



Anatomical distribution of celiac artery with histochemical investigation to the proventriculus of barn owl (*Tyto alba*)

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Abstract

The present investigation was performed to transpire the celiac artery distribution, histological, and histochemical characteristics of the proventriculus in eight adult barn owls (*Tyto alba*) of both sexes. Six birds were subjected to anatomical investigation of the celiac artery distribution and two owls were used for routine histomorphological techniques. The proventricular length, width, and lumen diameter were measured at 14.18 ± 0.08 , 6.46 ± 0.17 and 1.46 ± 0.14 mm, respectively. The celiac artery in barn owl gave off six collateral arteries before its division into right and left branches. The arteria hepatica dextra does not originate from the right celiac division. Unlike other birds, there were left dorsal and left ventral gastric arteries. Histologically, the proventricular wall consisted of main four tunics. The lining epithelium is simple columnar with plicae and sulci. The muscularis mucosa is absent. The submucosal gastric glands were in two rows in the cranial proventricular portion while were arranged in one parallel row in the middle and caudal portions with pear-shaped, oval to round tubuloalveolar lobules. The mucosal folds, tubular mucosal glands, tubuloalveolar lobules, and their mucus secretion in the collecting ducts were positively reacted to PAS and alcian blue stains. The interlobular collagen fibers, elastic fibers, and reticular network were intensely reacted to Masson's trichrome, Orcein, and Gomori's reticulin stains, respectively. These anatomical and histomorphological features of the barn owl proventriculus were aimed to provide recent data comparable with most species of birds and the presence of diversity that might be attributed to their feeding demeanor.

Keywords Celiac artery · Histochemistry · Proventriculus · Barn owl

Introduction

The barn owl (*Tyto alba*) commonly known as the Common Barn Owl, is from the family Tytonidae that found almost all over the world and characterized by its distinct rounded head with a heart-shaped facial disc, white to brown plumage, medium-sized, measuring 290–440 mm from head to toes and variable body weight ranging from 187 to 700 g. They are strictly nocturnal with auditory adaptations to help them locate prey in complete darkness (Bruce 1999). The global average lifespan of a barn owl is approximately 21 months with the average lifespan of barn owls in the UK being 4 years (Robinson 2017). Females can be differentiated from

their male counterparts by their larger size, darker color, and presence of flecking under their wings (Taylor 1993).

In birds, the single organs such as proventriculus, gizzard, liver, spleen, pancreas, and intestine has been reported to receive a celiac arterial ramification, mainly arising from two celiac divisions, the right and left (Dursun 2002). The former celiac division was larger than the latter one (Getty 1975). On contrary, the celiac anatomical reports by (Aycan and Duzler 2000; Maher 2019) in eagle owls and fowl and (Chiasson 1964) in pigeons, revealed different celiac branches without its bifurcation. Unlike the reports of (Aslan and Takci 1998; Kurtul 2002; Kurtul and Hazirolu 2002) who stated celiac bifurcation after giving esophageal branches in chickens, ducks, geese, and pigeons.

Recently, there is an anatomical interest in celiac distribution and histological features of proventriculus for domestic and wild avian species that added details in the morphology such as reported previously in eagle owl (Aycan and Duzler 2000), red falcon (Haligur and Duzler 2010), goose (Ragab et al. 2013), cattle egret (Khalifa 2014), chicken (Rezk and

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El-Bably 2014), rock pigeon and Egyptian laughing dove (Madkour and Mohamed 2019), common starling (Sayrafi and Aghagolzadeh 2020), sparrow hawk (Can et al. 2021) and hooded crow (Abdel Maksoud et al. 2022), without any referring data on barn owl. Therefore, in addition to histochemically identifying the barn owl proventriculus, the current study intends to provide anatomical details about the origin, course, and distribution of the celiac artery to the previous literature.

Materials and methods

The anatomical studies

The present investigation was conducted on a total number of eight barn owls of both sexes, which were obtained from a pet shop located in Giza governorate with a weight range of 650–700 g. The birds were euthanized then slaughtered to completely evacuate the whole blood vessels which were irrigated with 0.9% physiological saline to clean the vessels. To visualize the celiac artery's origin, course, and distribution, a red-colored latex with Rotring® drawing ink (Zeichentusche), was inoculated into the arterial side through the heart apex of six owls and then immersed in 10% formalin solution for 3 days to be well fixed. The specimens were subjected to examination through anatomical dissection. The present work has been approved by the institutional animal care and use committee (IACUC) of Cairo University allocated with IACUC number of (VET CU 01122022535). All macroscopic anatomical illustrations were recorded and photographed using a digital photo camera Nikon Coolpix L310 14.1 Megapixels. The nomenclature used in this study was adopted according to Nomina Anatomica Avium (NAA) used by (Baumel et al. 1993), as well as those used by previous literature.

The histological and histochemical studies

For histological examination, two barn owls were used (one male and one female). Following euthanasia, the birds were irrigated through the left ventricle by physiological saline of 0.9% followed by a buffered formalin solution of 10%. Specimens from proventriculus were obtained and trimmed then preserved in a buffered formalin solution of 10%. The trimmed samples were dehydrated in ascending grades of ethanol, cleared using xylene, and embedded in Paraffin for preparing blocks. The blocks were sectioned using a rotary microtome to obtain 4–5 µm thick sections. In addition to Hematoxylin and Eosin (H&E stain), other special histochemical stains were used including; Periodic Acid Schiff (PAS) for demonstration of neutral mucopolysaccharides, Alcian Blue (AB) stain for detection of acid

mucopolysaccharides, Masson's trichrome stain for collagen and smooth muscle fibers, Orcein stain for detection of elastic fibers and Gomori's reticulin stain for detection of reticular fibers. The used histological techniques and stains were applied as outlined by Suvarna et al. (2019).

The morphometric measurements

A digital caliper was used to measure each bird's proventriculus in millimeters according to its gross morphology and illustrated in bar charts (Fig. 10/A). The proventriculus layers and their junctions' histomorphometric measures in microns were also obtained using Image J software (<http://Fiji.sc/Fiji>).

The statistical analysis

The mean value \pm standard error (SE) was analyzed using IBM SPSS statistics. A significant difference was detected when $p < 0.05$. Sections stained with H&E stain were used for the histomorphometric study. Approximately 10 tubular cross sections from each part were measured by low power lens (X 4). A computerized microscopic image analyzer attached to a full HD microscopic camera (Leica Microsystems, Germany) was used to determine the histomorphometric parameters. The data were tested first for normal distribution using the Normality test. Normally distributed data were compared with ANOVA (One-Way Analysis of Variance). Significant differences were determined by Duncan's Multiple Range Test. The data sets, that had not fulfilled the assumption of normal distribution, were analyzed using the Kruskal–Wallis One Way Analysis of

Variance on Ranks. Significant differences were determined by Dunn's Test. All statistical analyses were performed by SigmaStat (Jandel scientific software V3.1).

Results

The anatomical and morphometric studies

The celiac artery (Fig. 1/2) of the barn owl was emitted from the aorta (Fig. 1/1) at the level between the 5th rib (Fig. 1/f) dorsally and in front to proventriculus ventrally (Fig. 1/L). The celiac artery was observed to give off collateral branches after its emission from the aorta by an approximate distance of 1 cm then terminated by dividing into a left celiac branch (Fig. 2A/9) and a right celiac branch (Fig. 2A/8). The collateral branches of the celiac artery were six in number; esophageal artery, dorsal proventricular artery, dorsal gastric artery, splenic arteries, right hepatic artery, and duodenojejunal artery.

