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Full length article

Gross anatomical features of the air sacs of the common kingfisher *(Alcedo atthis)*

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ABSTRACT
This research was conducted with the main aim to investigate the morphology of air sacs system in kingfisher. Eight healthy, adult kingfishers were used to explore the morphological characteristics of the air sacs, which were examined grossly and with latex and cast preparations. In general, the morphological features of the kingfisher air sacs are similar to other avian species. We observed nine air sacs; four paired sacs (cervical, cranial thoracic, caudal thoracic and abdominal air sacs) and one unpaired sac; the clavicular air sac. The cervical air sac communicated to the lung by the medioventral bronchus and gave off intermuscular, subscapular and subcutaneous diverticula. The clavicular air sac communicated with bronchial tree through the medioventral bronchus and had subscapular, axillary, humeral, subpectoral and sternal diverticula. The cranial and caudal thoracic air sacs were communicated with the lung through the lateroventral bronchi. Each cranial thoracic air sac gives diverticulum which fused medially forming one large diverticulum; while, there were no diverticula extending from the caudal thoracic air sacs. The left abdominal sac was the largest air sac. The right and left abdominal sacs gave off branches to diverticula that pneumatized synsacrum. The abdominal air sacs gave off femoral diverticula caudal to the hip joint in addition to the perirenal diverticula. In conclusion, the present study provided detailed and comprehensive data about the morphology of air sacs system in kingfisher. In general, the air sacs of kingfisher are almost similar to other bird species with few variations. These findings could be enhancing anatomical knowledge of respiratory system of kingfisher bird.

INTRODCTION

Birds have a total of nine air sacs, which are connected to their lungs and trachea. The air sacs are divided into four groups: cervical, cranial thoracic, caudal thoracic, and abdominal. Each group of air sacs has a specific function in the respiratory process, and they work together to allow birds to efficiently extract oxygen from the air (Casteleyn et al., 2018). Birds do not possess a diaphragm, so they do not present any differentiation between thoracic and abdominal cavities. The respiratory system of birds is divided into lower and upper respiratory tract. The upper respiratory system is formed by the nasal cavity, larynx and trachea; whereas, the lower respiratory tract is formed by the lungs and air sacs (Baume et al., 1993; Çevik-Demirkan et al., 2006; Dyce et al., 2010; Al-Mamoori and Al-Abdula, 2016; Viegas et al., 2024).

Air sacs are one of the unique structures of the avian respiratory system that aid in the sustain continuous airflow and ventilation of the lung during the breathing cycle (Powell &Mitchell, 2000). Air sacs also have an significant role in the regulation of body temperature (Dawson & Whittow, 2000). Avian air sacs are important in flight and swimming by decreasing the density of the body (Kent & Carr, 2008; Dyce et al., 2010). Because air sacs are extensions of the bronchial system that are closely arranged between the internal body organs and even pierce some of the skeletal bones via diverticula (Duncker, 2004; Sawad & Udah, 2012). Morphological features of air sacs have been reported for several species of birds (Bezuidenhout et al., 1999; El-Mahdy, 2005; Cevik-Demirkan et al., 2006; Demirkan et al., 2006; Sawad & Udah, 2012; El-sayed & Hassan, 2019). However, there is no information about air sac structure in the kingfisher.

The kingfisher is a carnivorous flight bird (Fry et al., 1999). It is distributed over Europe, Asia, and North Africa. In temperate regions, it lives in clear, slow-flowing streams and rivers, and lakes with vegetated banks. Tropical populations habit the slow-flowing rivers, mangrove creeks and swamps *(*Fry et al., 1999).

Kingfisher catches fish from 1–2 m above the water, on a branch, river bank. when food is detected, it bobs its head to gauge the distance and plunges steeply down to seize the prey usually not deeper than 25 cm below the surface. Its wings are opened underwater and the open eyes are protected by the transparent third eyelid. it then raises beak-first from the surface and flies back to its perch. The fish is adjusted until it is held near its tail and beaten against the perch several times. Once dead, the fish is positioned lengthways and swallowed head first. A few times each day, a small greyish pellet of fish bones and other indigestible remains is regurgitated *(*Fry et al., 1999).

