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Gross Morphological Structure of Digestive System in Water Monitor Lizard *Varanus salvator* (Squamata: Varanidae)

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Abstract

Currently, the water monitor lizard (*Varanus salvator*) is recognized as an economic animal especially for the leather trade. Since the anatomical study of its digestive organs is essential for farming and feeding management, we conducted an anatomical study of the digestive organs of this species. This study aimed to describe the gross morphological structure of the digestive organ. This organ consisted of a slender tongue that was deeply bifid and retracted in a sheath, a short pharynx, a slender esophagus with a thick muscular walled tube a striated stomach that was largest in the curved part, a coiled small intestine without a caecum, a striated large intestine (the posterior part of which was connected to the coprodeal cloaca), a pyramidal liver with 3 lobes, a gallbladder embedded at the lower part of the middle liver lobe, and a yellowish pancreas. This study provided information about the gross morphological and internal surface structures of the digestive organs in *V. salvator* that could be used in the biological and veterinary sciences and other related studies.

Keywords: Digestive organs, gastrointestinal tract, gross anatomy, Varanidae, water monitor lizards

Introduction

The water monitor lizard (*Varanus salvator*) belongs to the order Squamata, family Varanidae [1], which can be found in wetland areas even in towns and cities, mainly near ponds and canals [2]. It is found primarily in Southeast Asia [2-4]. It is economically important, and millions are killed each year for their skin, meat, and fat [4,5]. The skin is used in the leather trade, the meat is eaten, and the fat is used in traditional medicine [6-8]. In Thailand, this species is on the protected species list, which can hinder research being conducted on it; therefore, this species has been little studied [9]. Another reason for the paucity of data available for this species is superstition regarding water monitors; some people believe that they are evil and bring bad luck, and are considered the lowest and dirtiest animal in Thailand [10].

Most of the reptilian digestive system is similar to that of other vertebrates, with some additional features [11,12]. The digestive organs are composed of an oral cavity, a pharynx, esophagus, stomach, small intestine, large intestine, cloaca, and accessory digestive glands [13]. The liver, gallbladder, and pancreas are the main accessory digestive organs.

To correct for the lack of basic knowledge of the species, a gross anatomical study of its digestive organs is essential for its farming and feeding management, and would provide the useful data for further physiological, pathological, and phylogenetic studies. Anatomical studies that investigate the structure of the digestive organs are particularly important in understanding the digestive processes of animals [14]. Therefore, the purpose of this study was to describe the gross anatomical structure of the digestive organs in water monitor lizard (*V. salvator*), which could provide a basic knowledge of its anatomy that could be useful in veterinary studies.

Materials and methods

Animal preparation

Two adult caught specimens (male and female) were obtained from Varanus Farm, Kasetsart University, Kamphaengsaen Campus, Nakhon Pathom Province, Thailand between June and August 2014. The animals were treated in accordance with the guidelines of the local ethics committee after permission was given by the Department of National Parks, Wildlife, and Plant Conservation, Ministry of Natural Resources and Environment (approval Nos. MNRE 0909.6/15779 and MNRE 0909.6/3154). The specimen's snout-vent length was about 81.25 ± 13.08 cm with average weight of 10.04 ± 2.26 kg. After one day of fasting, the animals were anesthetized with 5 mg/kg of Zoletil® 100 (tiletamine-zolazepam) that was injected intramuscularly (modified from [15]). Once the animals were in deep anesthesia, they were euthanized with 10 mg/kg of Nembutal® (sodium pentobarbital) that was injected intraperitoneally (modified from [14]). The animals were then fixed and examined.

Gross morphological study

The fixation process was performed in 3 steps. Firstly, the bodies were carefully dissected by making a longitudinal incision on one side of the lateral surface of the throat to find the carotid artery. Secondly, they were perfused with an embalming solution (modified from [16,17]) in the external carotid artery with 4 kg/cm^2 pressure using a diffusion pump. Finally, approximately 500 ml of embalming solution was injected into the peritoneal cavity (or until the tail is hardened) and the whole body was then preserved in a tank with 10 % formalin for 1 week.

The animals were then dissected by making a longitudinal incision on the midventral surface. Photographs of the digestive organs were taken while they were still in the body and after being taken out of the body. In addition, the gastrointestinal tract (GIT) was cut longitudinally to investigate the structure of the internal surface in both longitudinal folds and valves. The lengths and diameters of the digestive tracts of each animal were estimated using a measuring tape and a Vernier caliper to the nearest 0.05 mm.