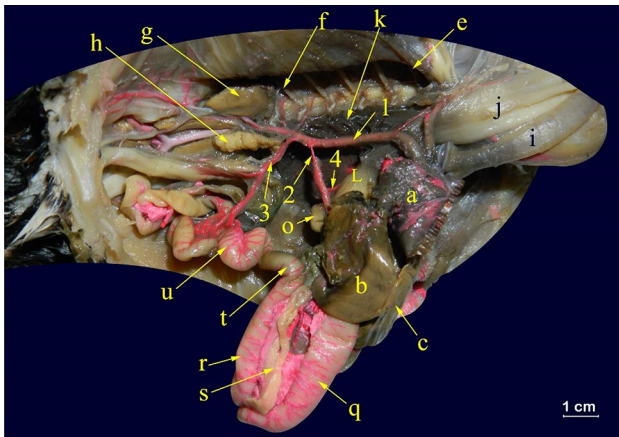


Fig. 1 Photograph showing the right side of thoracic & abdominal organs with celiac artery in Barn Owl. Gross anatomical legends of figure: **a** Heart, **b** Right hepatic lobe, **c** Left hepatic lobe, **d** Gall bladder, **e** First rib, **f** 5th rib, **g** Kidney, **h** Ovary, **i** Trachea, **j** Esophagus, **k** Left lung, **l** Proventriculus, **m** Isthmus gaster, **n** Gizzard, **o** Spleen, **p** Esophago-proventricular junction, **q** Descending duodenum, **r** Ascending duodenum, **s** Pancreas, **t** Duodenojejunal flexure, **u** Jejunum coils

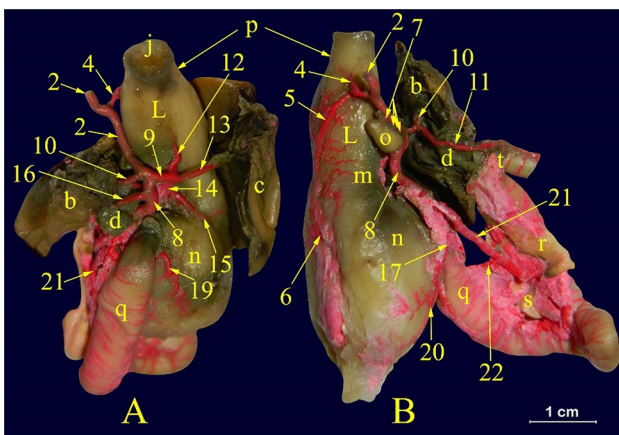


Fig. 2 Photograph showing ventral (**A**) & dorsolateral (**B**) view of Barn Owl single organs with celiac artery distribution. 1. Aorta. 2. Celiac artery. 3. Cranial mesenteric artery. 4. Esophageal artery. 5. Dorsal proventricular artery. 6. Dorsal gastric artery. 7. Splenic arteries. 8. Right branch of celiac artery. 9. Left branch of celiac artery. 10. Right hepatic artery. 11. Duodenojejunal artery. 12. Ventral proventricular artery. 13. Left hepatic artery. 14. Left gastric artery. 15. Left dorsal gastric artery. 16. Artery of gall bladder. 17. Gastroduodenal artery. 18. Duodenal branch of 17. 19. Left ventral gastric artery. 20. Ventral gastric artery. 21. Pancreaticoduodenal artery. 22. Duodenal & pancreatic branches of 21

1. **Esophageal artery** (*A. esophagealis*) (Fig. 2/4) is very short in barn owls and formed by a common trunk with the dorsal proventricular artery (Fig. 2B/5) in all examined specimens, extending in a craniodorsal direction,

and divided into 2–3 small twigs which distributed dorsally toward the esophagus.

2. **Dorsal proventricular artery** (*A. proventricularis dorsalis*) (Fig. 2B/5) originated with the esophageal artery by a common stem and was directed toward the dorsal aspect of the proventriculus, crossing the isthmus gaster (Fig. 2B/m) till reaching the ventriculus (Fig. 2/n). Throughout its course, the dorsal proventricular artery branched off into numerous small branches toward the right and left sides of the proventriculus.
3. **Dorsal gastric artery** (*A. gastrica dorsalis*) (Fig. 2B/6) was the direct continuation of the dorsal proventricular artery which was observed to distribute on the dorsal border of the ventriculus, throwing off many little twigs along its path.
4. **Splenic arteries** (*Aa. lienales*) (Fig. 2B/7) originated from the right aspect of the celiac artery before its division into the right and left branches. The splenic arteries were three to four branches distributed directly to the splenic parenchyma.
5. **Right hepatic artery** (*A. hepatica dextra*) (Fig. 2/10) arises by a common stem with the duodenojejunal artery (Fig. 2B/11) from the celiac artery at the level of splenic base and just before splitting of the celiac artery into ramus dexter and ramus sinister to end by sinking into the lobus hepaticus dexter (Fig. 2/b).
6. **Duodenojejunal artery** (*A. duodenojejunalis*) (Fig. 2B/11), was long originated from the celiac artery by a common stem with the right hepatic artery and upon reaching the right hepatic lobe, leaving the right hepatic artery in a right angle crossing the gall bladder (Fig. 2/d) and duodenal lobe to attach the terminal part of ascending duodenum to distribute in the duodenojejunal flexure (Fig. 2B/t).

The celiac trunk, after emitting the right hepatic artery, has been divided into two terminal arteries, the smaller is the left celiac branch (*ramus sinister arteriae celiacae*) (Fig. 2A/9), and the larger is the right celiac branch (*ramus dexter arteriae celiacae*) (Fig. 2A/8). The latter considered the direct continuation of the main celiac trunk:

A. Left branch of celiac artery (*Ramus sinister arteriae celiacae*) (Fig. 2A/9), was found to be extended cranio-ventral following its origin, and consequentially, ventral to the level of the proventriculus-gizzard junction. It appeared to be trifurcated at one point into three main arteries; the ventral proventricular artery, the left hepatic artery, and the left gastric artery.

