membrane, two layers were found – a thicker inner annular and a thinner outer longitudinal layer, formed by smooth muscle cells. Between themselves, the layers of the muscular membrane are separated by thin layers of loose fibrous connective tissue. Between the muscle plate of the mucous membrane and the muscular membrane, as well as in the outer layer of the muscular membrane, elements of the nerve plexuses were found – nerve nodes and bundles of nerve fibers, respectively, submucosal (Meissner) and muscular membrane (myenteric, Auerbach) (Fig. 6). The nerve ganglions contained several neuronal cell bodies of the multipolar type (Fig. 7). The serous membrane is represented by a thin connective tissue plate covered with mesothelium.



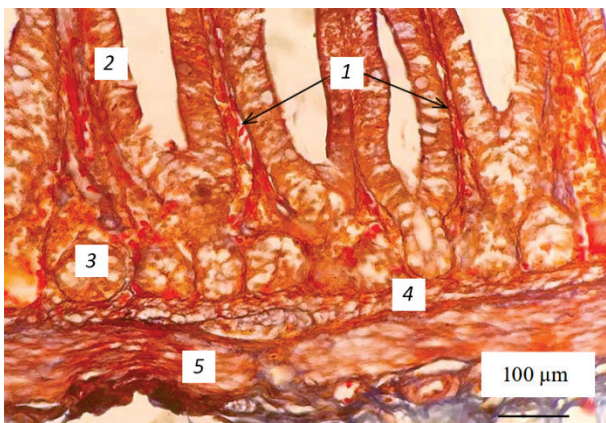
**Fig. 1.** Duodenum and pancreas fragment of a 180 day old budgerigar (histological preparation): 1 – intestinal villi; 2 – intestinal crypts; 3 – muscular membrane; 4 – pancreas; hematoxylin and eosin stain



**Fig. 2.** Jejunum wall of a 30 day old budgerigar (histological preparation): 1 – intestinal villi; 2 – intestinal crypts; 3 – muscular membrane; hematoxylin and eosin stain



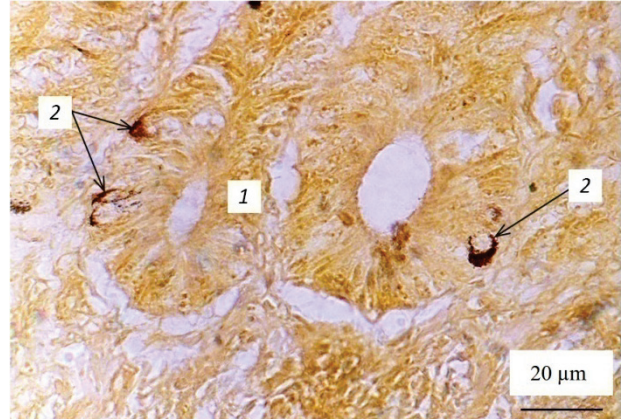
**Fig. 3.** The wall of the rectum of a 14 day old budgerigar (histological preparation): 1 – intestinal villus; 2 – intestinal crypt; 3 – muscular plate of the mucosa; 4 – the inner layer of the muscular membrane; 5 – the outer layer of the muscular membrane; hematoxylin and eosin stain



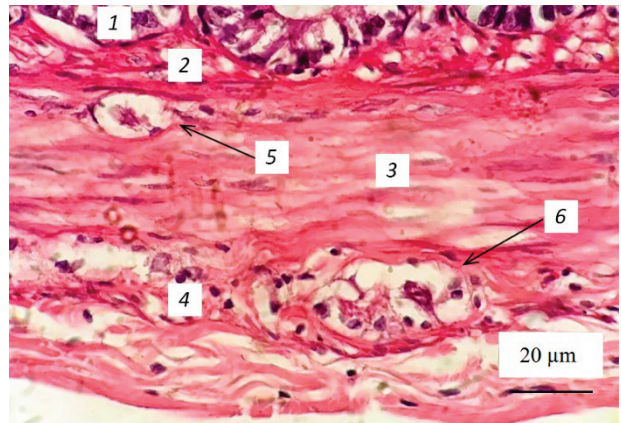
**Fig. 4.** The wall of the ileum of a 60 day old budgerigar (histological preparation): 1 – blood capillaries of the intestinal villi; 2 – epithelium of the intestinal villi; 3 – intestinal crypts; 4 – muscular plate of the mucosa; 5 – muscular; Mallory stain

The general pattern of age-related changes in the morphometric parameters of the microstructures of the budgerigar intestines was their increase from a day old to 14–30 days old. An increase in the diameter of the intestines occurred mainly up to 21 days of age (Table 1). During this period, it increased in the duodenum by 78.9%, jejunum – by 56.3%, ileum – by 58.3% and rectum – by 75.0%. Moreover, during this period, it increased most intensively in the first week: in the duodenum by 52.6%,

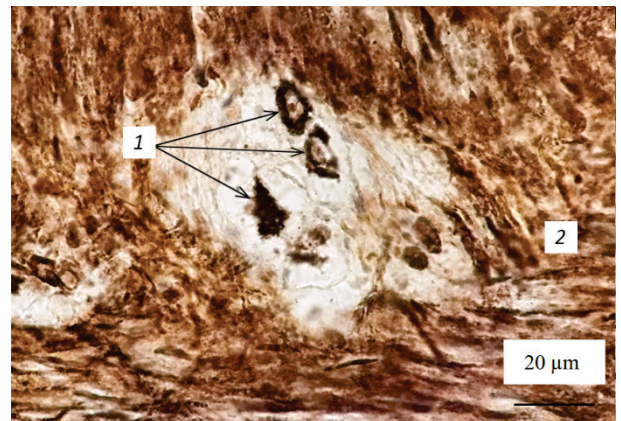
jejunum – by 18.8%, ileum – by 33.3% and rectum – by 66.7%. During the second week, it increased by 10.0%, 5.0%, 13.0% and 10.0% respectively, during the third week – by 6.0%, 25.0%, 6.0% and in the rectum it decreased by 5.0%. After the age of 21 days, the changes in this indicator were multidirectional; it slightly increased or decreased in relation to the previous age. The diameter of the intestines reached the greatest value in the duodenum and jejunum at 21 days of age, in the ileum – at 30 days of age, in the rectum – at 14 days of age.



**Fig. 5.** The wall of the ileum of a 180 day old budgerigar (histological preparation): 1 – intestinal crypts; 2 – enteroendocrine cells; Grimelius stain



**Fig. 6.** Jejunum gut wall of a 60 day old budgerigar (histological preparation): 1 – intestinal crypt; 2 – muscular plate of the mucous membrane; 3 – the inner layer of the muscular membrane; 4 – the outer layer of the muscular membrane; 5 – nerve node of the submucosal nerve plexus; 6 – nerve node of the myenteric nerve plexus; hematoxylin and eosin stain



**Fig. 7.** Nerve ganglion of the myenteric nerve plexus in the rectal wall of a one-year-old budgerigar (histological preparation): 1 – nerve cells; 2 – the outer layer of the muscular membrane; impregnation with silver nitrate according to Bolshevsky