Results

Gross morphology of the digestive organs

The morphology of the digestive organ was composed of an oral organ, a pharynx, esophagus, stomach, small intestine, large intestine, and accessory organs (liver, gallbladder, and pancreas).

The first component of the oral organ was comprised of the teeth, palate, and tongue (**Figure 1**). The tongue was about 15.95 cm in length, slender, deeply bifid, and retracted in a sheath. The pharynx was about 8.90 cm in length. The body cavity consists of the body fat (abdominal fat), peritoneum and digestive organs (from the esophagus to the intestine and major accessory organs; **Figures 2** and **3**). The total GIT length (measured from the anterior part of the esophagus to the posterior part of the intestine) was about 126.79 cm.

The esophagus connected the pharynx to the stomach, was slender, and was about 27.65 cm in length (measured from the anterior part to the posterior part of the esophagus) or about 21.81 % of the GIT length. This organ was quite thick, with a muscular walled tube divided into 3 parts: the anterior, middle, and posterior esophagus. The external (measured from top to bottom, or left to right, from the outside edges of the esophageal tube) and internal (measured from top to bottom, or left to right, from the inside hole of the esophageal tube) diameters of the esophagus were about 2.70 and 2.28 cm (anterior), 1.48 and 1.37 cm (middle), and 1.32 and 0.96 cm (posterior), respectively.

The stomach was striated, and was about 42.51 cm in length (measured from the anterior part to the posterior part of the stomach) or about 33.53 % of the GIT length. It was left-curved and slightly wider and longer than the esophagus. The stomach had 2 distinct regions, the fundus and the pylorus. The fundic region could be divided into the oral and aboral fundus. The lengths of the fundus and pylorus were about 27.25 or about 64.10 % of the stomach length and 15.26 cm or about 35.90 % of the stomach length, respectively. The external (measured from top to bottom, or left to right, from the outside edges of the gastric tube) and internal (measured from top to bottom, or left to right, from the inside hole of the gastric tube) diameters of the stomach were about 2.47 and 1.50 cm (oral fundus), 3.95 and 3.29 cm (aboral fundus), and 2.88 and 1.95 cm (pylorus), respectively.

The small intestine was a coiled tube that was about 62.50 cm in length or about 49.29 % of the GIT length. It was divided into anterior and posterior regions, but there was no external differentiation between them. At the first loop after the pylorus were the opening ends of the pancreatic and common bile ducts. The external (measured from top to bottom, or left to right, from the outside edges of the small intestinal tube) and internal (measured from top to bottom, or left to right, from the inside hole of the small intestinal tube) diameters of the small intestine were about 1.63 and 1.28 cm (anterior region) and 1.59 and 1.29 cm (posterior region), respectively. The transitional area between the small and large intestine was abrupt and the caecum was absent.

The large intestine was a straight tube that was about 17.50 cm in length or about 13.80 % of the GIT length and was shorter and wider than the small intestine. The external (measured from top to bottom, or left to right, from the outside edges at the widest part of the large intestinal tube) and internal (measured from top to bottom, or left to right, from the inside hole at the widest part of the large intestinal tube) diameters of the large intestine were about 2.17 and 2.15 cm, respectively.

The liver was roughly pyramidal in shape and divided into 3 lobes: a large middle lobe and smaller left and right lobes. The middle lobe was the largest about 14.55 cm in length and had the gallbladder embedded at the bottom. Additionally, the right lobe was the smallest about 9.54 cm in length and was drawn out into a long slender tailpiece. The gallbladder was a large membranous sac that was about 4.67 cm long and was embedded in the lower part of the middle lobe. The pancreas was a yellowish organ that was about 7.61 cm in length. It was spread out in the mesentery between the anterior small intestine and the pyloric stomach. A single pancreatic duct emerged from the edge of the pancreas and opened into the anterior small intestine near the openings of the common bile ducts from the liver and gallbladder.

Internal surface morphology of the GIT

The esophagus had a variable number of thick, longitudinal folds, with 14 folds in the anterior part (**Figure 4A**), 10 folds in the middle (**Figure 4B**), and 8 - 9 folds in the posterior part (**Figure 4C**). The transition between the esophagus and stomach was unclear because we could not locate the sphincter (**Figure 4D**).