1. **Ventral proventricular artery** (*A. proventricularis ventralis*) (Figs. 2–3/12), originated from the left celiac branch as 2–3 small branches, directed toward the ven-

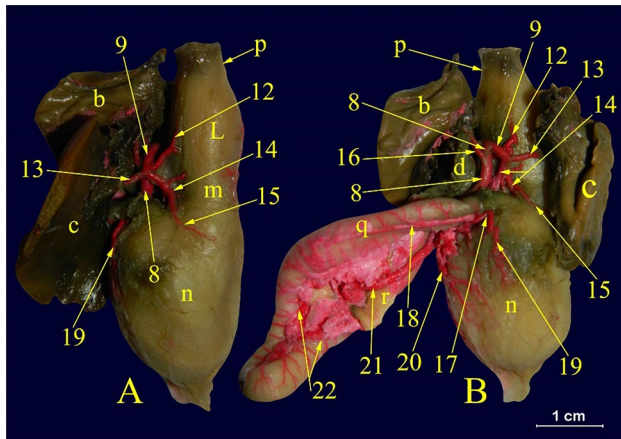


Fig. 3 Photograph showing ventro-lateral (A) & ventral (B) view of Barn Owl single organs with celiac artery distribution. 1. Aorta. 2. Celiac artery. 3. Cranial mesenteric artery. 4. Esophageal artery. 5. Dorsal proventricular artery. 6. Dorsal gastric artery. 7. Splenic arteries. 8. Right branch of celiac artery. 9. Left branch of celiac artery. 10. Right hepatic artery. 11. Duodenojejunal artery. 12. Ventral proventricular artery. 13. Left hepatic artery. 14. Left gastric artery. 15. Left dorsal gastric artery. 16. Artery of gall bladder. 17. Gastroduodenal artery. 18. Duodenal branch of 17. 19. Left ventral gastric artery. 20. Ventral gastric artery. 21. Pancreaticoduodenal artery. 22. Duodenal & pancreatic branches of 21

tral aspect of the proventriculus and isthmus gaster to terminate and ramify along their ventral borders.

2. **Left hepatic artery** (*A. hepatica sinistra*) (Figs. 2A–3/13) was greater than the right one, arising from the left celiac branch at the ventro-lateral region of the gizzard and continuing to gain entry to the left hepatic lobe (Figs. 2A–3/c) without giving off any extrahepatic branches.
3. **Left gastric artery** (*A. gastrica sinistri*) (Figs. 2A–3/14), has been regarded as the celiac artery's left branch's straight continuation, directed toward the isthmus gaster to branch off into 3–4 fine twigs at the junction between proventriculus and gizzard then continued to the dorsal left portion of the muscular stomach as left dorsal gastric artery (*arteria gastrica sinistri dorsalis*) (Figs. 2A–3/15).
- B. **Right branch of celiac artery** (*Ramus dexter arteriae celiacae*) (Fig. 2A/8), running caudoventrally and on the right aspect of the proventriculus to follow a straight course beginning from the isthmus gaster to the junction between the descending and ascending duodenum. Through its course, this artery branched off the artery of the gall bladder, the gastroduodenal artery, and the ventral gastric artery and continues as the pancreaticoduodenal artery.
1. **Artery of gall bladder** (*A. vesicae biliaris*) (Figs. 2A–3B/16) is the first artery that originated from the right celiac branch near the bifurcation of the celiac trunk and

at a level distal to and parallel to the right hepatic artery (Fig. 2/10), directing toward and distributed in the gall bladder wall.

2. **Gastroduodenal artery** (*A. gastroduodenalis*) (Figs. 2B–3B/17) is the second branch that originated from the right celiac branch contradictory to the right side of the pylorus then continued for a short distance under cover of descending duodenum to split into a duodenal branch (*ramus duodenalis*), distributed along the descending duodenum (Fig. 3B/q) and left ventral gastric artery (*arteria gastrica sinistri ventralis*) (Fig. 3/19) distributed to the pylorus and craniodorsal tenuis muscle.
3. **Ventral gastric artery** (*A. gastrica ventralis*) (Fig. 2B/20) is the third branch that originated from the right celiac branch at the ventral midline of the gizzard and right to the duodenal loop then continued caudoventrally to irrigate the ventral border of the muscular stomach.
4. **Pancreaticoduodenal artery** (*A. pancreaticoduodenalis*) (Fig. 2B/21) is regarded as the right celiac branch's direct continuation with the same diameter, passing through the pancreatic parenchyma (Fig. 2B/s) till reaching the duodenal flexure to be ramified along its course on each side to give off duodenal and pancreatic branches (Fig. 3B/22).

The histological and histochemical studies

The proventriculus of the barn owl, which was investigated in histological sections, was found to owing a spindle-shaped tube with four different layers that organized from inside to outside as the following; mucosal tunic, submucosal tunic, muscular tunic, and serosal tunic (Fig. 4a–c). The proventricular length, width, and lumen diameter were measured at 14.18 ± 0.08 , 6.46 ± 0.17 and 1.46 ± 0.14 mm, respectively (Fig. 10). The mucosal layer was appeared in outline, carrying numerous long proventricular folds (plicae) (Fig. 4a/black arrow) which separated by sulci (Fig. 4a/red arrow) with different depths. The plicae constituting the mucosal lamina epithelialis which was lined by simple tall columnar cells with nuclei situated at its base (Fig. 5b). The apical portion of the plicae was found strongly reacted to periodic acid Schiff (Fig. 6a–b) and alcian blue stains (Fig. 7a–c). The lamina propria was the underlying mucosal structure containing numerous simple tubular glands (Fig. 5b–d). The lamina muscularis mucosa was diminished along the course of the proventricular wall except at the isthmus gaster or at the proventriculo-gizzard junction (Fig. 8a) which separates lamina propria from the submucosal tunic.

The submucosa is made up of the main constituent submucosal (gastric) glands that are found of tubuloalveolar type with primary and secondary ducts and representing