Despite a wealth of books and studies devoted to avian anatomy, very little attention has been paid to the respiratory system (air sacs) of kingfisher. The present study was conducted to examine the gross morphological structures of air sacs of the kingfisher in the Damietta governorate, Egypt.

MATERIALS AND METHODS

Study area and study birds

Eight mature healthy kingfisher's birds of both sexes and weight of 34–46 g were collected from wild bird hunters in the Damietta governorate, Egypt to study the macroscopic anatomy of the air sacs and their connections to the bronchial tree. This study was carried out under the approval of scientific research ethics committee, Faculty of Veterinary Medicine, Suez Canal University, Ismailia, Egypt during the period between 2021-2023. All birds were transferred to Department of Anatomy, histology & embryology, where a detailed morphological examination of the air sacs has to be performed. The birds were anesthetized intramuscularly with 2% xylazine HCl at the dose of 3 mg/kg (Farouk et al., 2017; El-sayed & Hassan, 2019). The studied birds were then decapitated and kept for other studies.

Gross examination

For examination the gross morphology of the air sacs and their relationship to the surrounding organs, three euthanized birds were gently massaged to evacuate the pulmonary system and to avoid rupture of air sacs (O'Connor, 2004). Then the abdominal wall was incised from the cloaca to sternum, then a transverse incision caudal to the keel bone was made. The incised abdominal wall, peritoneal fat and the internal viscera were reflected to expose the air sacs and their related visceral organs and bones according to technique described by Al-Mamoori (2016) and Viegas et al. (2024) with some modification.

Latex and cast preparations

Gum milk latex colored with red ink was injected via the trachea then a tight ligation was made and the three specimens were immersed in 10% formalin for 3–4 days. Subsequently, the injected birds were dissected to examine the lungs, air sacs and their related organs using the technique as described by EL-BABLY et al. (2014) with some modifications.

The remaining two birds were injected through trachea with a (2:1) mixture of Kem-Apoxy 150 and its catalyst then the trachea was tightly ligated. The injected birds were left to harden at room temperature for 3–4 days. Next, the hardened specimens were immersed in 100% water solution of potassium hydroxide (KOH) for 2–3 days at room temperature to macerate the soft tissues. The macerated specimens were gently washed in running tap water leaving the cast which was then left to dry at room temperature according to technique described by El-Sayed and Hassan (2019). On these specimens we determined the position, shape and size of the air sacs and their diverticula. For proper Latin terminology we used the *Nomina Anatomica Avium* (Baumel et al., 1993).

All photographs were taken with Canon digital camera 10 MP.

RESULTS

The results revealed that, the kingfisher has nine air sacs; four paired air sacs; cervical, cranial thoracic, caudal thoracic, and abdominal air sacs and one unpaired sac, the clavicular air sac. The air sacs were deeply situated among the visceral organs in the body cavity, in addition to their several diverticula inside most bones of the of the trunk, pectoral and pelvic girdles.

