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SOME TOPOGRAPHICAL AND MORPHOLOGICAL STUDIES ON AIR SACS OF DOMESTIC PIGEON (COLUMBA LIVIA DOMESTICA) USING CORROSION CASTS

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SUMMARY

The work was carried out on fifteen adult pigeons of both sexes. The gross morphological features of the air sacs were thoroughly investigated using Vinyl chloride acetate corrosion casts.

It was found that the pigeon as an example of a powerful flying bird had 4 pairs of transparent air sacs (cervical, cranial thoracic, caudal thoracic and abdominal), in addition to an unpaired interclavicular sac. They were symmetrically occupying either side of the body cavity.

The cervical sacs aerated the cervical vertebrae approximately from the 3rd or 4th as well as the first two thoracic vertebrae. The single interclavicular air sac was the most complicated among all air sacs in the pigeons. It occupied the ventral part of the thoracic inlet and overlay the cervical sacs laterally and connected with their cranial ends. Meanwhile, the interclavicular sac gave off extrathoracic humeral and axillary diverticula, which pneumatized the humeri and bones of the pectoral girdles.

It was also observed that the cranial and caudal thoracic air sacs showed no bony communications, and never aerate bones.

The paired abdominal sacs were larger than the other air sacs. They enclosed between their medial surfaces the intestinal tract, kidneys and the gonads. Also, each of them sent a diverticulum which ventilated the interior of the pelvic bone and the synsacrum.

The obtained results of the air sacs in the pigeon were discussed with the findings given by previ-

ous authors in other species of birds.

INTRODUCTION

Birds have an extraordinary respiratory system which plays an important role in keeping the body temperature constant (Selianski, 1986 and Fowler, 1991).The air sacs, as one of the respiratory components, are responsible for pulmonary ventilation, regulation of body temperature and decreasing the specific gravity of the avian body during flight (Kent and Carr, 2001 and Dyce, Sack and Wensing, 2002). Moreover, they are situated deeply in the body cavity as well as between the body internal organs and also project forming diverticulae to aerate some pneumatic bones of the skeleton of the limbs, pectoral and pelvic girdles and the trunk (King and Mc Lelland, 1975 and Nickel, Schummer and Seiferle, 1977). Domestic pigeons as a member of order Columbiformes are granivorous , feed on seeds and are of powerful flight; the pigeon flies more economically than a light aircraft (Tucker,1969). At the same time, pigeons among domestic birds had a long association with man, both as a source of food and as cage birds (Margaret, 1982). Also, they are of special value because of their efficiency in converting vegetable into animal protein required for human population (king,1975).

Although some studies have been made on the morphology of the air sacs in different species of birds as chickens, turkeys and ducks (King,1975; Nickel et al.,1977; Shively,1987 and Mc Lelland, 1990) as well as migrating quails (El-Mahdy, 1994), yet, the available informations concerning the air sacs are insufficient in pigeons. Therefore, the present study was performed in an attempt to obtain some informations on the morphological features of the air sacs in pigeons as a model of powerful flying birds.

MATERIAL AND METHODS

A total of fifteen adult pigeons, of both sexes, weighing about 500-600 gm. were used in the present study. The birds were slaughtered, allowed to exsanguinate, then, the ventral body walls of seven of them were longitudinally incised from the cloacal aperture as far as the sternum. Another transverse incision was made just behind the caudal edge of the sternum. The flaps of the abdominal wall were, then, reflected on both sides. It was necessary to remove some of the peritoneal folds and the layer of fat on the gizzard in order to expose the viscera. The intestinal tract was subsequently displaced to determine the relations of the abdominal sacs with the kidneys and gonads. The other eight birds were prepared for casts and injected via the trachea with Vinyle chloride acetate colored red and blue (about 70-80ml for each bird). Vinylite casts of the air sacs of pigeons were prepared by the method of Hossler and Olson (1984).