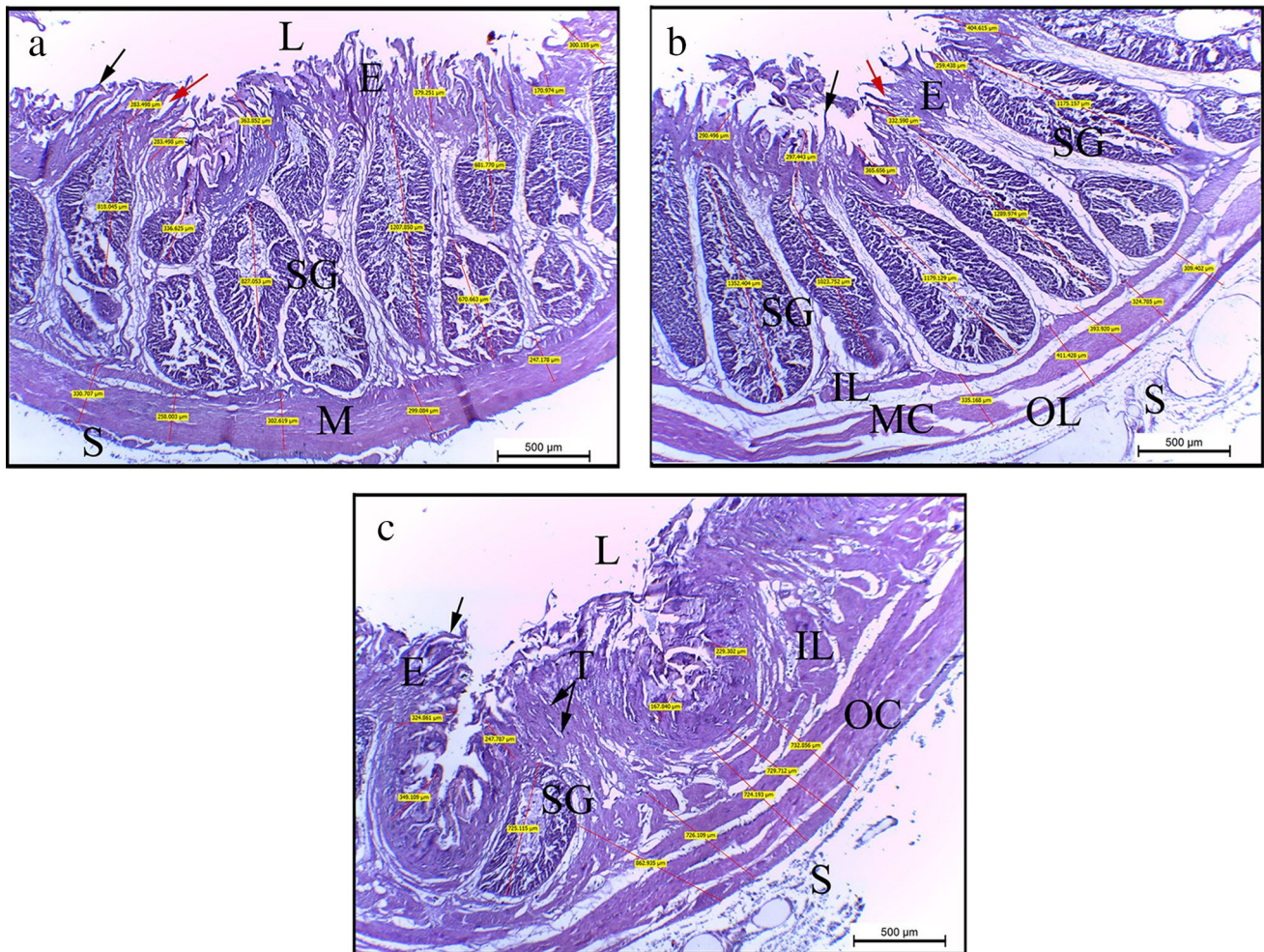


Fig. 4 **a** Photomicrograph of cross section in the cranial proventricular portion of barn owl showing: epithelium (E) protruded toward the lumen (L) forming plicae (black arrow) and sulci (red arrow) of different heights. The submucosal gastric glands (SG) constituting the greatest part of the wall and arranged in two rows with wide collecting duct opening into the lumen and of tubuloalveolar type of lobules that surrounded by connective tissue and rested on thin inner longitudinal and thick outer circular muscular layers (M) which enclosed by a thin serosa (S). H&E stain: 40X. **b** Photomicrograph of cross section in the middle proventricular portion of barn owl showing: epithelium (E) protruded toward the lumen forming plicae (black arrow) and sulci (red arrow) of different heights. The submucosal gastric glands (SG) constituting the greatest part of the wall and arranged in

the greatest portion of the proventricular wall. These glands were characteristically organized in large pear-shaped, round to oval or polymorphic lobules which were arranged in two rows only in the cranial part of the proventriculus (Fig. 4a/SG) while in the middle (Fig. 4b/SG) and caudal parts (Fig. 4c/SG) were found in a single parallel row. These glands were lined with cuboidal cells with acidophilic cytoplasm with spherical nuclei. Each lobule's terminal portion exposed the secondary duct. (Fig. 5c/SD), then pour into the

one single row with wide collecting duct opening into the lumen and of tubuloalveolar type of lobules that surrounded by connective tissue and rested on thin inner longitudinal (IL), thick middle circular (MC) and thin outer longitudinal (OL) muscular layers which enclosed by a thick serosa (S). H&E stain: 40X. **c** Photomicrograph of cross section in the middle proventricular portion of barn owl showing: epithelium (E) protruded toward the lumen (L) forming plicae (black arrow) of different heights. Note: the tubular mucosal glands (T) and only one submucosal gastric gland (SG) was appeared in the microscopic field that surrounded by connective tissue and rested on thin inner longitudinal (IL), thick outer circular (OL) muscular layers which enclosed by a thick serosa (S). H&E stain: 40X

collecting duct (Fig. 5a/CD), that delivered to the proventricular lumen.

The core of the gastric glands appeared condensed with rounded cells containing spherical nuclei which were more prevalent in the glandular peripheral portions than the central. There was a loose connective tissue constituted mainly by elastic and collagen fibers filling spaces between each gastric secretory lobule and strongly reacted positively to orcein (Fig. 9a, b) and Masson's trichrome (Fig. 6c, d) stains, respectively while the reticular fibers were concentrated

Fig. 5 Photomicrographs of cross section in the proventricular wall of barn owl showing: **a** the submucosal gastric glands (SG), separated by connective tissue (CT), forming greatest portion of the wall with a wide collecting duct (CD) opened into the lumen which lined by epithelium (E) that forming plicae (black arrow) and sulci (red arrow) of different heights. H&E stain: 100X. **b** the epithelium (E) with plicae (black arrow) and sulci (red arrow) lined by tall columnar cells with basal nuclei. Note: the tubular mucosal glands (MG). H&E stain: 400X. **c** the tubuloalveolar lobule; containing tubules (T) and alveoli (A). H&E stain: 400X. **d** the mucosal sulci (red arrow) and the simple and branched tubular mucosal glands (MG) in lamina propria. H&E stain: 400X

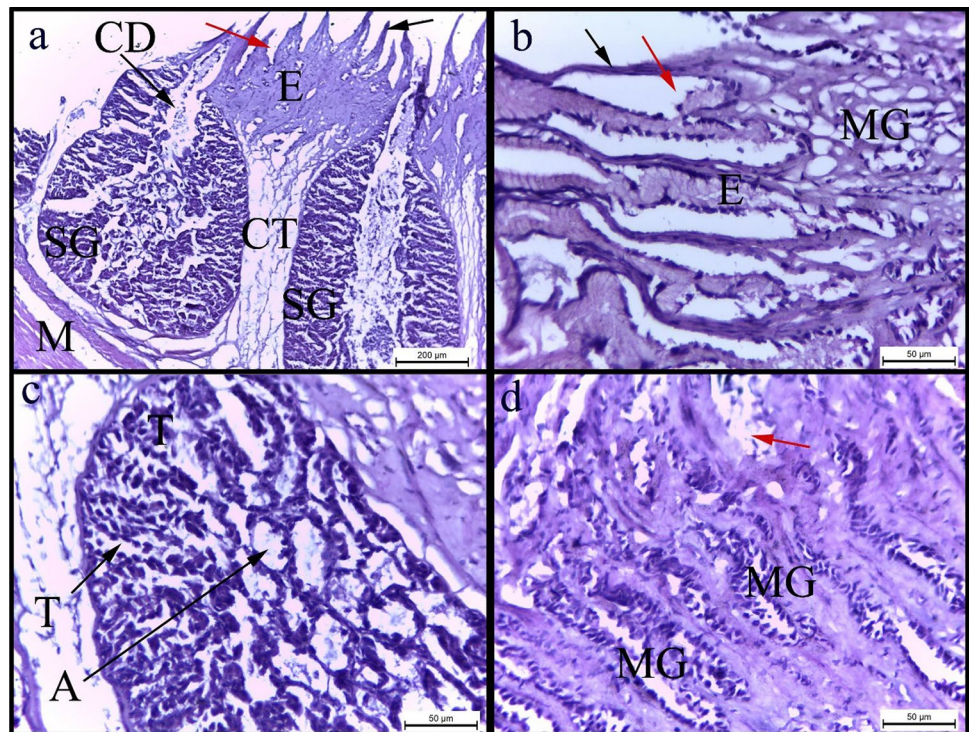
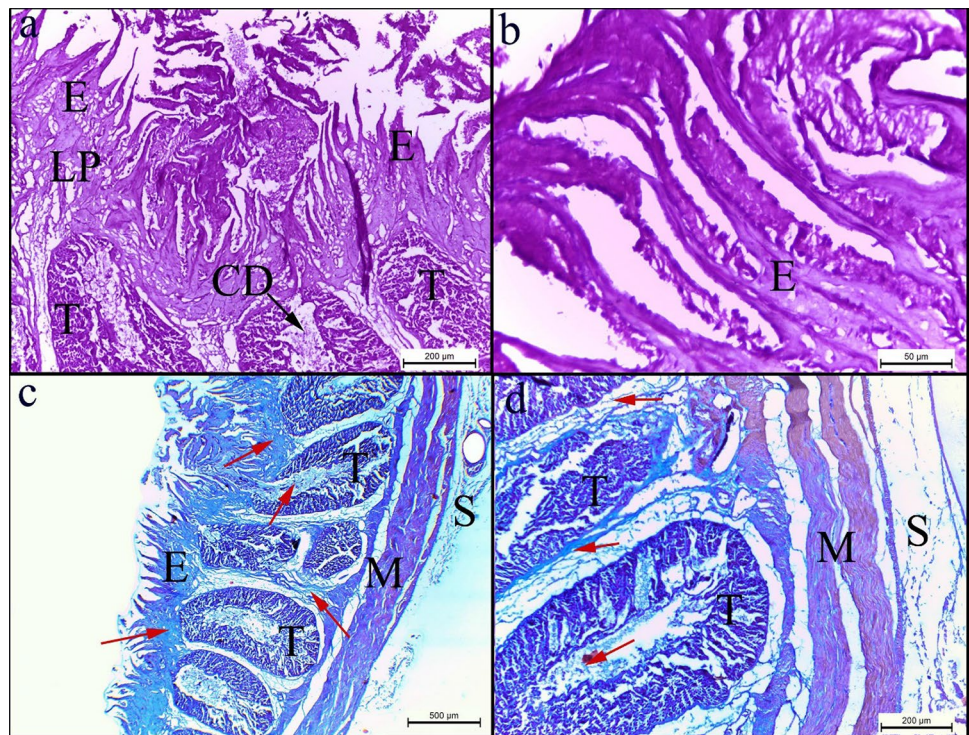