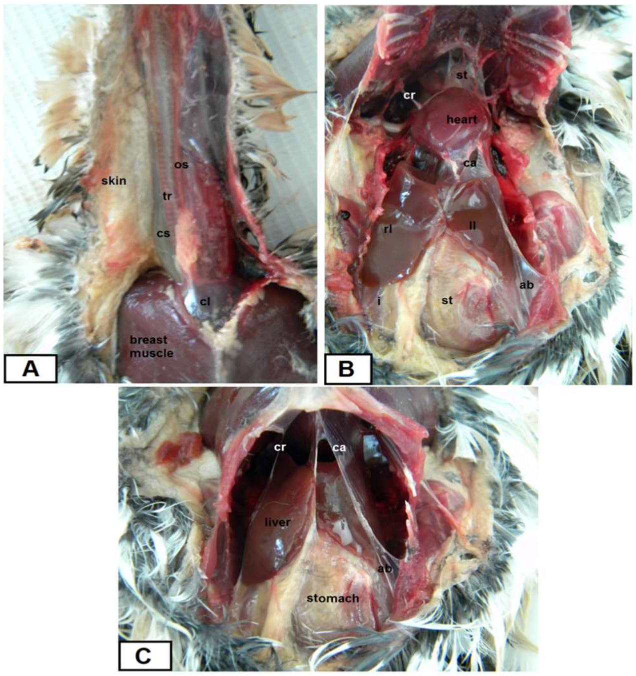
The cervical air sacs, *Saccus Cervicalis*, were positioned at the base of the neck ventral to the first thoracic and last two cervical vertebrae (Figs. 1, 2 &3), in front of the lung and communicated with lung via the medioventral bronchus (Fig. 2). The two sacs were connected medially and related dorsally to the neck musculature and ventrally to the trachea, oesophagus and clavicular sac. Each cervical air sac possessed vertebral, subcutaneous and intermuscular diverticula. The vertebral diverticulum passed along each side of the vertebral column from the 2nd thoracic vertebra to the 1st cervical vertebra (Fig.2). Each vertebral diverticulum had two tubular extensions; one inside the vertebral canal and the other inside the transverse canal. These two tubular extensions were connected through the intervertebral foramina. The subcutaneous diverticulum (Fig.2) fused with that of other side to surround the trachea. The intermuscular diverticulum (Figs. 2 and 3), which about 2 cm in length and was situated between the cervical vertebrae and shoulder girdle muscles.

The clavicular air sac, *Saccus Clavicularis*, was a large, unpaired sac, that was formed by the union of the right and left sacs. The clavicular air sac fills the thoracic inlet and was entirely delimited by the pectoral girdle and sternum (Figs.1, 2 & 3). The trachea and oesophagus are coursed between the clavicular and cervical air sacs. The clavicular air sac enclosed the syrinx and expanded around the heart base extending ventral to the cranial half of each lung to communicate with it by the medioventral bronchus. The clavicular air sac extended from the level of last three cervical vertebrae to the 3rd thoracic vertebrae (Figs. 1, 2 and 3). The clavicular air sac possessed extra-thoracic and intra-thoracic diverticula. The extra-thoracic diverticula include subscapular, humeral and subpectoral, that were situated around the muscles and bones of the shoulder girdle. The subscapular diverticulum (Figs. 2 and 3) was situated between the scapula, the cervical air sac and the first two ribs. The subpectoral diverticulum was placed under the pectoral muscles (Figs. 2 and 3). The humeral diverticulum was sited dorsal to the subpectoral diverticulum (Figure-). Only one intrathoracic diverticulum of the clavicular sac; sternal diverticulum, which was located ventromedial to the cranial thoracic air sacs and was located between the sternum, base of the heart and cranial part of the lung, and invaded the sternum (Figs. 2 and 3).