The stomach had numerous thick, small folds (rugae) that ran in a zigzag manner parallel to each other. The oral fundic stomach was 57 - 63 thick, with small folds. The aboral fundic stomach had about 70 folds, and the pyloric stomach had 6 - 7 thick folds (**Figure 4E**). The stomach narrowed to a thick muscular sphincter, or pyloric valve (**Figure 4F**).

The small intestine also had numerous folds that ran in a zigzag manner parallel to each other. The small intestinal folds of the anterior region were larger than those of the posterior region (**Figures 4G,H**). The transition between the small and large intestine was clearly indicated by a valve (**Figure 4I**).

The large intestine had numerous longitudinal folds that zigzagged in some parts (**Figure 4J**). The posterior part of the large intestine was connected to the coprodeal cloaca, which included the coprodeum as a large sphincter (**Figure 4K**).

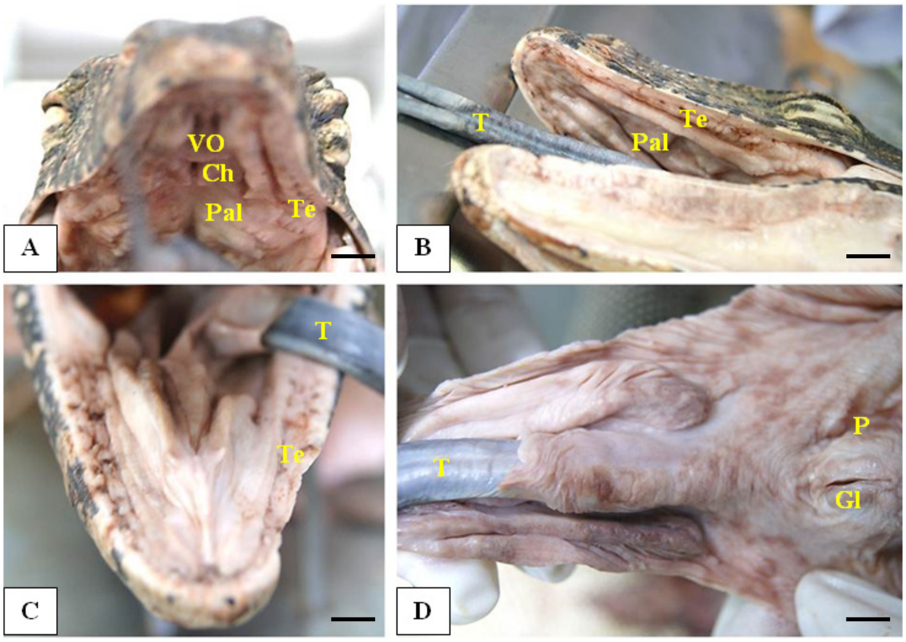

Figure 1 Oral organ of *Varanus salvator*. A, upper jaw showing the palate and teeth; B, lower jaw showing the teeth and tongue; C, lateral head showing the palate, teeth and tongue; D, lower jaw showing the tongue, glottis and pharynx. Opening from the vomeronasal organ (VO). Choana (Ch). Teeth (Te). Tongue (T). Palate (Pal). Glottis (Gl). Pharynx (P). Scale bars = 1 cm.