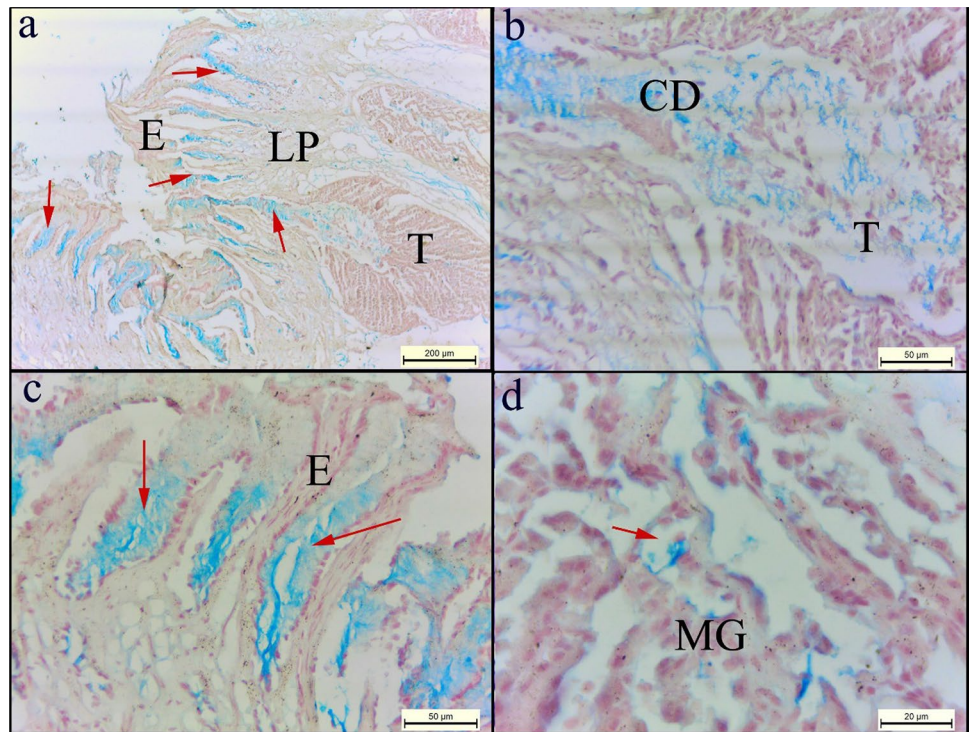
Fig. 6 Histochemical photomicrographs of the proventricular wall of barn owl showing: **a** and **b** the apical pieces of the surface epithelial cells (E), mucous secretion, the tubular glands and the lobular ducts (CD) of the deep glands reacted strongly positive with PAS. Bar **a** 100X; **b** 400X. **c** and **d** networks of collagen fibers surround the submucosal glandular lobules (T) and secretions of secretory ducts reacted to Masson's trichrome stain (red arrows). Bar **c** 40X; **d** 100X



surrounding the whole tubuloalveolar gastric lobules and distributed internally within the secretory unit forming a network which reacted positively to reticulin stain (Fig. 9c, d) and appeared as dark brown to black fibers.

The muscular tunic in barn owl proventriculus was very characteristic, organized in two layers; a thin inner longitudinal and thick outer circular in the cranial (Fig. 4a/M) and caudal (Fig. 4c/IL-OC) portions of the proventricular wall while this tunic was arranged in three layers in the

Fig. 7 Histochemical photomicrographs of the proventricular wall of barn owl showing: **a** and **c** Sulphomucins in lamina epithelialis (E) and deep proventricular glands (T) (red arrows) stained by alcian blue. **b** Sulphomucins in the collecting duct of the lobule (CD) and **c** in the tubular mucosal glands (MG) (red arrow) of lamina propria (LP). (Stain: Alcian blue; Bar: **a** 100X; Bar: **b**, **c** 400X; Bar: **d** 1000X)



middle portion; an inner longitudinal (Fig. 4b/IL), middle circular (Fig. 4b/MC) and a thinner outer longitudinal (Fig. 4b/OL) layer. Furthermore, the inner longitudinal layer was made up of thick muscle bundles at the proventriculo-gizzard junction (Fig. 8a/IL-OC) with a thin cuticle covering the mucosal surface (Fig. 8b/CU). The serosal tunic consisted of loose connective tissue (lamina subserosa) lined by lamina epithelialis serosa of mesothelial cells, blood vessels, and ganglionic cells but did not contain any muscle fibers (Fig. 4b/S).

All histomorphometric measurements were obtained and statistically analyzed, measuring the height of mucosal folds (plicae), the length of the submucosal gastric glandular lobules, and the thickness of the tunica muscularis in the cranial, middle and caudal proventricular wall as well as at the proventriculo-gizzard junction and illustrated in bar charts (Fig. 10B–D).