**Table 1**  
Budgerigar intestinal diameter (mm) at all ages (n = 5, x ± SD)

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	1.92 ± 0.31 <sup>a</sup>	1.58 ± 0.27 <sup>ab</sup>	1.17 ± 0.22 <sup>a</sup>	1.20 ± 0.22 <sup>a</sup>
3	2.23 ± 0.18 <sup>ab</sup>	1.42 ± 0.11 <sup>a</sup>	1.34 ± 0.17 <sup>ab</sup>	1.25 ± 0.17 <sup>a</sup>
7	2.89 ± 0.33 <sup>b</sup>	1.93 ± 0.32 <sup>ab</sup>	1.56 ± 0.32 <sup>ab</sup>	2.03 ± 0.34 <sup>b</sup>
14	3.18 ± 0.57 <sup>b</sup>	2.02 ± 0.28 <sup>b</sup>	1.82 ± 0.25 <sup>ab</sup>	2.23 ± 0.33 <sup>b</sup>
21	3.37 ± 0.45 <sup>b</sup>	2.45 ± 0.33 <sup>b</sup>	1.93 ± 0.27 <sup>b</sup>	2.13 ± 0.16 <sup>b</sup>
30	2.80 ± 0.32 <sup>b</sup>	2.17 ± 0.17 <sup>b</sup>	2.30 ± 0.33 <sup>b</sup>	2.11 ± 0.22 <sup>b</sup>
60	2.72 ± 0.29 <sup>b</sup>	2.28 ± 0.21 <sup>b</sup>	2.26 ± 0.32 <sup>b</sup>	2.03 ± 0.33 <sup>b</sup>
180	2.78 ± 0.32 <sup>b</sup>	2.20 ± 0.26 <sup>b</sup>	1.89 ± 0.32 <sup>b</sup>	1.89 ± 0.25 <sup>b</sup>
365	2.93 ± 0.31 <sup>b</sup>	2.12 ± 0.31 <sup>b</sup>	1.67 ± 0.26 <sup>ab</sup>	2.03 ± 0.31 <sup>b</sup>

Note: different letters indicate the values significantly differing one from another within a column on the results of comparison using the Tukey test (P < 0.05) with Bonferroni correction.

An increase in the thickness of the intestinal wall occurred mainly up to 30 days of age (Table 2). During this period, it increased in the duodenum by 65.4%, in the jejunum – by 125.3%, in the ileum – by 64.3% and in the rectum – by 83.5%. During this period, it increased most intensively in the first week: in the duodenum by 93.1%, in the jejunum by 79.3%, in the ileum by 25.6% and in the rectum by 18.1%. During the second week, it increased by 8.0%, 1.6%, 12.2% and 6.1% respectively. In the period from 21 to 30 days of age, this indicator decreased in the duodenum by 10.0% and increased in the jejunum, ileum and rectum by 15.1%, 12.9% and 35.7%, respectively. After 30 days of age, this indicator slightly increased or decreased in relation to the previous age (P > 0.05). The wall thickness in the duodenum reached the greatest value at 14 days of age, in the jejunum, ileum and rectum – at 30 days of age.

**Table 2**  
Budgerigar intestinal wall thickness (µm) at all ages (n = 5, x ± SD)

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	554 ± 41 <sup>a</sup>	306 ± 36 <sup>a</sup>	317 ± 39 <sup>ab</sup>	233 ± 40 <sup>a</sup>
3	670 ± 46 <sup>ab</sup>	428 ± 46 <sup>b</sup>	293 ± 33 <sup>a</sup>	273 ± 31 <sup>ab</sup>
7	1058 ± 80 <sup>c</sup>	529 ± 56 <sup>bc</sup>	399 ± 50 <sup>bc</sup>	300 ± 30 <sup>ab</sup>
14	1141 ± 84 <sup>c</sup>	534 ± 58 <sup>bc</sup>	446 ± 50 <sup>bc</sup>	319 ± 30 <sup>ab</sup>
21	1008 ± 54 <sup>bc</sup>	575 ± 51 <sup>cd</sup>	423 ± 17 <sup>bc</sup>	343 ± 38 <sup>b</sup>
30	911 ± 85 <sup>b</sup>	654 ± 56 <sup>d</sup>	517 ± 58 <sup>c</sup>	451 ± 49 <sup>c</sup>
60	988 ± 68 <sup>bc</sup>	503 ± 47 <sup>bc</sup>	503 ± 59 <sup>c</sup>	437 ± 31 <sup>c</sup>
180	982 ± 71 <sup>bc</sup>	529 ± 33 <sup>bc</sup>	459 ± 46 <sup>bc</sup>	391 ± 45 <sup>bc</sup>
365	985 ± 53 <sup>bc</sup>	586 ± 19 <sup>c</sup>	394 ± 45 <sup>b</sup>	354 ± 30 <sup>bc</sup>

Note: see Table 1.

The increase in the thickness of the intestinal mucosa, as well as its walls, occurred mainly up to 30 days of age (Table 3). During this period, it increased in the duodenum by 66.4%, jejunum – by 40.8%, ileum – by 65.7% and rectum – by 72.9%. During this period, it increased most intensively in the duodenum and jejunum in the first week, by 96.0% and 88.5%, respectively, in the ileum – in the first and fourth weeks, by 25.6% and 26.1%, respectively, in the rectum – in the fourth week by 41.4%. After 30 days of age, the values of this indicator were lower. The thickness of the mucosa reached the greatest value in the duodenum at 14 days of age, in the jejunum, ileum and rectum – at 30 days of age.

**Table 3**  
Budgerigar intestinal mucosal thickness (µm) at all ages (n = 5, x ± SD)

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	519 ± 55 <sup>a</sup>	238 ± 35 <sup>a</sup>	274 ± 22 <sup>ab</sup>	209 ± 27 <sup>a</sup>
3	634 ± 55 <sup>ab</sup>	335 ± 50 <sup>ab</sup>	246 ± 27 <sup>a</sup>	226 ± 33 <sup>ab</sup>
7	1017 ± 75 <sup>c</sup>	448 ± 46 <sup>bc</sup>	344 ± 52 <sup>b</sup>	222 ± 32 <sup>ab</sup>
14	1099 ± 79 <sup>c</sup>	458 ± 44 <sup>bc</sup>	388 ± 44 <sup>bc</sup>	236 ± 34 <sup>ab</sup>
21	966 ± 87 <sup>bc</sup>	490 ± 54 <sup>bc</sup>	360 ± 37 <sup>bc</sup>	256 ± 35 <sup>ab</sup>
30	864 ± 43 <sup>b</sup>	573 ± 48 <sup>c</sup>	454 ± 50 <sup>c</sup>	362 ± 35 <sup>b</sup>
60	924 ± 91 <sup>bc</sup>	423 ± 45 <sup>bc</sup>	439 ± 56 <sup>c</sup>	333 ± 38 <sup>ab</sup>
180	890 ± 45 <sup>bc</sup>	421 ± 42 <sup>b</sup>	389 ± 35 <sup>bc</sup>	296 ± 33 <sup>b</sup>
365	878 ± 45 <sup>bc</sup>	468 ± 56 <sup>bc</sup>	323 ± 26 <sup>ab</sup>	269 ± 33 <sup>ab</sup>

Note: see Table 1.

An increase in the height of the villi of the intestinal mucosa, as well as the thickness of the mucous membrane, occurred mainly up to 30 days of age (Table 4). During this period, it increased in the duodenum by 66.5%, jejunum – by 196.8%, ileum – by 54.2% and rectum – by 62.0%. During this period, it increased most intensively in the first week: in the duodenum – by 100.0%, jejunum – by 147.5%, ileum – by 38.4% and rectum – by 11.3%. After 30 days of age, changes in this indicator were not significant. The height of the villi reached the highest value in the duodenum at 14 days of age, in the jejunum and rectum at 30 days of age, and in the ileum at 60 days of age.