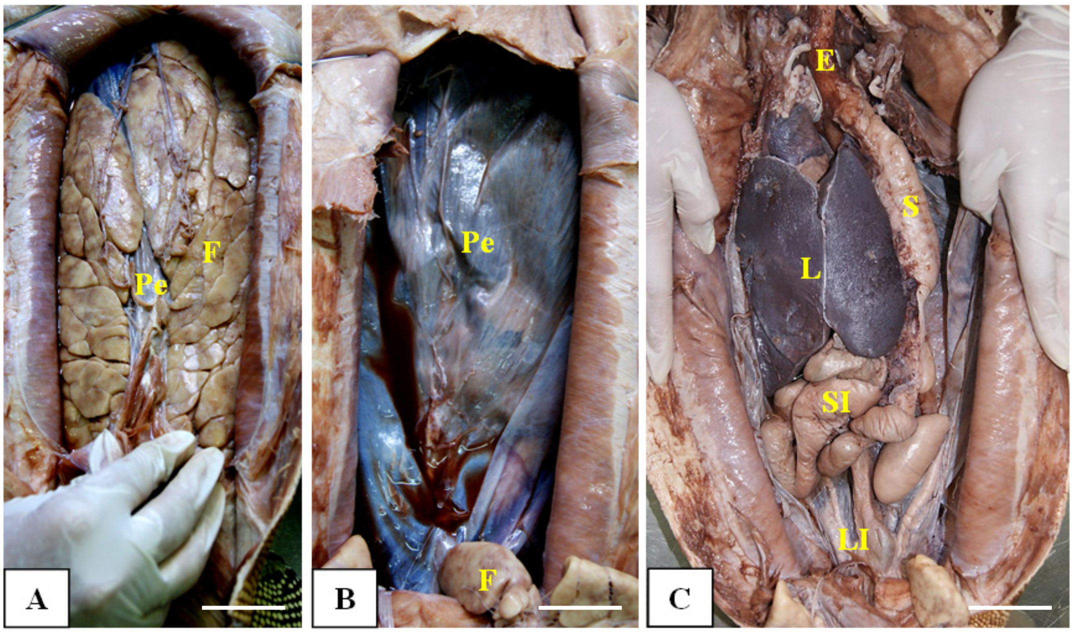

Figure 2 Gross digestive organs of *Varanus salvator* male. Fat body (F). Peritoneum (Pe). Esophagus (E). Stomach (S). Small intestine (SI). Large intestine (LI). Liver (L). Scale bars = 5 cm.