Discussion

The anatomical and morphometric studies

In many related avian species, including the rock pigeon and the Egyptian laughing dove, the proventriculus length measured 17.40 ± 0.59 mm for the pigeon and 12.74 ± 0.32 mm for the dove while the length of the proventriculo-gizzard junction measured 4.39 ± 0.16 mm for the pigeon and 3.05 ± 0.26 mm for the dove (Madkour and

Mohamed 2019). The present study revealed that the barn owl has a proventriculus length of 14.18 ± 0.08 mm, a width of 6.46 ± 0.17 mm, a lumen diameter of 1.46 ± 0.14 mm and a proventriculo-gizzard junction length of 3.16 ± 0.08 mm.

Our current investigation showed that the aorta gave rise to the barn owl's celiac artery at the 5th costa just at the mid-dorsal border of the proventriculus. This observation was similar to reports of (Malinovsky and Visnanska 1975) in domestic geese, (Kuru 1996) in chickens, (Aycan and Duzler 2000) in eagle owls, (Kurtul and Hazirolu 2002) in roosters, drakes, and pigeons, (Ari et al. 2010) in white turkeys, (Haligur and Duzler 2010) in red falcons, (Ragab et al. 2013) in geese, (Khalifa 2014) in cattle egrets, (Hassan and El-Sayed 2018) in hooded crows and (Can et al. 2021) in sparrow hawk.

The present study was in agreement with that recorded by (Haligur and Duzler 2010; Khalifa 2014; Alan et al. 2016; Noor 2017; Hassan and El-Sayed 2018; Can et al. 2021) that the celiac artery was described to terminate by dividing into right and left divisions. Contradictory to the above-mentioned records by Chiasson (1964) in pigeons and Aycan and Duzler (2000) in eagle owls who did not report such splitting to the celiac trunk. Alongside, the celiac artery was observed to be trifurcated in some experimental animals such as white rats (Maher and Reem 2018).

Previous reports by Aslan and Takci (1998) on geese, revealed that the ramus dexter and ramus sinister of the celiac artery had the same diameter. This result differed from

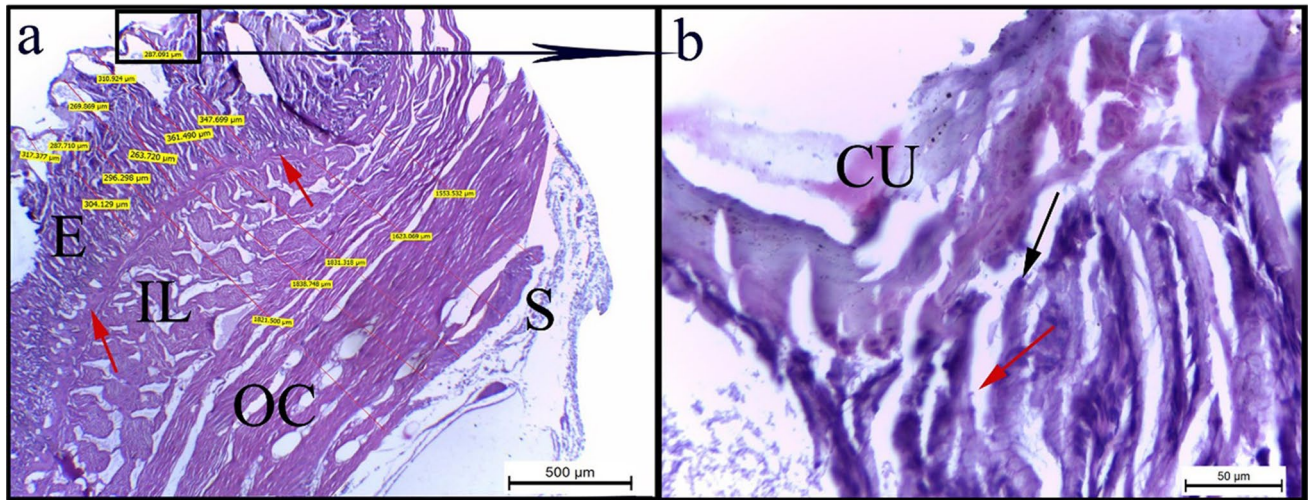


Fig. 8 Photomicrographs of cross section in the isthmus gaster (proventriculo-gizzard junction) of barn owl showing: **a** the four tunics of the isthmus gaster wall. Note: the appearance of lamina muscularis mucosa (red arrows) and thickening of the inner longitu-

dinal (IL) & outer circular (OC) muscular layers. H&E stain: 40X. **b** High magnification of the apical portion of mucosal folds showing a thin layer of cuticle (CU) covering the plicae (black arrow) & sulci (red arrow). H&E stain: 400X

our investigation in the present study in barn owls as well by Alan et al. (2016) in greater flamingos, Atalgin et al. (2012) in herons, and Ragab et al. (2013) in domestic geese who confirmed that the ramus dexter had a larger diameter and longer than the ramus sinister.

Our observations in barn owls were in accordance with (Haligur and Duzler 2010; Ragab et al. 2013; Alan et al. 2016; Can et al. 2021) who revealed that the dorsal

proventricular artery and the esophageal artery forming a common trunk that emitted from the celiac artery at its beginning. However, the esophageal artery was reported as the first branch originating from the celiac trunk by (Ayca and Duzler 2000; Ari et al. 2010; Rezk and El-Bably 2014) while other literature recorded that the dorsal proventricular artery was the first branch emitted (Kurtul and Haziroglu

Fig. 9 Histochemical photomicrographs of the proventricular wall of barn owl showing: **a** and **b** Orcein staining; black arrows: showing elastic fibers & collagen fibers (CF) around and within the tubuloalveolar lobule (T) of the deep proventricular glands that containing primary ducts (PD). Bar: 400X. **c** and **d** Gomori's reticulin staining; red arrows: showing reticular fibers around the tubuloalveolar lobule (T) while arrow heads: showing reticular network within the lobule. Bar: 400X