**Table 4**  
Budgerigar intestinal mucosal thickness (µm) at all ages (n = 5, x ± SD)

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	469 ± 19 <sup>a</sup>	158 ± 25 <sup>a</sup>	203 ± 26 <sup>ab</sup>	145 ± 22 <sup>a</sup>
3	591 ± 45 <sup>ab</sup>	256 ± 21 <sup>b</sup>	166 ± 23 <sup>a</sup>	150 ± 14 <sup>ab</sup>
7	938 ± 92 <sup>c</sup>	391 ± 56 <sup>cd</sup>	281 ± 35 <sup>c</sup>	161 ± 26 <sup>ab</sup>
14	998 ± 145 <sup>c</sup>	401 ± 35 <sup>cd</sup>	298 ± 38 <sup>cd</sup>	157 ± 23 <sup>ab</sup>
21	859 ± 43 <sup>bc</sup>	424 ± 29 <sup>d</sup>	277 ± 24 <sup>bc</sup>	172 ± 22 <sup>ab</sup>
30	781 ± 25 <sup>bc</sup>	467 ± 26 <sup>d</sup>	313 ± 27 <sup>c</sup>	234 ± 26 <sup>b</sup>
60	831 ± 24 <sup>bc</sup>	313 ± 24 <sup>bc</sup>	327 ± 26 <sup>c</sup>	229 ± 31 <sup>b</sup>
180	805 ± 23 <sup>bc</sup>	348 ± 35 <sup>c</sup>	280 ± 31 <sup>bc</sup>	186 ± 25 <sup>ab</sup>
365	781 ± 24 <sup>b</sup>	403 ± 23 <sup>cd</sup>	235 ± 37 <sup>b</sup>	174 ± 20 <sup>ab</sup>

Note: see Table 1.

The smallest indicators of the width of the intestinal villi were in chicks 1–3 days old (Table 5). The increase in the width of the villi of the intestinal mucosa, as well as their height, occurred mainly up to 30 days of age. During this period, it increased in the duodenum by 45.8%, jejunum – by 46.3%, ileum – by 75.9% and rectum – by 74.6%. During this period, this indicator increased most intensively in the duodenum, ileum and rectum in the first week by 52.7%, 63.5% and 56.7%, respectively, in the jejunum – during the second week – by 26.9%. The width of the intestinal villi reached the greatest value in the duodenum at 21 days of age, in the jejunum and ileum – at 60 days of age, in the rectum – at 30 days of age.

**Table 5**  
Budgerigar intestinal villi width (µm) at all ages (n = 5, x ± SD)

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	67.5 ± 2.9 <sup>ab</sup>	73.8 ± 2.8 <sup>b</sup>	45.2 ± 2.2 <sup>a</sup>	47.3 ± 2.4 <sup>a</sup>
3	55.0 ± 2.8 <sup>a</sup>	47.8 ± 2.5 <sup>a</sup>	53.7 ± 2.7 <sup>ab</sup>	50.9 ± 3.0 <sup>ab</sup>
7	103.1 ± 4.2 <sup>cd</sup>	76.5 ± 3.0 <sup>bc</sup>	73.9 ± 3.0 <sup>bc</sup>	74.1 ± 3.2 <sup>b</sup>
14	130.7 ± 6.0 <sup>d</sup>	97.1 ± 5.7 <sup>bc</sup>	75.8 ± 3.6 <sup>bc</sup>	81.3 ± 4.4 <sup>b</sup>
21	132.3 ± 6.3 <sup>d</sup>	102.3 ± 4.9 <sup>c</sup>	72.8 ± 3.5 <sup>b</sup>	77.9 ± 3.7 <sup>b</sup>
30	98.4 ± 5.0 <sup>bc</sup>	108.0 ± 4.7 <sup>c</sup>	79.5 ± 3.8 <sup>bc</sup>	82.6 ± 4.5 <sup>b</sup>
60	101.7 ± 6.2 <sup>cd</sup>	111.3 ± 6.2 <sup>c</sup>	98.3 ± 4.0 <sup>c</sup>	80.7 ± 4.1 <sup>b</sup>
180	99.3 ± 4.6 <sup>c</sup>	88.7 ± 4.4 <sup>bc</sup>	89.3 ± 4.4 <sup>bc</sup>	70.5 ± 3.8 <sup>ab</sup>
365	74.1 ± 4.5 <sup>b</sup>	79.7 ± 3.5 <sup>bc</sup>	77.0 ± 3.3 <sup>bc</sup>	73.4 ± 3.7 <sup>ab</sup>

Note: see Table 1.

The increase in the surface area of the villi of the intestinal mucosa, as well as their height, occurred mainly up to 30 days of age (Table 6). During this period, it increased in the duodenum by 143.4%, in the jejunum – by 332.5%, in the ileum – by 170.7% and in the rectum – by 185.3%. During this period, it increased most intensively in the duodenum in the first and second weeks, by 35.0%, respectively, in the jejunum in the first and second weeks, by 155.6% and 30.1%, respectively, in the ileum and rectum – in the first week, by 126.1%, and 75%, respectively. After 30 days of age, the changes in this indicator were not so significant. It reached the greatest value in the duodenum at 14 days of age, in the jejunum and rectum – at 30 days of age, in the ileum – at 60 days of age.

The highest values of villi density were found in parrots 1–3 days old (Table 7). In older birds, this figure was lower. It reached the lowest value at 21 days of age in the jejunum and rectum, at 60 days of age – in the duodenum and ileum.

The smallest values of the depth of the crypts of the intestinal mucosa were typical for birds 3–7 days old (Table 8). The increase in this indicator occurred mainly up to 30 days of age. Compared to day old chicks, it was 63.8% larger in the duodenum, 66.7% in the jejunum, 99.5% in the ileum, and 99.7% in the rectum. During this period, such changes occurred most

intensively in the duodenum up to 7 days of age, in the jejunum – 3–21 to 30 days of age, in the ileum and rectum – from 7 to 14 days of age and from 21 to 30 days of age. After 30 days of age, the value of this indicator was lower compared to birds of a younger age. The depth of the crypts reached the greatest value in the duodenum at 21 days of age, in the ileum and rectum – at 30 days of age, in the jejunum – at 60 days of age.

**Table 6**  
Surface area of budgerigar intestinal villi ( $\times 10^3 \mu\text{m}^2$ ) at all ages ( $n = 5, x \pm \text{SD}$ )

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	31.6 $\pm$ 4.7 <sup>a</sup>	11.7 $\pm$ 1.8 <sup>a</sup>	9.2 $\pm$ 0.8 <sup>ab</sup>	6.8 $\pm$ 0.8 <sup>a</sup>
3	32.5 $\pm$ 4.9 <sup>ab</sup>	12.3 $\pm$ 1.6 <sup>ab</sup>	8.9 $\pm$ 0.9 <sup>a</sup>	7.7 $\pm$ 1.0 <sup>ab</sup>
7	96.7 $\pm$ 11.4 <sup>d</sup>	29.9 $\pm$ 4.1 <sup>b</sup>	20.8 $\pm$ 2.8 <sup>bc</sup>	11.9 $\pm$ 1.6 <sup>b</sup>
14	130.5 $\pm$ 15.8 <sup>c</sup>	38.9 $\pm$ 5.1 <sup>c</sup>	22.6 $\pm$ 2.8 <sup>bc</sup>	12.8 $\pm$ 1.7 <sup>bc</sup>
21	113.7 $\pm$ 11.8 <sup>cd</sup>	43.4 $\pm$ 4.0 <sup>cd</sup>	20.2 $\pm$ 2.3 <sup>bc</sup>	13.4 $\pm$ 1.5 <sup>bc</sup>
30	76.9 $\pm$ 3.8 <sup>c</sup>	50.6 $\pm$ 6.5 <sup>d</sup>	24.9 $\pm$ 3.1 <sup>c</sup>	19.4 $\pm$ 2.8 <sup>c</sup>
60	84.5 $\pm$ 7.3 <sup>cd</sup>	34.8 $\pm$ 2.6 <sup>bc</sup>	32.1 $\pm$ 2.5 <sup>d</sup>	18.5 $\pm$ 1.9 <sup>c</sup>
180	79.9 $\pm$ 5.4 <sup>cd</sup>	30.9 $\pm$ 2.9 <sup>bc</sup>	25.0 $\pm$ 1.7 <sup>cd</sup>	13.1 $\pm$ 1.5 <sup>bc</sup>
365	57.9 $\pm$ 5.1 <sup>b</sup>	32.1 $\pm$ 3.9 <sup>bc</sup>	18.1 $\pm$ 1.5 <sup>b</sup>	12.8 $\pm$ 1.4 <sup>bc</sup>

Note: see Table 1.