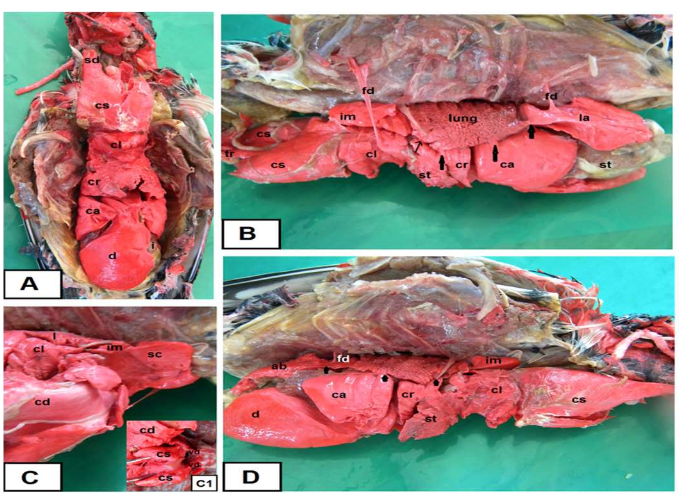
The paired cranial thoracic air sacs, *Saccus thoracicus cranialis*, were roughly triangular. They were the smallest air sacs and placed underneath the lateral body wall ventral to each lung, caudolateral to the clavicular air sac, cranioventral to the caudal thoracic air sacs and cranial to the abdominal air sacs (Figs. 1, 2 & 3). The cranial thoracic air sac showed costal impressions as they extended from the level of the 3rd rib to the posterior end of the sternum. Each cranial thoracic air sac fused cranially with the clavicular air sac and communicated together with the ventral surface of each lung through the medioventral bronchus (Fig. 2). Medially, the visceral surfaces of both sacs were enclosed between the proventriculus, heart and the cranial part of the right hepatic lobe. Each cranial thoracic air sac gives diverticulum which fused medially form one large diverticulum related to right abdominal wall externally and to the right lobe of liver, gizzered and intestine internally

The paired caudal thoracic air sacs, *Saccus thoracicus caudalis*, were symmetrical sacs situated craniolateral to the abdominal sacs, at the rear of the caudal border of the corresponding cranial thoracic sacs and caudoventral to the corresponding lung (Figs. 1, 2 & 3), to which they communicated through a lateroventral bronchus (Fig. 2). These air sacs were larger than the cranial thoracic sacs. Laterally, the caudal thoracic air sacs were related to the lateral abdominal wall and this lateral surface showed the costal impressions of the last three ribs (Figs. 1 & 2). Medially, the left caudal thoracic sac was related to the left lobe of liver; while the right one was related to the parietal surface of the right hepatic lobe, and right abdominal air sac (Figs. 1, 2 & 3). There were no diverticula coming from the caudal thoracic air sacs.

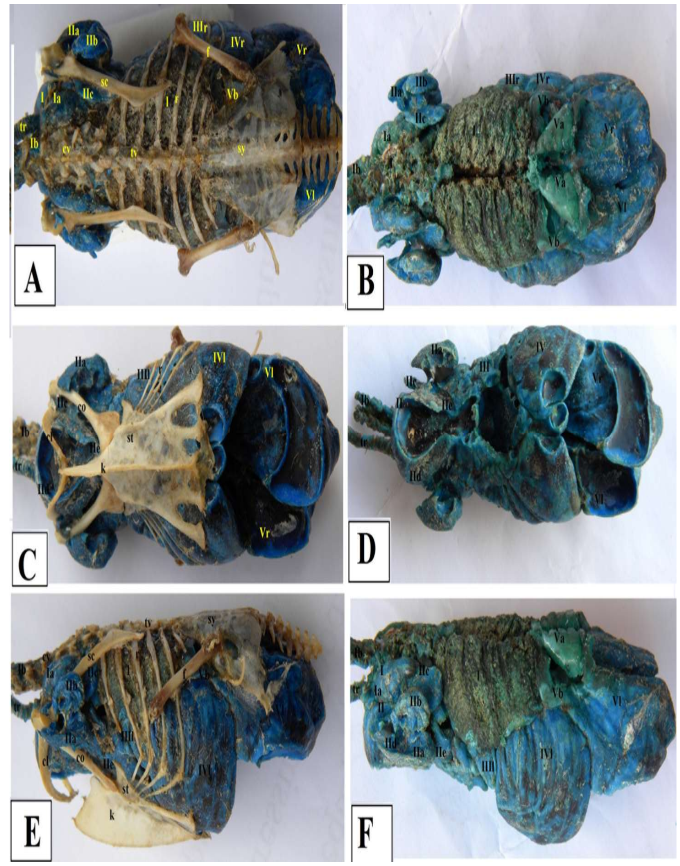
The paired abdominal air sacs, *Saccus abdominalis*, were asymmetrically placed and located behind the caudal thoracic air sacs. The left abdominal air sac was smaller than the caudal thoracic sac and located above the gizzard. The left air sac was placed caudo-dorsal to the caudal thoracic sacs; while, the right air sac was located caudoventral to the caudal thoracic air sac (Figs. 1, 2 & 3). The visceral side of the right abdominal air sac was related to the gizzard, intestine, liver and ovary in female birds (or testis in male birds); while, the left air sac was related to the gizzard. The parietal surface of the right and left abdominal air sacs was against to the synsacrum (Fig. 2). The abdominal air sacs communicate the lung through the lateroventral bronchi (Fig. 2). The right and left abdominal sacs detach branches to diverticula that pneumatized the synsacrum. The caudal-most portion of each sac was narrower and gave off a femoral diverticulum (Fig. 3) that was located behind the hip joint (Figs. 2 and 3).