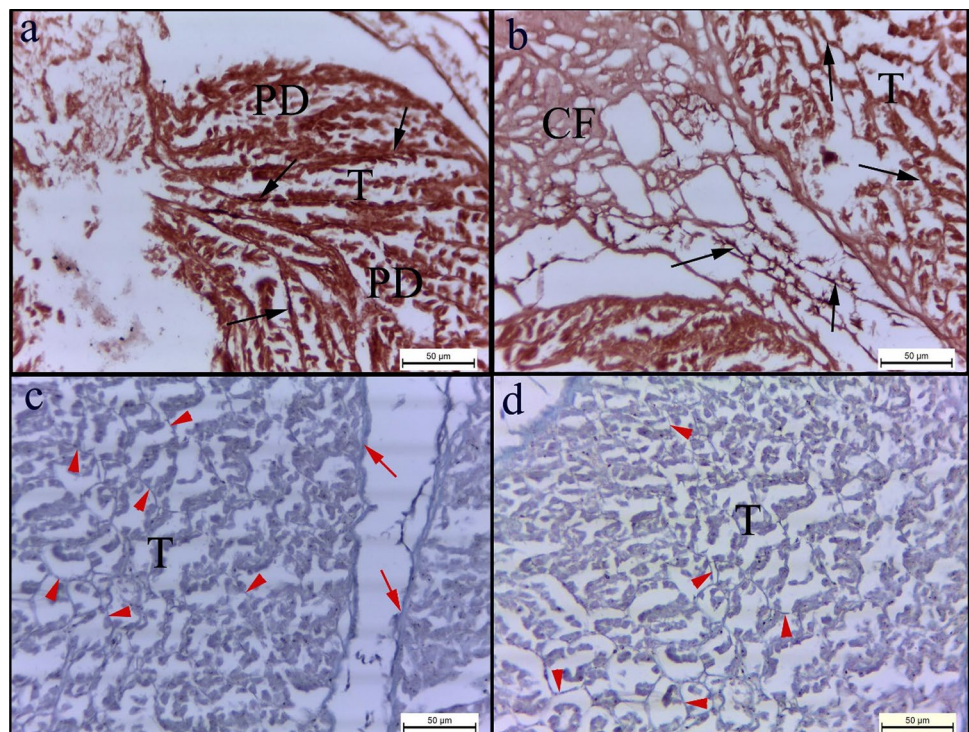
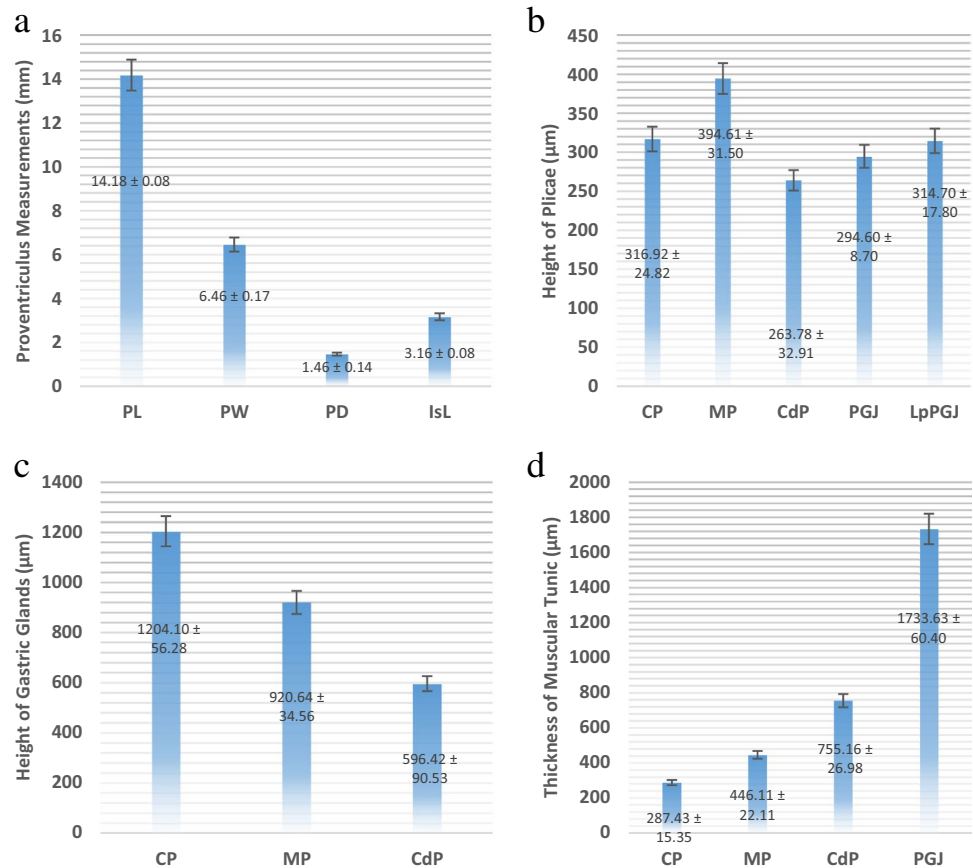


Fig. 10 Bar charts illustrating: **A** Proventriculus measurements, **B** Height of plicae, **C** Height of gastric gland lobules & **D** Thickness of muscular tunic, *PL* proventriculus length, *PW* proventriculus width, *PD* proventriculus diameter, *IsL* isthmus length, *CP* cranial proventriculus, *MP* middle proventriculus, *CdP* caudal proventriculus, *PGJ* proventriculo-gizzard junction, *LpPGJ* lamina propria at proventriculo-gizzard junction



2002) in roosters, ducks, and pigeons and (Hassan and El-Sayed 2018) in hooded crows.

Some reports by (Kuru 1996; Aslan and Takci 1998; Aycan and Duzler 2000; Rezk and El-Bably 2014) revealed that the splenic arteries originated from the ramus dexter. While other reports such as (Pinto et al. 1998; Cardoso et al. 2000; Dursun 2002) revealed that the splenic arteries originated from the ramus sinister. In the present study, the splenic arteries were ascertained to originate by 3–4 smaller twigs that originated directly from the main celiac trunk. This result of the current investigation was similar to the observations of (Khalifa 2014; Can et al. 2021).

In some avian species, the arteria hepatica dexter originated from the ramus dexter and the arteria hepatica sinistra from the ramus sinister (Ari et al. 2010; Rezk and El-Bably 2014; Alan et al. 2016). While in previous literature, (Haligur and Duzler 2010; Can et al. 2021) reported that the right hepatic artery emitted from the ramus sinister of the celiac artery. Unlike, Aycan and Duzler (2000) in the eagle owl where the right hepatic artery originated directly from the main celiac trunk. Furthermore, the current investigation revealed that the celiac artery, just before splitting, detached the right hepatic artery as a common trunk with the duodenojejunal artery.

Our results were similar to those of (Aycan and Duzler 2000) in eagle owl who reported that the celiac artery did not give off the right dorsal gastric artery, right ventral gastric artery, or ileocecal artery. Otherwise, in the present study, the continuation of the ramus sinister of the celiac artery had been detached off the left dorsal gastric artery while the gastroduodenal artery was detached off the left ventral gastric artery. A result that did not be reported by any of the previous literature.

The present observations were not similar to those found by (Baumel et al. 1993) in various avian species such as; (Aycan and Duzler 2000) in eagle owls; (Kuru 2010) in domestic fowls; (Duzler et al. 2011) in Japanese quail; (Vasconcelos et al. 2012) in ostrich; (Can et al. 2021) in sparrow hawk that the artery of gall bladder supplying the vesicae fellae with vascular sustenance, was found to branch from the right hepatic artery or by (Haligur and Duzler 2010) in red falcon who described the a. vesicae biliaris arose from the ramus sinister of the celiac artery. But it was ascertained to originate separately from the celiac artery's ramus dexter in the current investigation of the barn owl.

It was noticed in our study that the celiac artery's right branch directly continued as pancreaticoduodenal artery

like the observations of (Halıgür and Duzler 2010) in red falcon, (Kuru 2010) in chicken, and (Khalifa 2014) in cattle egrets where it runs in the mesentery connecting the ascending and descending parts of the duodenum to the flexura duodeni, giving off Rr. pancreatici and Rr. duodenales. While (Mahdy 2009) in the ostrich stated that the right celiac branch bifurcates into the right gastric and pancreaticoduodenal arteries.

The histological and histochemical studies

Concerning the barn owl proventricular histological examination, the sections indicated the presence of four structural tunics forming the proventricular wall; the mucosa, the submucosa, the muscularis, and the outermost serosa. This finding was similar to that reported by (El Nahla et al. 2011; Hussein and Rezk 2016) in cattle egrets, (Hassan and Moussa 2012) in ducks and pigeons, (Sayrafi and Aghagolzadeh 2020) in common starlings and (Saran and Meshram 2020) in guinea fowl. Unlike other authors who recorded the absence of the submucosal tunic as Zhu et al. (2013) in yellow-billed grosbeak and Zhu (2015) in black-tailed crane.