**Table 7**  
Intestinal villus density of budgerigars at all ages ( $n = 5, x \pm \text{SD}$ )

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	14.72 $\pm$ 1.18 <sup>a</sup>	10.28 $\pm$ 0.82 <sup>b</sup>	14.56 $\pm$ 1.11 <sup>a</sup>	13.41 $\pm$ 1.38 <sup>ab</sup>
3	8.89 $\pm$ 0.78 <sup>b</sup>	12.82 $\pm$ 1.35 <sup>a</sup>	13.73 $\pm$ 1.22 <sup>ab</sup>	13.50 $\pm$ 1.63 <sup>a</sup>
7	6.10 $\pm$ 0.62 <sup>cd</sup>	7.89 $\pm$ 0.30 <sup>c</sup>	8.52 $\pm$ 0.38 <sup>bc</sup>	9.91 $\pm$ 0.40 <sup>b</sup>
14	6.03 $\pm$ 0.50 <sup>cd</sup>	7.02 $\pm$ 0.92 <sup>c</sup>	8.67 $\pm$ 0.92 <sup>b</sup>	10.71 $\pm$ 1.02 <sup>b</sup>
21	5.38 $\pm$ 0.58 <sup>d</sup>	6.83 $\pm$ 0.57 <sup>c</sup>	7.80 $\pm$ 0.51 <sup>bc</sup>	9.82 $\pm$ 0.63 <sup>b</sup>
30	5.82 $\pm$ 0.67 <sup>cd</sup>	7.12 $\pm$ 0.38 <sup>c</sup>	7.88 $\pm$ 0.67 <sup>bc</sup>	10.18 $\pm$ 0.89 <sup>b</sup>
60	4.89 $\pm$ 0.43 <sup>d</sup>	9.28 $\pm$ 0.58 <sup>bc</sup>	6.87 $\pm$ 0.72 <sup>c</sup>	11.40 $\pm$ 1.11 <sup>b</sup>
180	6.33 $\pm$ 0.73 <sup>cd</sup>	9.39 $\pm$ 1.02 <sup>bc</sup>	8.06 $\pm$ 0.30 <sup>bc</sup>	10.32 $\pm$ 0.56 <sup>b</sup>
365	6.92 $\pm$ 0.70 <sup>c</sup>	9.17 $\pm$ 0.83 <sup>bc</sup>	8.44 $\pm$ 0.78 <sup>bc</sup>	10.23 $\pm$ 0.92 <sup>b</sup>

Note: see Table 1.

**Table 8**  
Depth of budgerigar gut crypts ( $\mu\text{m}$ ) at all ages ( $n = 5, x \pm \text{SD}$ )

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	47.8 $\pm$ 5.1 <sup>ab</sup>	74.1 $\pm$ 8.4 <sup>bc</sup>	63.8 $\pm$ 5.5 <sup>ab</sup>	60.8 $\pm$ 6.0 <sup>ab</sup>
3	39.1 $\pm$ 5.4 <sup>d</sup>	68.2 $\pm$ 5.6 <sup>b</sup>	68.1 $\pm$ 5.7 <sup>b</sup>	68.6 $\pm$ 6.4 <sup>ab</sup>
7	75.2 $\pm$ 7.4 <sup>b</sup>	49.2 $\pm$ 5.4 <sup>ab</sup>	50.2 $\pm$ 5.9 <sup>a</sup>	54.7 $\pm$ 5.9 <sup>a</sup>
14	97.1 $\pm$ 12.1 <sup>c</sup>	48.3 $\pm$ 5.1 <sup>a</sup>	74.8 $\pm$ 7.0 <sup>bc</sup>	71.2 $\pm$ 8.1 <sup>b</sup>
21	102.3 $\pm$ 5.9 <sup>c</sup>	57.4 $\pm$ 6.7 <sup>ab</sup>	69.3 $\pm$ 3.8 <sup>bc</sup>	77.0 $\pm$ 6.6 <sup>bc</sup>
30	78.3 $\pm$ 6.5 <sup>bc</sup>	95.7 $\pm$ 8.6 <sup>c</sup>	127.3 $\pm$ 10.7 <sup>d</sup>	121.4 $\pm$ 9.2 <sup>d</sup>
60	88.2 $\pm$ 7.8 <sup>bc</sup>	100.3 $\pm$ 7.5 <sup>c</sup>	100.3 $\pm$ 7.5 <sup>cd</sup>	97.7 $\pm$ 7.4 <sup>cd</sup>
180	86.6 $\pm$ 5.2 <sup>bc</sup>	60.4 $\pm$ 5.3 <sup>ab</sup>	97.0 $\pm$ 8.1 <sup>c</sup>	102.3 $\pm$ 5.9 <sup>cd</sup>
365	86.3 $\pm$ 7.4 <sup>bc</sup>	52.0 $\pm$ 7.5 <sup>ab</sup>	74.8 $\pm$ 7.8 <sup>bc</sup>	88.3 $\pm$ 6.4 <sup>c</sup>

Note: see Table 1.

Despite the presence of a mathematically significant age difference in the values of the density of the crypts, we have not established any definite regularity in its changes (Table 9).

Compared to the mucosa, the increase in the thickness of the muscular membrane of the intestine was more extended over time and differed significantly in different intestines (Table 10). During the first month, it increased in the duodenum by 32.5%, in the jejunum – by 16.6%, in the ileum – by 44.3% and in the rectum – by 325.5%. Moreover, during this period, it increased most intensively in the first week: in the duodenum – by 19.4%, in the jejunum – by 19.0%, in the ileum – by 29.1% and rectum – by 273.5%. After 30 days of age, the changes in this indicator were greater compared to changes in the thickness of the mucosa. Compared with the previous age, the thickness of the muscular membrane of the duodenum at 60, 180 and 365 days of age was greater by 38.7%, 31.6% and 28.9%, of the jejunum at 180 days of age more by 35.4%. At the same time, this indicator in other age periods, as well as the ileum and rectum did not undergo significant changes. The thickness of the muscular membrane was the largest in the duodenum and jejunum at 365 days of age, in the ileum – at 180 days of age, in the rectum – at 60 days of age.