F i g u r e 1. *A photograph of the gross dissection of the air sacs of the kingfisher, neck (A), thoracoabdomen (B), and abdomen (C). Saccus cervicalis (cs), Saccus clavicularis (cl), Saccus thoracicus cranialis (cr), Saccus thoracicus caudalis (ca), and Saccus abdominalis (ab), Diverticula sternalia (st), traches (tr), oesophagus (os), right lbe of liver (rl), left lobe of liver (ll).*



F i g u r e 2 A photograph of *Anatomical description of gum milk latex injected air sacs of king fisher; ventral view (A), left view (B), reflected cervical diverticulum (C) and reflected cervical air sac (C1), showing. Saccus cervicalis (cs), Saccus clavicularis (cl), Saccus thoracicus cranialis (cr), Saccus thoracicus caudalis (ca), and Saccus abdominalis dextra (ab), Saccus abdominalis senstra (la), Diverticula vertebralis, Diverticula sternalia (st), Diverticula subcutanea (ss), Diverticula femoralis (fd), lung (L), lateroventral*



F i g u r e 3. *A photograph of a colored cast injected air sacs of the king fisher. The figure showed the air sacs from different approaches as the dorsal view (A&B), ventral view (C&D), and lateral right view (E&F). kingfisher has five air sacs; Saccus cervicalis (I), Saccus clavicularis (II), Saccus thoracicus cranialis (III), Saccus thoracicus caudalis (IV), and Saccus abdominalis (V). There are several extensions from these sacs; Diverticula vertebralia (Ib), Diverticula interrnuscularia (Ia), Diverticulum subscapulare (IIc), Diverticulum axillare (IIb), Diverticulum subpectorle (IId), Diverticulum humerale (IIa), Diverticula sternalia (IIe), Diverticula perirenalia (Va), and Diverticula femoralia (Vb)*

DISCUSSION

The respiratory system of birds differs significantly from that of mammals and has an important role in making a sound, thermoregulation and gas purification (Dewangan, 2011**).** It includes specific organs which are unique to the birds i.e., the syrinx and air sacs (Dyce et al., 2010). Research indicated that the number, size and shape of the air sacs and their diverticula are quite different among bird's species. Depending on the species, it has been found that birds have from six to eleven air sacs (Bejdić et al., 2021). Considering the scarcity of anatomical studies in the kingfisher, the present study aimed to evaluate the anatomy of the air sacs in the kingfisher at Damietta governorate, Egypt**.**

The results of current work research revealed that, the air sacs observed in kingfisher were similar to that reported in other avian species (Cevik-Demirkan et al., 2006; Samah at al., 2014; El-sayed & Hassan, 2019). However, the interpulmonary diverticulum of the cervical air sacs recorded in rock partridge (Kurtul et al., 2004) were not observed in the kingfisher.

The current work documented that the cervical sacs of the kingfisher consisted of a pair of chambers and diverticula like that observed in most birds (King, 1966). On the other hand, in some birds such as the turkey (Meleagris) and goose, the cervical air sac fused with the lateral part of the clavicular sac to form the cervicoclavicular air sac (King & Atherton, 1970; Onuk et al., 2009). We observed in the kingfisher that the vertebral diverticula of the cervical air sacs pass cranially and caudally along the vertebral column and similar findings recorded in domestic birds (El-sayed & Hassan, 2019). Bejdic et al. (2021) reported partial fusion of the cervical air sac in Crimson Rosella.