The proventricular mucosa of barn owls revealed numerous plicae (folds) and sulci lined by simple tall columnar cells which reacted positively to periodic acid Schiff stain (neutral mucopolysaccharide) and alcian blue stain (acidic mucopolysaccharides). The results were in accordance with Ahmed et al. (2011), Mosallam et al. (2016) on Japanese quail, Hamdi et al. (2013) on the black-winged kite, and Demirbağ et al. (2015) on sparrow hawk and crow and Hussein and Rezk (2016) on cattle egrets. While the lining epithelium of duck proventriculus was found to secrete only neutral mucopolysaccharides by (Shyla et al. 1992). The proventricular secretion of acid and neutral mucopolysaccharides from the surface mucosa, as illustrated by the present investigation, constitutes a strong mucosal barrier, providing mucosal surface support against enzymatic, chemical, and mechanical aberrations in addition to bacterial invasion (Hamdi et al. 2013).

Our investigation in barn owls was consistent with the reports of (Kadhim et al. 2011 and Sayrafi and Aghagolzadeh 2020) who confirmed that the surface epithelium, its mucosal tubular glands, and the collagen network surrounding the deep gastric glands were positively reacted with Masson's trichrome stain which indicated a distinction between the mucopolysaccharides secretion and the surrounding connective tissue.

The present study was in accordance with the results of Attia (2008) in quail, Abumandour (2013) in falcon, and Yovchev (2022) in wild bronze turkey, who reported that the muscular mucosal layer of the proventriculus wall was absent. While Catroxo et al. (1997) in red-capped cardinal birds and Abdel Maksoud et al. (2022) in hooded crow

confirmed the occurrence of the muscular mucosal layer separating between the lamina propria and submucosal layer.

As contrary to all previous authors except Eidaaroos et al. (2008) and Hussein and Rezk (2016) on cattle egrets who agreed with our observation that a thin cuticle was present, covering the terminal portion of the proventricular mucosal surface and at the beginning of the isthmus gaster. Another observation which not found in the present investigation but reported by many authors was the presence of the nodular and diffuse lymphatic tissues and intraepithelial lymphocytes underlying the mucosal folds that reflect the immunological response of the proventriculus (Salem and Abdel-Rahman 2000; Zaher et al. 2012; Abdel Maksoud et al. 2022).

The present study revealed that the major structural component of the proventricular wall was the well-developed submucosal (deep gastric) glands. The result was similar to Ogunkoya and Cook (2009) in three species of Australian passerines. While Abumandour (2014) in Eurasian Hobby and Al-Saffar and Al-Samawy (2015) in pigeons reported that the muscular tunic was the major structural and greatest portion of the proventricular wall.

Our current results in barn owls were in resonance with the results of Sayrafi and Aghagolzadeh (2020) in common starling and Abdel Maksoud et al. (2022) in hooded crow who revealed two types of glands in the proventriculus, a simple and branched tubular glands in the lamina propria, and submucosal (deep proventricular) glands which of tubuloalveolar type in the submucosa, but we added the deep gastric glands were arranged in two rows in the cranial part and only one single row in the middle and caudal proventricular parts showing a pear-shaped to rounded oval or polymorphic appearance. While Zhu et al. (2013) in the yellow-billed grosbeak and Udoumoh and Ikejiobi (2017) in African pied crow asserted that the proventricular glands were only of compound tubular type.

The present study agreed with that recorded by Selvan et al. (2008) in guinea fowl, Batah et al. (2012) in the coot bird, Al-Saffar and Al-Samawy (2015) in the mallard, and Abdel Maksoud et al. (2022) in hooded crow revealing only one location to the deep proventricular glands which was the submucosa. While others, Ogunkoya and Cook (2009) and Sayrafi and Aghagolzadeh (2020) recorded two places, within the muscular mucosal layer and lamina propria.

Concerning the histochemical examination of the proventricular wall, the present observations were in agreement with Zhu (2015) in black-tailed crane, Demirbağ et al. (2015), Udoumoh and Ikejiobi (2017) in African pied crow, Sayrafi and Aghagolzadeh (2020) in common starling and Abdel Maksoud et al. (2022) in crows that the surface epithelium, mucins, tubular and deep glands of the proventriculus were strongly reacted with periodic acid Schiff stain. While the alcian blue stain showed intense reaction with the lining epithelium, covering mucin, mucosal tubular glands,

and the collecting ducts of the tubuloalveolar lobules but weak reactions to the oxynticopeptic cells of the tubuloalveolar lobules.

The submucosal proventricular glands which are made up of tubuloalveolar lobules were enclosed by a connective tissue septum, constituted of collagen fibers, elastic fibers, and a reticular network that was proven by Masson's trichrome, orcein, and Gomori's reticulin stains, respectively. These findings were similar to the study conducted by Selvan et al. (2008) in guinea fowl, Das et al. (2017) in Kadaknath fowl, and Sayrafi and Aghagolzadeh (2020) in common starling.

In barn owls, the muscular tunic consisted of inner longitudinal and outer circular muscle layers. This result was also reported by (Rossi et al. 2005; Abumandour 2014; Al-Saffar and Al-Samawy 2015). But, other authors recorded that the two muscular layers were arranged as inner circular and outer longitudinal, (Kadhim et al. 2011) in red jungle fowl and (Abdel Maksoud et al. 2022) in hooded crow. On the other hand, the proventricular muscular tunic in birds was constituted of two layers as mentioned by the previous authors. However, the current investigation in barn owls revealed three muscular layers only in the middle proventricular portion which was supported by Banks (1992) in fowl, who recorded an inner longitudinal, middle circular, and an outer longitudinal layer of smooth muscle fibers. But, Denbow (2000) in parrots stated that the outer longitudinal layer was absent and the inner circular was present.

The barn owls' serosal tunic was constituted of loose connective tissue lined by serosal epithelium, blood vessels, and ganglionic cells. These results were similar to that reported by Rossi et al. (2005) in partridge, Ogunkoya and Cook (2009) in Australian passerines, and Sayrafi and Aghagolzadeh (2020) in common starling. But did not contain any muscle fibers which was asserted by Rossi et al.

Conclusion

The distribution of celiac artery in barn owls was found different from most species of birds. It gave six collateral arteries then terminated by division into right and left branches. the arteria hepatica dextra does not originate from the right celiac division. Unlike other birds, there were left dorsal and left ventral gastric arteries. Histologically, the lamina muscularis mucosa was absent along the course of the proventricular wall. The submucosal proventricular glands constitute the greatest portion of the wall and appeared as tubuloalveolar glandular lobules separated greatly from each other and lined with simple cuboidal oxynticopeptic cells and owing primary, secondary and wide collecting ducts that pour on the lumen. These anatomical and histological

differences of the barn owl proventriculus could explain its adaptation to different feeding behavior.

Author contributions MMA and SH: methodology; conceptualization; data curation; writing, reviewing; data analysis; editing and final revision.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no conflict of interest.

Ethical approval This work has been approved by the Institutional animal care and use committee (IACUC) with IACUC number of VET CU 01122022535.

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