Four of the injected birds were corroded in a concentrated hydrochloric acid (50%) for 24 hours. The corroded vinylite casts were washed carefully with running tap water till the soft tissues were completely removed and left to dry in the room temperature. The prepared casts of the air sacs were thoroughly examined and grossly described. The remaining four pigeons were thoroughly and carefully macerated for studying the skeletal relations of their air sacs.

The terminology used in this study was adopted according to the Nomina Anatomica Avium (Baumel,J.J.; King,A.S.; Lucas,A.M.; Breazile,J.E. and Evans,H.E., 1979).

RESULTS

Nine transparent air sacs (Sacci pneumatici) were found in the pigeon. They were represented by a single interclavicular air sac, while the others were paired, symmetrically occupying either side of the body cavity and included the cervical, cranial thoracic, caudal thoracic and abdominal air sacs.

Cervical air sacs (Sacci cervicales):

They were represented by two symmetrical nearly rectangular in form lying at the base of the neck on either side of the trachea (Figs.10/2, 11/3 & 12/2). Each extended from the 8^{th} or 9th cervical vertebra up to the 1^{st} or 2nd thoracic vertebra and was in direct contact with the cervical musculature (Fig.1/2). They lay dorsal and medial to the interclvicular air sac. They blended together on the dorsal aspect of the trachea under the last three cervical vertebrae. The fused part of both right and left cervical air sacs was measured about 2cm. long and extended cranially in the form of two short tubes which were connected with the overlying surface of the interclavicular air sac, whereas caudally, it reached the cranial parts of both lungs and is enclosed between them. The cervical air sacs aerated the cervical vertebrae approximately from the 3^{rd} or 4^{th} in addition to the first two thoracic vertebrae.

Interclavicular air sac (Saccus interclavicularis):

It was a single relatively large, nearly triangular ballooned sac which lay at the thoracic inlet between the two clavicular bones, ventral to the trachea, extending approximately from the level of the 12^{th} or 13^{th} cervical vertebra up to the 2^{nd} thoracic vertebra (Figs.1/1, 2/3, 9/2, 11/2 and 13/2). It extended caudally to lie ventral to the cranial third of both lungs . Such sac was medially and dorsally related to the cranial ends of both cervical sacs, with which it was connected. It aerated the sternum , also surrounded the syrinx and extended around the base of the heart. Two unequal cushion- like diverticula were given off from each of the lateral borders of the interclavicular air sac and extended extra-thoracically. The larger represented the humeral diverticulum (Diverticulum humeri) and communicated with the cavities of the humeri and also aerated the vertebral parts of the 2nd & 3rd ribs (Figs.9/'2, 10/'3, 12/' and 13/'2).While the smaller axillary diverticulum (Diverticulum axillare) extended toward the axillary region just caudal to the articulation between the scapula, coracoid and humerus and pneumatized the coracoid bones (Figs. 2/4,9/"2, 10/3, 12/3 and 13/"2)

Cranial thoracic air sacs (Sacci thoracici craniales):

They were represented by two small flattened nearly triangular sacs and were the smallest among the pigeon air sacs. They began on both sides approximately at the level of the 2nd intercostal space and extended backward up to the 3rd and 4th ribs under their vertebral segments (Figs.9/3, 10/4, 11/4 and 13/3).They were related dorsally to the ventral surfaces of the lungs , while the heart, cranial parts of the hepatic lobes and the proventriculus were enclosed between the medial surfaces of such sacs(Figs. 3/3, 4/3 and 7/4). Both the right and left cranial thoracic air sacs possessed no connections to the bones. Their anterior ends were completely fused with the caudal border of the interclavicular air sac and also attached by two small tube-like connections with the cervical air sacs.