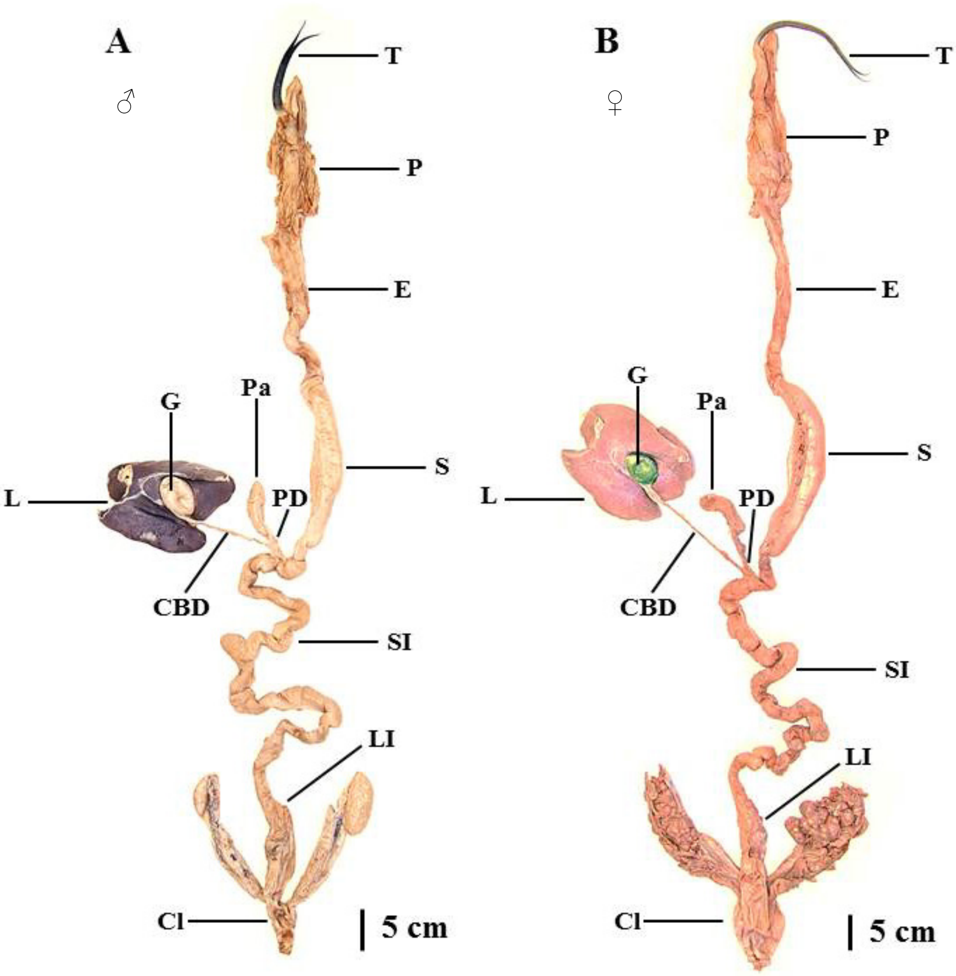

Figure 3 Gross anatomy of the digestive organs of *Varanus salvator*. A, digestive organs of the male (♂); B, digestive organs of the female (♀). Tongue (T). Pharynx (P). Esophagus (E). Stomach (S). Small intestine (SI). Large intestine (LI). Cloaca (Cl). Liver (L). Gallbladder (G). Common bile duct (CBD). Pancreas (Pa). Pancreatic duct (PD).