**Table 9**  
Density of intestinal crypts of budgerigars of all ages ( $n = 5, x \pm \text{SD}$ )

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	20.1 $\pm$ 3.0 <sup>b</sup>	15.2 $\pm$ 1.8 <sup>ab</sup>	18.7 $\pm$ 2.3 <sup>ab</sup>	19.6 $\pm$ 2.8 <sup>b</sup>
3	20.6 $\pm$ 2.5 <sup>b</sup>	14.7 $\pm$ 2.1 <sup>a</sup>	15.4 $\pm$ 1.9 <sup>a</sup>	15.4 $\pm$ 1.9 <sup>ab</sup>
7	15.8 $\pm$ 1.8 <sup>ab</sup>	19.7 $\pm$ 2.8 <sup>ab</sup>	16.6 $\pm$ 1.6 <sup>ab</sup>	15.5 $\pm$ 1.7 <sup>ab</sup>
14	14.4 $\pm$ 1.0 <sup>ab</sup>	17.6 $\pm$ 1.9 <sup>ab</sup>	19.0 $\pm$ 2.6 <sup>ab</sup>	16.1 $\pm$ 2.0 <sup>ab</sup>
21	15.7 $\pm$ 0.7 <sup>ab</sup>	17.3 $\pm$ 1.8 <sup>ab</sup>	20.2 $\pm$ 2.6 <sup>ab</sup>	15.3 $\pm$ 1.9 <sup>a</sup>
30	13.2 $\pm$ 1.7 <sup>a</sup>	20.1 $\pm$ 2.4 <sup>b</sup>	21.4 $\pm$ 2.6 <sup>b</sup>	16.4 $\pm$ 1.8 <sup>ab</sup>
60	16.6 $\pm$ 1.6 <sup>ab</sup>	19.3 $\pm$ 2.8 <sup>ab</sup>	22.3 $\pm$ 2.5 <sup>b</sup>	15.8 $\pm$ 1.1 <sup>ab</sup>
180	17.0 $\pm$ 2.0 <sup>ab</sup>	22.8 $\pm$ 2.6 <sup>b</sup>	23.3 $\pm$ 2.6 <sup>b</sup>	17.0 $\pm$ 2.1 <sup>ab</sup>
365	21.7 $\pm$ 2.8 <sup>b</sup>	24.1 $\pm$ 3.5 <sup>b</sup>	24.6 $\pm$ 3.4 <sup>b</sup>	16.7 $\pm$ 0.8 <sup>ab</sup>

Note: see Table 1.

**Table 10**  
The thickness of the muscular membrane of the intestines ( $\mu\text{m}$ ) of the budgerigars of all ages ( $n = 5, x \pm \text{SD}$ )

Age, days	Intestine			
	duodenum	jejunum	ileum	rectum
1	32.0 $\pm$ 3.8 <sup>a</sup>	65.2 $\pm$ 6.0 <sup>a</sup>	40.6 $\pm$ 4.4 <sup>a</sup>	19.6 $\pm$ 1.6 <sup>a</sup>
3	32.2 $\pm$ 4.2 <sup>ab</sup>	90.2 $\pm$ 9.0 <sup>bc</sup>	43.6 $\pm$ 6.0 <sup>ab</sup>	42.6 $\pm$ 4.8 <sup>b</sup>
7	38.2 $\pm$ 5.2 <sup>ab</sup>	77.6 $\pm$ 8.0 <sup>ab</sup>	52.4 $\pm$ 4.6 <sup>ab</sup>	73.2 $\pm$ 6.2 <sup>c</sup>
14	37.4 $\pm$ 5.4 <sup>ab</sup>	72.2 $\pm$ 5.2 <sup>ab</sup>	54.6 $\pm$ 6.8 <sup>b</sup>	77.2 $\pm$ 7.2 <sup>cd</sup>
21	38.0 $\pm$ 5.2 <sup>ab</sup>	81.0 $\pm$ 7.2 <sup>b</sup>	58.2 $\pm$ 5.8 <sup>b</sup>	82.0 $\pm$ 4.8 <sup>cd</sup>
30	42.4 $\pm$ 7.0 <sup>ab</sup>	76.0 $\pm$ 6.8 <sup>ab</sup>	58.6 $\pm$ 7.2 <sup>b</sup>	93.4 $\pm$ 9.2 <sup>cd</sup>
60	58.8 $\pm$ 4.0 <sup>b</sup>	75.6 $\pm$ 4.8 <sup>ab</sup>	57.6 $\pm$ 5.8 <sup>b</sup>	96.6 $\pm$ 9.6 <sup>d</sup>
180	76.8 $\pm$ 3.8 <sup>c</sup>	102.4 $\pm$ 9.0 <sup>c</sup>	64.0 $\pm$ 5.4 <sup>b</sup>	87.6 $\pm$ 10.8 <sup>cd</sup>
365	99.8 $\pm$ 7.4 <sup>c</sup>	111.8 $\pm$ 7.8 <sup>c</sup>	64.6 $\pm$ 4.2 <sup>b</sup>	77.0 $\pm$ 3.6 <sup>cd</sup>

Note: see Table 1.

The thickness of the inner and outer layers of the muscular membrane in the duodenum, depending on age, ranged from 24.2 to 69.8  $\mu\text{m}$  and from 7.6 to 30.0  $\mu\text{m}$  respectively, in the jejunum – from 51.6 to 67.4  $\mu\text{m}$  and from 7.6 to 44.4  $\mu\text{m}$ , in the ileum – from 26.4 to 39.6  $\mu\text{m}$  and from 12.2 to 26.2  $\mu\text{m}$ , in the rectum – from 12.6 to 64.4  $\mu\text{m}$  and from 7.0 to 32.2  $\mu\text{m}$ . Accordingly, the relative thickness of the inner layer in the duodenum, depending on age, ranged from 70.0% to 77.5%, in the jejunum – from 55.8% to 79.1%, in the ileum – from 59.0% to 72.5%, in the rectum – from 64.3% to 69.5%. In one year-old birds, the relative thickness of the inner layer of the muscular membrane in the duodenum was 70.0%, jejunum – 60.3%, ileum – 59.4%, and rectum – 68.3%. The general pattern of the dynamics of this indicator was a decrease with age in the relative thickness of the inner layer and, accordingly, an increase in the thickness of the outer layer.

The relative thickness of the serous membrane of the intestines of the budgerigar in different age periods ranged from 0.8% to 2.5%. According to the results of determining the AAI of ten morphometric parameters of the budgerigar intestine, the presence of a mathematically significant difference in the value of some morphometric parameters in different intestines was established (Table 11).

Their general pattern was a decrease in such indicators as wall thickness, mucosa, villi height, their surface area and an increase in creep density in the direction from the duodenum to the rectum.

## Discussion

Knowledge of the feeding habits of Psittacidae is essential to understanding their survival in the wild, as well as adequate human care. Hand rearing is a common practice for parrots, but feeding research is limited (Comejo et al., 2022). The development and functional activity of the digestive organs is a determining factor in the intensity of growth and development of birds, especially after hatching, and depends both on the internal mechanisms of histo- and organogenesis and on external factors, such as the composition and amount of the diet (Walthall et al., 2005). Wild bird species have significant differences in the morphology and physiology of the digestive organs from domestic ones. Features of the age structural organization of the organs of the digestive apparatus of the budgerigar are an insufficiently studied section of comparative morphology, so their study is an urgent task.