The intermuscular diverticula in the kingfisher did not penetrate between the cervical muscles, but in some birds, they do penetrate these muscles and accompany some branches of the brachial plexus (Duncker, 1971). In accordance with findings of King, (1966) in Pelecaniformes, Akester et al., (1973) in *Leptoptilos*, Samah et al. (2014) in golden Pekin duck and El-sayed & Hassan (2019) in hooded crow. The current work observed extensive subcutaneous diverticula of the cervical air sacs.

The kingfisher has a single clavicular air sac in the thoracic inlet like that recorded in most avian species (El-sayed & Hassan, 2019). Moreover, Bejdic et al. (2021), studied the clavicular air sac in Crimson Rosella and researched to similar results. However, the findings of Bezuidenhout et al. (1999) in contrast with current results, who studied the respiratory air sacs in ostriches and reported that the left and right medial clavicular air sacs fuse with each other ventrally to the trachea to form a single. median compartment.

The present work recorded only the sternal diverticulum inside the thoracoabdomen. but, in most birds, the intrathoracic diverticula of the clavicular air sac are the cardiac and sternal diverticula (Duncker, 1971; El-sayed & Hassan, 2019). The cardiac diverticulum was reported in ducks and the albatross (Murray &Fisher, 1967; Cevik-Demirkan et al., 2006), but in contrast to the findings of current study in kingfisher. In most birds the ex-trathoracic diverticula include a subscapular diverticulum (between the scapula and the thoracic cage), an axillary diverticulum (between the muscles around the shoulder region), a humeral diverticulum (invading the humerus), a subpectoral diverticulum (under the pectoral muscles) and a supra-humeral diverticulum (covering the head of the humerus (Baumel et al., 1993; Bejdić et al.,1999; Onuk et al., 2009). In the present research, the supra-humeral diverticulum was not observed in the kingfisher. Furthermore, the extensive subcutaneous diverticula that have been reported in Pelecaniforms, Ciconiiforms, and Coraciiforms (King, 1966) were not observed in the current study. The axillary diverticulum was not observed in the kingfisher. The cranial thoracic air sacs of kingfisher were larger than the caudal thoracic, and similar to that reported in domestic birds (Taşbaş et al., 1994; El-syaed and Hassan, 2019). These results are in contrary to findings observed in Passeriformes (Duncker, 1971) and the long-legged buzzard (Orhan et al., 2009).

We noticed that the cranial thoracic air sacs in kingfisher have one large diverticulumin which is in contrast to observations in domestic fowl (Getty, 1975; Taşbaş et al., 1994), in mallard ducks (Cevik-Demirkan et al., 2006) and in hooded crow (El-syaed and Hassan, 2019) which they have no diverticula. Orhan et al. (2009) observed that in the long-legged buzzard the thoracic air sacs aerated most of the sternal ribs except the last two, as well as extending a cardiac diverticulum under the heart. Moreover, another diverticulum of each thoracic air sac is an extension along the oesophagus of phalacrocoracids (Duncker, 1971). On the other hand, the caudal thoracic sac is absent in *Meleagris* (King& Atherton, 1970)

In the current study, the abdominal sac was located in the dorso-caudal region of the coelom, which is similar to findings previously reported in the birds (Çevik-Demirkan et al., 2006; ONUK et al., 2009). In crow, El-syaed and Hassan, (2019) reported that the abdominal air sac was the largest sac in respiratory system of bird compared to others sacs investigated, this finding is in contrast with our findings.

The current work revealed that the abdominal airs sacs in the kingfisher did not gave off perirenal diverticula unlike many birds (Duncker, 1971; & El-syaed and Hassan, 2019).