Caudal thoracic air sacs (Sacci thoracici caudales):

A pair of symmetrical air sacs which were much larger than the cranial thoracic sacs and caudal to which they lay. Each extended ventral to the respective lung under cover of the sternal segments of the 3rd or 4th ribs and continued backward to terminate approximately 1cm. ventral and caudal to the last (7th) rib(Figs.7/5, 9/4, 10/5, 11/5 and 13/4). These air sacs were somewhat cone-shaped, the bases of which were dorso-laterally, while the apices were ventro-medially. These sacs were close to the smooth convex parietal surface of the liver and they surrounded most of such organ by their medial surfaces, whereas their lateral surfaces were attached to the body wall (Fig.4/5). The caudal thoracic air sacs were also communicated cranially by two short narrow tubes with the cranial thoracic sacs. Meanwhile, like the cranial thoracic sacs, the caudal thoracic air sacs had no communications with the bones.

Abdominal air sacs (Sacci abdominales):

They appeared to be the largest among all air sacs in the pigeon. Both the right and left abdominal sacs, as seen from the corrosion casts, were nearly equal in size and occupied either side of the body cavity. Each extended just behind the respective lung from the last (5th) thoracic vertebra and the vertebral part of the last rib cranially to the level of the synsacrum caudally (Figs.9/5, 10/6, 11/6,12/6&7 and 13/5). The lateral surfaces of both sacs were closely attached to the body wall dorsally, whereas their ventral borders appeared free. Thorough gross dissection revealed that the intestinal tract, kidneys as well as the testicles (in male birds) and the ovary (in female birds) were enclosed between the medial surfaces of both abdominal air sacs (Fig. 5/5, 6/7 and 8/8). Each abdominal air sac provided a small more or less cup-shaped (Fig. 9/'5) or tube-like (Fig. 10/'6) pelvic diverticulum from its dorsal border which carried air to the pelvic bone and synsacrum.

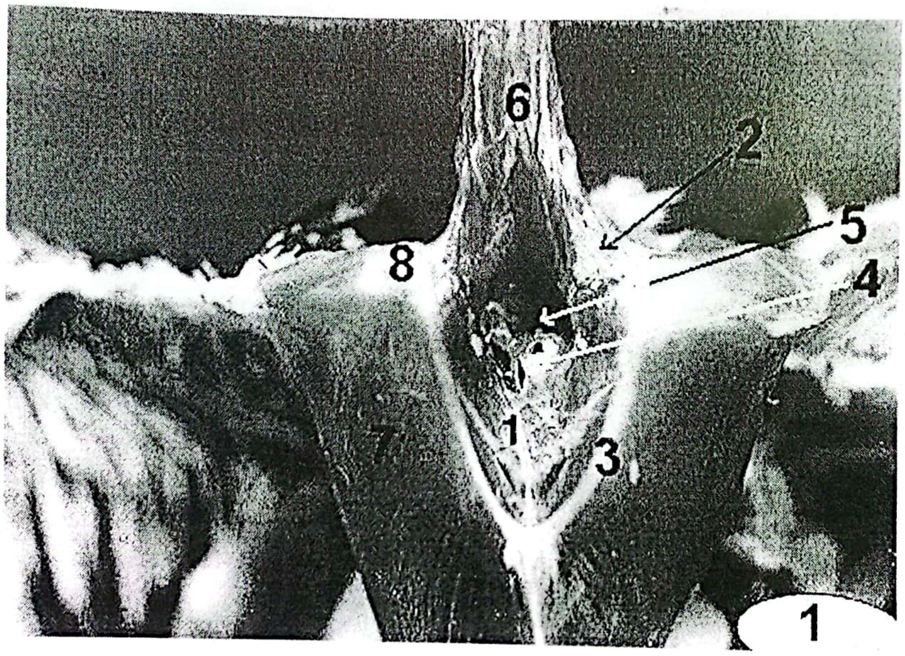


Fig. (1): A photograph of the ventral view of a pigeon at the base of the neck and thoracic inlet

1- Interclavicular air sac

2- Left cervical air sac

3- Clavicle (furculum)