**Table 11**  
Budgerigar Gut Average Age Indicator (AAI) (n = 5, x ± SD)

Index	Intestine			
	duodenum	jejunum	ileum	rectum
Diameter, mm	2.7 ± 0.5	2.0 ± 0.41	1.8 ± 0.4	1.9 ± 0.4
Wall thickness, µm	896.4 ± 185.4 <sup>c</sup>	474.3 ± 97.8 <sup>b</sup>	389.5 ± 73.1 <sup>ab</sup>	309.1 ± 62.8 <sup>a</sup>
Mucosal thickness, µm	866.5 ± 182.4 <sup>c</sup>	428.1 ± 95.4 <sup>b</sup>	357.3 ± 69.6 <sup>ab</sup>	267.8 ± 52.8 <sup>a</sup>
Muscle membrane thickness, µm	50.6 ± 47.2 <sup>a</sup>	83.6 ± 30.4 <sup>b</sup>	54.9 ± 16.4 <sup>ab</sup>	71.0 ± 48.8 <sup>ab</sup>
Villus height, µm	783.7 ± 163.8 <sup>c</sup>	351.4 ± 95.8 <sup>b</sup>	264.5 ± 52.9 <sup>ab</sup>	178.7 ± 32.6 <sup>a</sup>
Villus width, µm	71.2 ± 17.3	87.2 ± 20.2	73.9 ± 12.6	71.0 ± 21.3
Villus surface are, ×10 <sup>3</sup> µm <sup>2</sup>	78.2 ± 33.6 <sup>b</sup>	31.6 ± 12.9 <sup>ab</sup>	20.2 ± 7.5 <sup>ab</sup>	12.9 ± 4.2 <sup>a</sup>
Villus density	7.2 ± 3.0 <sup>a</sup>	8.9 ± 1.9 <sup>ab</sup>	9.4 ± 2.8 <sup>ab</sup>	11.0 ± 1.4 <sup>b</sup>
Crypt depth, µm	77.9 ± 21.3	67.3 ± 19.4	80.6 ± 23.4	82.4 ± 21.7
Crypt density	17.2 ± 2.9 <sup>ab</sup>	19.0 ± 3.2 <sup>ab</sup>	20.2 ± 3.1 <sup>b</sup>	16.4 ± 1.3 <sup>a</sup>

Note: see Table 1.

In the intestinal wall of the budgerigar, we have identified three membranes: mucous, muscular and serous. The mucosa forms characteristic structures: villi and crypts, which greatly increases the surface area of the intestine. Three layers are established in the mucous membrane: epithelial, lamina propria and muscular lamina. As part of the epithelial layer of the intestinal villi, enterocytes with borders, which are the most common type of cells, goblet cells, the number of which increases towards the rectum, were isolated. The vast majority of crypt epitheliocytes are represented by enterocytes without a border, as well as enteroendocrine cells. Our goblet cell data are in complete agreement with those of Rodrigues et al. (2012) regarding their greater number in the rectum of the macaw compared to the thin section and contradicting the data of Matsumoto et al. (2009), according to which goblet cells are absent in the intestine of the budgerigar. The muscularis mucosa consists of 1–3 layers of smooth muscle cells with a longitudinal orientation consistent with the data of Feder (1969), Rodrigues et al. (2012). No submucosa was found in the intestinal wall. This fact is consistent with the corresponding data on the absence in domestic chickens (Hodges & Michael, 1975; Kachave et al., 2009), and somewhat contradicts information about its presence or weak development in the intestines of various bird species – budgerigar (Feder, 1969), macaws (Rodrigues et al., 2012), wild duck (Khaleel & Atia, 2017), broiler chickens (Dehkordi & Shakaram, 2018), greylag geese (Kadhim et al., 2018), roadside hawk (de Araújo Silva et al., 2022).

For most poultry species, it is the first week of rearing that is decisive, which determines the further growth intensity and, accordingly, the state of resistance and productivity. The intensity of growth itself depends on the morphofunctional state of the digestive apparatus, which must provide the body with sufficient nutrients and biologically active substances. That is why the first weeks of the postnatal period of ontogeny are the most important in the development of the intestine (Iji et al., 2001). Features of the histological structure of the lamina propria of the intestinal mucosa of a budgerigar 1–7 days old showed active processes of histogenesis of loose connective tissue, which manifested itself in an increase in the number of cells and fibrous structures.

The general age pattern of the dynamics of most morphometric parameters (with the exception of the density of villi and crypts) of the budgerigar intestine was their increase. Such changes occurred mainly during the first month of the postnatal period of ontogeny. Thus, during the first month, the thickness of the intestinal wall increased by 64.3–125.3%, the thickness of the mucosa, by 40.8–72.9%, the height of the villi by 54.2–196.8%, and the width of the villi by 45.8–75.9%, villi surface area by 143.4–332.5%, crypt depth – by 63.8–99.7%. During the second month, the value of these indicators increased to a much lesser extent or even decreased. At the same time, during the first month of life of parrots, the most intensive increase in morphometric parameters occurred mainly in the first week. So, during this time, the thickness of the intestinal wall increased by 18.1–93.1%, the thickness of the mucous membrane – by 4.2–96.0%, the height of the villi – by 11.3–100.0%, the width of the villi – by 3.7–63.5%, villi surface area by 30.1–155.6%. Our data are consistent with the information that the most intensive increase in the microstructures of the intestines of poultry occurs in the first two weeks of postnatal ontogenesis (Watkins et al., 2004; Yovchev et al., 2013; Dehkordi & Shakaram, 2018). The increase in the thickness of the budgerigar intestinal mucosa occurred mainly due to an increase in the height of the

villi. It should be noted that changes in the size of microstructures in different guts of parrots occurred simultaneously. In addition, even their decrease compared to younger age was observed, consistent with information regarding the asynchronous development of intestinal structures (Sell et al., 1991; Iji et al., 2001; Liu & Oberg, 2010). As pointed out by Tang et al. (2020), chickens with a well-developed ileum thickness have an exceptional microbial composition and metabolic potential that is closely related to small intestine morphogenesis and homeostasis. In chickens, the height and area of the villi, as well as the depth of the crypts of the duodenum, increase most rapidly up to 6 days of age, the jejunum and ileum – up to 10 days of age, after which these parameters remain almost unchanged (Uni et al., 1995). It is worth noting the very dynamic nature of the increase or decrease in the size of the intestinal microstructures of budgerigar chicks. Along with a rapid increase in the morphometric parameters of the parrot intestine during the first or second week of the postnatal period of ontogenesis, the high intensity of growth and development of this organ emphasizes the achievement of the maximum parameters of its microstructures at a fairly early age, mainly at 21–30 days of age. Attention is drawn to the later achievement of the greatest indicators of the thickness of the muscular membrane of the intestines in comparison with the mucosa. This fact probably reflects the leading role of the intestinal mucosa in providing the body with nutrients; on the other hand, thickening of the muscular coat is more important for its motor function in older birds.

According to Feder (1969), in the composition of the muscle membrane of the intestines of the budgerigar, its outer layer is reduced and only the inner circular layer is present, and according to Matsumoto et al. (2009), there is no outer layer in the muscular layer of the rectum. According to Rodrigues et al. (2012), in macaws the muscular membrane is built according to the usual type and consists of two layers: the inner circular and the outer longitudinal, the thickness of which almost does not differ from the thickness of the muscularis mucosa. According to the results of our studies, the muscular membrane of the intestines of the budgerigar consists of two layers – a thicker inner and thinner outer, respectively, with a circular and longitudinal direction of the arrangement of bundles of muscle cells. The relative thickness of the inner layer in the muscular coat of the budgerigar, depending on the gut and age, was determined in the range from 55.8% to 79.1%. In adult birds, this indicator was the highest in the duodenum and rectum and the lowest in the jejunum and ileum. The general pattern of the age dynamics of the muscular membrane of the intestine was a decrease with age in the thickness of the inner layer and, accordingly, an increase in the outer layer.