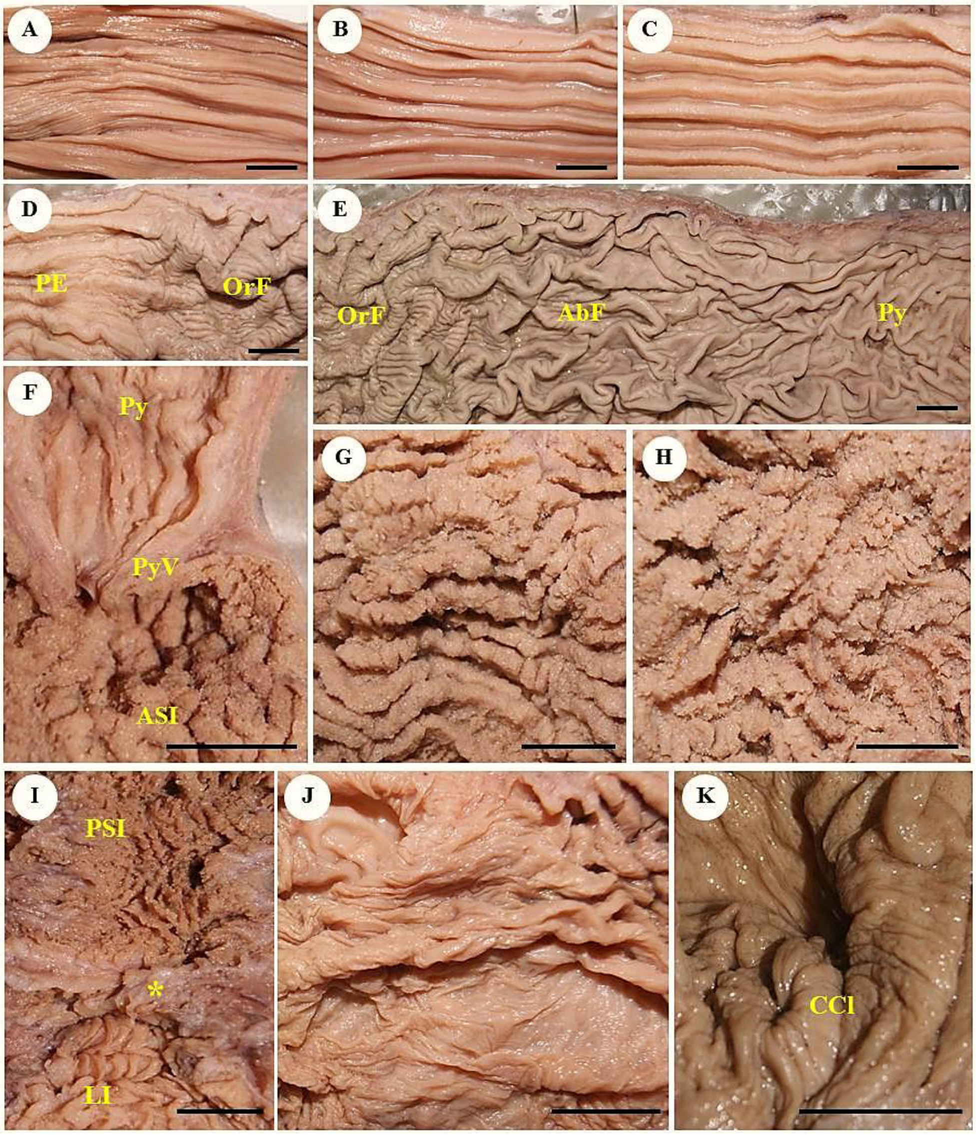

Figure 4 Internal surface morphology of the gastrointestinal tract of *Varanus salvator*. A, anterior esophagus; B, middle esophagus; C, posterior esophagus; D, the transition between the esophagus and stomach; E, stomach; F, pyloric valve; G, anterior small intestine; H, posterior small intestine; I, the transition between the small intestine and large intestine; J, large intestine; K, coprodeal cloaca. Posterior esophagus (PE). Oral fundus (OrF). Aboral fundus (AbF). Pylorus (Py). Pyloric valve (PyV). Anterior small intestine (ASI). Posterior small intestine (PSI). Large intestine (LI). Coprodeal cloaca (CCl). An asterisk (*) indicates a valve. Scale bars = 1 cm.

Discussion

In general, tongue morphology varies with feeding behavior. In varanid lizards, telescopic tongues support the projection of the fore-tongue out of the mouth, in order to retrieve air and substrate chemicals for evaluation by the vomeronasal organ (Jacobson's organ) for food identification and location [1,18,19]. Food swallowing in lizards involves the ventral surface of the pharynx covered with numerous mucous cells for transportation of food from the pharynx into the esophagus and then the stomach [20]. Most vertebrates, including varanid lizards, bolt their food and swallow it whole, and the esophagus expands to accommodate it [19]. The 3 parts of the esophageal tube were divided by our observation from length equally. We found the difference in the diameter of the esophageal tube and the number of esophageal folds in each part that may be related to providing the extended surface for the accommodation of a large bolus of food in *V. salvator*. This area of *V. niloticus* and *Uromastyx aegyptiaca* produces mucus and is secreted to aid the passage of food [21,22]. The stomachs of other reptiles are heavy, muscular, distensible tubes, and are usually J-shaped and largest in the curved part. We found that the *V. salvator* stomach is left-curved and slightly wider and longer than the esophagus. It can be divided into 2 distinct regions, the fundus and pylorus, and narrows to a thick, muscular sphincter or pyloric valve, which can control the movement of the food bolus from the stomach into the small intestine [1,13,14,22].

The size of reptilian small intestines is related to body length, which is moderate in lizards [13]. In *U. aegyptiaca* (an herbivorous lizard) and *Chamaeleon africanus* (an insectivorous lizard), the small intestine extends from the pylorus to the caecum as a narrow tube. The structure near the pylorus is a wide tube that gradually narrows towards the caecum [22,23]. However, the caecum was not found in this study, probably because *V. salvator* is a carnivorous lizard and it is unnecessary, as it has a role in the fermentation of food (polysaccharides). This is perhaps related to their feeding on scavenger behavior which has been partially fermented by microorganisms during the post-mortem. The first loop after the pylorus, which receives the pancreatic and common bile ducts, is considered the duodenum while the rest is the ileum. There is no external indication to separate the duodenum and the ileum. We noticed that the internal surface of the duodenal small intestine has numerous, tall folds. In addition, low folds could also be found in between the tall ones. Therefore, the small intestine in the duodenal region is a wide cavity full of folds, whereas the ileal region is a narrow cavity lined with only a few longitudinal folds. The folds of the small intestine of *V. salvator* run in a zigzag manner parallel to each other and similar to that in the *U. aegyptiaca* lizard [22].

The reptilian large intestine is a straight or C-shaped tube and flows into the cloaca and is the least muscular and most thin-walled structure in the digestive tract [1]. In *U. aegyptiaca*, the large intestine is composed of a very conspicuous caecum, colon, and rectum [22]. At the posterior edge of the caecum, there is a small blind sac or appendix [22]. However, the caecum between the transitional area of the small and large intestines was not present in any of our *V. salvator* specimens. Moreover, the colonic and rectal regions of their large intestines could not be clearly distinguished. Therefore, further histological study of this colorectal region is required to identify the very last area of GI tract in this particular species. In addition to the GIT, we also investigated the accessory digestive glands. However, the liver, gallbladder and pancreas of *V. salvator* are similar to those of other lizards [22,24,25].

Conclusions

In conclusion, most of *V. salvator* digestive organs are similar to that of other lizards, however, they may be different in some features. This was the first report for a digestive anatomical study of *V. salvator* that could be used in the other related studies such as zoology, vertebrate zoology, vertebrate comparative anatomy as well as providing support for veterinary science and propagation for the economy in the future.

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