The contrary or consistent among the findings of previous studies and current study in kingfisher air sacs morphological features and their diverticula could be attributed to difference description of researchers to these organs (sacs) during their studies, the asymmetry of the abdominal viscera of birds (Mclelland, 1989). Moreover, Maina 2015) cited that, the anatomy of the lower part of the respiratory system is quite variable among the avian taxa and these variations come as results of bird's adaptation to the flight and different habitats.

CONCLUSIONS

Based on the anatomical features obtained in the current study, we concluded that the gross anatomy of the air sacs of kingfisher is almost similar to other birds with few variations. It is thought that the findings will make important contributions to the anatomy literature. However, more studies should be carried out for deeper understanding anatomical structures of other parts and diseases of respiratory of kingfisher bird.

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CONTRIBUTORS OF UTHORS

All authors AAM, WB, and HAS have equally contributed in the designing, carried out, extracted the data, writing the first draft and final of the manuscript. All authors have reviewed and approved the last submitted version.

COMPETING INTERESTS

Authors declare that there is no conflict of interest.

ETHICS APPROVAL

This study was performed in line with the principles of the Declaration of Helsinki 19. The study was approved by scientific research ethics committee, Faculty of Veterinary Medicine, Suez Canal University, Ismailia, Egypt.

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DATA AVAILABILITY STATEMENT

The data are available within the article

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الصفات التشريحية المظهرية للأكياس الهوائية لطائر الرفراف

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الملخص

أجريت هذه الدراسة بهدف التعرف على الصفات التشريحية المظهرية للأكياس (الحويصلات) الهوائية في طائر الرفراف. شملت الدراسة ثمانية طيور رفراف بالغة سليمة، تم فُحص الطيور بالعين وباستخدام مستحضرات اللاتكس والجبس. كشفت النتائج وبشكل عام، ان الصفات التشريحية المظهرية للأكياس الهوائية لطائر الرفراف تتشابه مع الاكياس الهوائية للأنواع الأخرى من الطيور. تم ملاحظة تسعة أكياس هوائية؛ أربعة أكياس هوائية مزدوجة (أكياس هوائية عنقية، وأكياس هوائية قحفية صدرية، وأكياس هوائية صدرية سفلية، وأكياس هوائية بطنية) وكيسًا واحدًا غير مزدوج؛ وهو الكيس الهوائي الترقوي. يتصل الكيس الهوائي العنقي بالرئة عبر القصبة الهوائية الوسطى البطنية، وينتج عنه رتوج بين العضلات وتحت الكتف وتحت الجلد. يتواصل الكيس الهوائي الترقوي مع القصبات الهوائية من خلال القصبة الهوائية الوسطى البطنية وله رتوج تحت الكتف وإبط وعضدي وتحت صدري وقصي. تتواصل الأكياس الهوائية الصدرية القحفية والذيلية مع الرئة من خلال القصبات الهوائية البطنية الجانبية. يكون كل كيس هوائي صدري قحفي رتوجًا يندمج في المنتصف مكونًا رتوجًا كبيرًا واحدًا؛ بينما لا توجد رتوج ممتدة من الأكياس الهوائية الصدرية الذيلية. كان الكيس الهوائي البطني الأيسر هو أكبر من بين الاكياس الهوائية المدروسة. كونت الأكياس البطنية اليمنى واليسرى فروعًا إلى رتوج تعمل على نفخ المفصل العجزي. كونت الأكياس الهوائية البطنية رتوجًا فخذيًا ذنبيًا لمفصل الورك بالإضافة إلى الرتوج حول الكلى. خلصت هذه الدراسة الى ان الحويصلات الهوائية لدى طائر الرفراف تتشابه تقريبًا مع أنواع الطيور الأخرى، مع اختلافات طفيفة، ربما تُعزز هذه النتائج المعرفة التشريحية للجهاز التنفسي لدى طائر الرفراف.

الكلمات المفتاحية: الاكياس الهوائية، الصفات التشريحية، طائر الرفراف.

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