As is known, in birds, unlike mammals, the microscopic structure of the intestine is somewhat different: the duodenum contains duodenal glands in the submucosa, and the intestines of the large intestine do not have villi (Al-Aaraji & Addi Ali, 2022; Awaad et al., 2022). As evidenced by the data obtained by us, microscopically all four intestines of the budgerigar: duodenal, jejunum, iliac and rectum corresponded to the general patterns of the structure of the intestines of birds. They are similar in microscopic structure and have no qualitative differences between themselves, which is consistent with the data of Matsumoto et al. (2009) regarding the lack of difference in histological structure between the jejunum and ileum in the budgerigar and data from Rodrigues et al. (2012) regarding the absence of a difference in histological structure between different segments of the small intestine in the macaw parrot.

According to Feder (1969), the villi in the duodenum are the longest in the budgerigar, gradually becoming shorter and thicker towards the rectum, according to Bartels et al. (1998), the villi gradually become smaller in the caudal direction. We have made an attempt to establish the presence or absence of differences in the quantitative parameters of the budgerigar intestinal microstructures between different intestines. Given that each of the indicators of the microscopic structure in each intestine changed with age in the direction of increase or decrease, and also that such changes occurred asynchronously between other intestines, it was difficult to compare them with each other. Therefore, in order to compare their values in different intestines, we applied the use of the average age indicator (AAI), which was determined as the arithmetic mean of 9 age parameters of each microstructure. In our opinion, the short period for selecting material for research at a younger age corresponded to the high intensity of changes in the values of the indicators. According to the results of the determination of the AAI, it was found that the thickness of the wall, mucosa, height and surface area of the villi was the largest in the duodenum, smaller in the jejunum, even smaller in the ileum and smallest in the rectum. In addition, the density of the villi was the lowest in the duodenum, and the highest in the rectum; the thickness of the muscular membrane was the smallest in the duodenum and the largest in the jejunum. At the same time, the diameter of the intestines, the width of the villi, and the depth of the crypts did not differ significantly from each other. Therefore, our information is in full agreement with the data of Bartels et al. (1998) and partly according to Feder (1969). According to Rodrigues et al. (2012), the intestinal wall of the macaw thickens in the caudal direction, and its lumen becomes smaller. According to our data, the budgerigar has the largest diameter and wall thickness in the duodenum, while in the rectum these figures are smaller.

## Conclusions

Despite the worldwide distribution of the budgerigar as a pet, as well as a significant list of diseases of their digestive organs, information on the microscopic structure of the intestine is insufficient and contradictory. At the same time, data on the structure and physiology of the digestive organs are the basis for compiling diets, developing diagnostic and treatment methods. According to the results of the research, it was found that the histological structure of the intestine corresponded to the general patterns of structure in birds. Microscopically, the duodenum, jejunum, ileum and rectum are difficult to distinguish among themselves, the differences relate only to quantitative indicators. The features of age-related changes in the size of the intestinal microstructures of the budgerigar during the first year of life, such as the diameter and thickness of the intestinal wall, the thickness of their mucous and muscular membranes, the height of the villi and the depth of the crypts, the surface area of the villi indicated their increase with age, and the most intense such changes happened in the first week. We consider it promising to study the structural features of other digestive organs of the budgerigar.

The authors declare that they have no potential conflict of interest in authoring or publishing this article.

## References

- Abdullah, D. A., Alobaidii, W. A., Alkateb, Y. N. M., Ali, F. F., Ola-Fadunsin, S. D., & Gimba, F. I. (2023). Molecular detection and prevalence of human-pathogenic *Enterocytozoon bieneusi* among pet birds in Mosul, Iraq. *Comparative Immunology, Microbiology and Infectious Diseases*, 95, 101964.
- Al-Aaraji, A. S., & Addi Ali, B. (2022). Effect of pomegranate peels aqueous extract on the histological structure of small intestine of local male rabbits (*Oryctolagus cuniculus*). *Archives of Razi Institute*, 77(5), 1935–1943.
- Alshamy, Z., Richardson, K. C., Hünigen, H., Hafez, H. M., Plendl, J., & Al Masri, S. (2018). Comparison of the gastrointestinal tract of a dual-purpose to a broiler chicken line: A qualitative and quantitative macroscopic and microscopic study. *PLoS One*, 13(10), e0204921.
- Awaad, A., Rushdy, A., & Adly, M. A. (2022). Comparative microanatomical and histochemical biodistribution profiles of different types of mucins in the intestinal mucosa of some tetrapod representatives. *Journal of Molecular Histology*, 53(2), 449–472.
- Baker, J. R. (1980). A survey of causes of mortality in budgerigars (*Melopsittacus undulatus*). *Veterinary Record*, 106(1), 10–12.
- Barazorda, R. S., Pokorný, J., & Filipová, A. (2022). Exokrinní pankreatická insuficience u papoušků [Exocrine pancreatic insufficiency in parrots]. *Veterinářství*, 72(2), 81–85 (in Czech).
- Baron, H. R., Stevenson, B. C., & Phalen, D. N. (2021). Comparison of in-clinic diagnostic testing methods for *Macrorhabdus ornithogaster*. *Journal of Avian Medicine and Surgery*, 35(1), 37–44.
- Bartels, T., Boos, A., Flachsbarth, M. F., & Wolf, P. (1998). Histologie des gastrointestinalen traktes des wellensittichs [Histology of the gastrointestinal tract of the budgerigar]. *Übersichten zur Tierernaehrung*, 25(2), 199–200 (in German).
- Beaufrière, H., Reavill, D., Heatley, J., & Susta, L. (2019). Lipid-related lesions in quaker parrots (*Myiopsitta monachus*). *Veterinary Pathology*, 56(2), 282–288.
- Comejo, J., Dierenfeld, E. S., Renton, K., & Brightsmith, K. (2021). Fatty acid profiles of crop contents of free-living psittacine nestlings and of commercial hand-feeding formulas. *Journal of Animal Physiology and Animal Nutrition*, 105(2), 394–405.
- de Araújo Silva, E. F., da Silva, J. G. M., da Silva, F. A., Santos, M. C. L., Galvão, A. P. O., de Aguiar Júnior, F. C. A., Garcia, J. E., & Magalhães, C. P. (2022). Morfometria macroscópica e histologia do trato intestinal do Gavião-carijó (*Rupornis magnirostris* Gmelin, 1788) [Macroscopic morphometry and histology of the intestinal tract of Roadside Hawks (*Rupornis magnirostris* Gmelin, 1788)]. *Brazilian Journal of Animal and Environmental Research Curitiba*, 5(3), 2985–3000 (in Portuguese).
- Dehkordi, R. A. F., & Shakaram, M. (2018). Morphology of rectum in broiler chicken and domestic fowl: Notability of retrograde peristalsis for water preservation. *Journal of Applied Animal Research*, 46(1), 599–603.
- Demir, A., & Gerbaga, Ö. K. (2021). Retrospective study of beak deformities in birds. *Turkish Veterinary Journal*, 3(1), 13–20.
- Donatti, R. V., Resende, M., Ferreira, F. C. J., Marques, M. V. R., Ecco, R., Shivasprasad, H. L., de Resende, J. S., & da Silva Martins, N. R. (2014). Fatal proventricular dilatation disease in captive native psittacines in Brazil. *Avian Diseases*, 58(1), 187–193.
- Feder, F. H. (1969). Beitrag zur makroskopischen und mikroskopischen Anatomie des Verdauungstraktes beim Wellensittich (*Melopsittacus undulatus*) [Contribution to the macroscopic and microscopic anatomy of the digestive tract in the budgerigar (*Melopsittacus undulatus*)]. *Anatomischer Anzeiger*, 125(3), 233–255 (in German).
- Fulton, R. M., & Mani, R. (2020). Avian gastric yeast (*Macrorhabdus ornithogaster*) and *Mycobacterium genavense* infections in a zoo budgerigar (*Melopsittacus undulatus*) flock. *Avian Diseases*, 64(4), 561–564.
- Gehart, H., & Clevers, H. (2019). Tales from the crypt: New insights into intestinal stem cells. *Nature Reviews Gastroenterology and Hepatology*, 16(1), 19–34.
- Hodges, R. D., & Michael, E. (1975). Structure and histochemistry of the normal intestine of the fowl. The fine structure of the duodenal crypt. *Cell and Tissue Research*, 160, 125–138.
- Hollmann, P. (1990). Das Sublinguale Speicheldrüsengranulom als haltungsbedingte Erkrankung bei einem Timneh-Graupapagei [Sublingual salivary gland granuloma as a husbandry-induced disease in an African grey parrot]. *Tierärztliche Praxis*, 18(3), 267–272 (in German).
- Hoppes, S. M., & Shivaprasad, H. L. (2020). Update on avian bomavirus and proventricular dilatation disease: Diagnostics, pathology, prevalence, and control. *Veterinary Clinics of North America: Exotic Animal Practice*, 23(2), 337–351.
- Iji, P. A., Saki, A., & Tivey, D. R. (2001). Body and intestinal growth of broiler chickens on a commercial starter diet. I. Intestinal weight and mucosal development. *British Poultry Science*, 42, 505–513.
- Kachave, C. D., Bhosle, N. S., Mamde, C. S., & Lambate, S. B. (2009). Histological observations on small intestine in broiler and layer of poultry birds. *Royal Veterinary Journal of India*, 5(1–2), 5–9.
- Kadhim, A. B., Dali, E. I., Sharoot, H. A., & Abdul-Rida, M. A.-H. (2018). Histo-morphological study of duodenum of goose (*Anser anser*). *Al-Qadisiyah Journal of Veterinary Medicine Sciences*, 17(2), 43–48.
- Khaleel, I. M., & Atia, G. D. (2017). Morphological and histochemical study of small intestine in indigenous ducks (*Anas platyrhynchos*). *IOSR Journal of Agriculture and Veterinary Science*, 10(7), 19–27.
- Lilbum, M. S., & Loeffler, S. (2015). Early intestinal growth and development in poultry. *Poultry Science*, 94(7), 1569–1576.
- Liu, E. H., & Oberg, K. (2010). The history and development of the gastroenteropancreatic endocrine axis. *Endocrinology and Metabolism Clinics of North America*, 39(4), 697–711.
- Matsumoto, F. S., de Carvalho, A. F., Francioli, A. L. R., Favaron, P. O., Miglino, M. A., & Ambrósio, C. E. (2009). Topografia e morfologia das vísceras do periquito-australiano (*Melopsittacus undulatus* Shaw, 1805) [Topography and visceral morphology of the budgerigar (*Melopsittacus undulatus* Shaw, 1805)]. *Ciência Animal Brasileira*, 10(4), 1263–1270 (in Portuguese).
- Pekmezci, D., Yetismis, G., Esin, C., Duzlu, O., Colak, Z. N., Inci, A., Pekmezci, G. Z., & Yildirim, A. (2020). Occurrence and molecular identification of zoo-

- notic microsporidia in pet budgerigars (*Melopsittacus undulatus*) in Turkey. *Medical Mycology*, 59(6), 585–591.
- Ravindran, V., & Abdollahi, M. R. (2021). Nutrition and digestive physiology of the broiler chick: State of the art and outlook. *Animals*, 11(10), 2795.
- Rodrigues, M. N., Abreu, J. A. P., Tivane, C., Wagner, P. G., Campos, D. B., Guerra, R. R., Rici, R. E. G., & Miglino, M. A. (2012). Microscopical study of the digestive tract of Blue and Yellow macaws. In: Méndez-Vilas, A. (Ed.). *Current microscopy contributions to advances in science and technology*. Pp. 414–421.
- Rossi, G., Dahlhausen, R. D., Galosi, L., & Orosz, S. E. (2018). Avian ganglioneuritis in clinical practice. *Veterinary Clinics of North America: Exotic Animal Practice*, 21(1), 33–67.
- Sell, J. L., Angel, C. R., Piquer, F. J., Mallarino, E. G., & Al-Batshan, H. A. (1991). Developmental patterns of selected characteristics of the gastrointestinal tract of young turkeys. *Poultry Science*, 70, 1200–1205.
- Tang, D., Li, Z., Mahmood, T., Liu, D., Hu, Y., & Guo, Y. (2020). The association between microbial community and ileal gene expression on intestinal wall thickness alterations in chickens. *Poultry Science*, 99(4), 1847–1861.
- Tsai, S. S., Park, J. H., Hirai, K., & Itakura, C. (1992). Catarrhal proventriculitis associated with a filamentous organism in pet birds. *Japanese Journal of Veterinary Research*, 40(4), 143–148.
- Uni, Z., Noy, Y., & Sklan, D. (1995). Post hatch changes in morphology and function of the small intestines in heavy and light strain chicks. *Poultry Science*, 74, 1622–1629.
- Walthall, K., Cappon, G. D., Hurr, M. E., & Zoetis, T. (2005). Postnatal development of the gastrointestinal system: A species comparison. *Birth Defects Research Part B Developmental and Reproductive Toxicology*, 74(2), 132–156.
- Watkins, E., Butler, P., & Kenyon, B. (2004). Posthatch growth of the digestive system in wild and domesticated ducks. *British Poultry Science*, 45, 331–341.
- Wickermann, S., & Krautwald-Junghans, M. E. (2021). Beurteilung der Haltungsbedingungen von Wellensittichen (*Melopsittacus undulatus*) und Nymphensittichen (*Nymphicus hollandicus*) in Deutschland [Evaluation of housing conditions of budgerigars (*Melopsittacus undulatus*) and cockatiels (*Nymphicus hollandicus*) in Germany]. *Tierarztl Prax Ausg K Kleintiere Heimtiere*, 49(6), 425–435 (in German).
- Wildmann, A. K., Cushing, A. C., Pfisterer, B. R., & Sula, M. J. M. (2022). Retrospective review of morbidity and mortality in a population of captive budgerigars (*Melopsittacus undulatus*). *Journal of Zoo and Wildlife Medicine*, 53(2), 433–441.
- Williams, T., & Athrey, G. (2020). Cloacal swabs are unreliable sources for estimating lower gastro-intestinal tract microbiota membership and structure in broiler chickens. *Microorganisms*, 8(5), 718.
- Woods, J. M., Eyer, A., & Miller, L. J. (2022). Bird welfare in zoos and aquariums: General insights across industries. *Journal of Zoological and Botanical Gardens*, 3(2), 198–222.
- Yetismis, G., Yildirim, A., Pekmezci, D., Duzlu, O., Ciloglu, A., Onder, Z., Simsek, E., Ercan, N., Pekmezci, G. Z., & Inci, A. (2022). First report and genotyping of *Dientamoeba fragilis* in pet budgerigars (*Melopsittacus undulatus*), with zoonotic importance. *Zoonoses and Public Health*, 69(5), 572–578.
- Yovchev, D., Dimitrov, D., & Penchev, G. (2013). Age weight and morphometrical parameters of the bronze turkey's (*Meleagris meleagris gallopavo*) intestines. *Bulgarian Journal of Agricultural Science*, 19(3), 611–614.
- Zadravec, M., Račnik, J., Slavec, B., Ballmann, M. Z., Kaján, G. L., Doszpoly, A., Zorman-Rojs, O., Marhold, C., & Harrach, B. (2022). Novel adenoviruses from captive psittacine birds in Slovenia. *Comparative Immunology, Microbiology and Infectious Diseases*, 90–91, 101902.