4- Trachea

5- Oesophagus

6- Cervical musculature

7- M. pectoralis (Pars thoracicus)

8- Point of shoulder joint

Fig.(2): A photograph of the ventral view of a pigeon at the base of the neck and thoracic inlet

1- Trachea

2- Cervical musculature

3- Interclavicular air sac

4- Axillary diverticulum of (3)

5- Clavicle (furculum)

6- Coracoid bone

7- Keel of the sternum (left lateral surface)

8- Point of shoulder joint

9- Pars thoracicus of M. pectoralis (Pectoralis major) (had been reflected)

Fig. (3): A photograph of the body cavity of an adult pigeon showing:

1- Caudal border of the sternum (reflected upward)

2- Heart

3- Right and left cranial thoracic air sacs

4- Left lobe of the liver (parietal surface)

5- Right lobe of the liver (Parietal surface)

6- Gizzard (muscular stomach)

7- Intestinal tract

Fig. (4): A photograph of the body cavity of an adult pigeon showing:

1- Caudal border of the sternum (reflected upward)

2- Heart

3- Left cranial thoracic air sac.

4- Right lobe of the liver (parietal surface)

5- Wall of the right caudal thoracic air sac

6- Gizzard

7- Intestinal tract

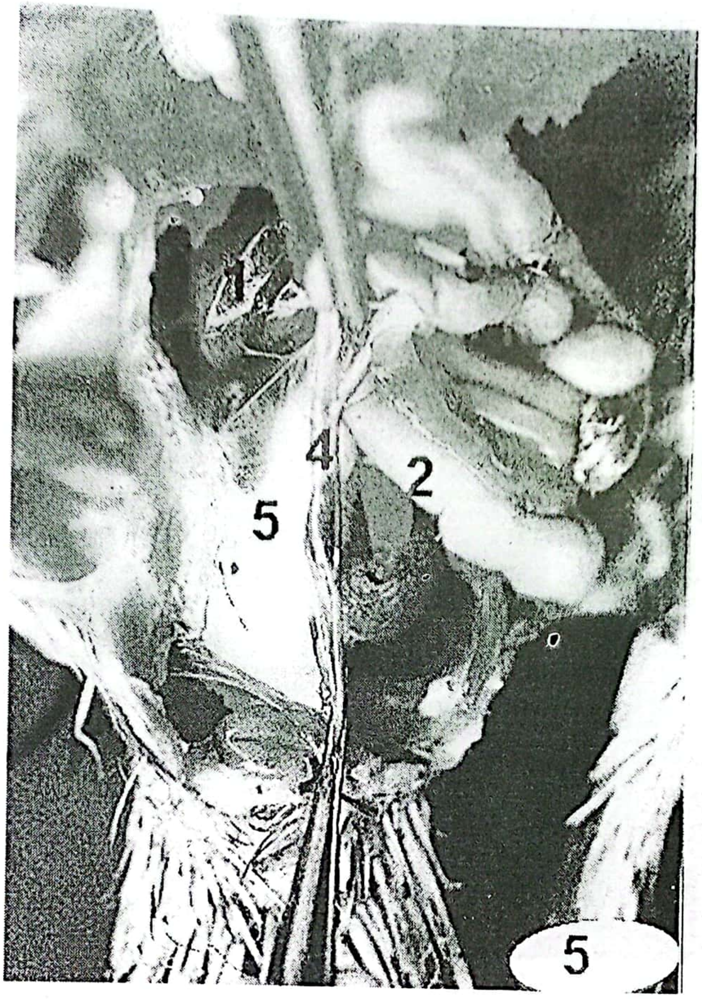


Fig.(5):A photograph of the body cavity of an adult pigeon showing:

1- Right lobe of the liver

2- Duodenum (displaced to the left side)

3- Gizzard

4- Rectum

5- Wall of the right abdominal air sac

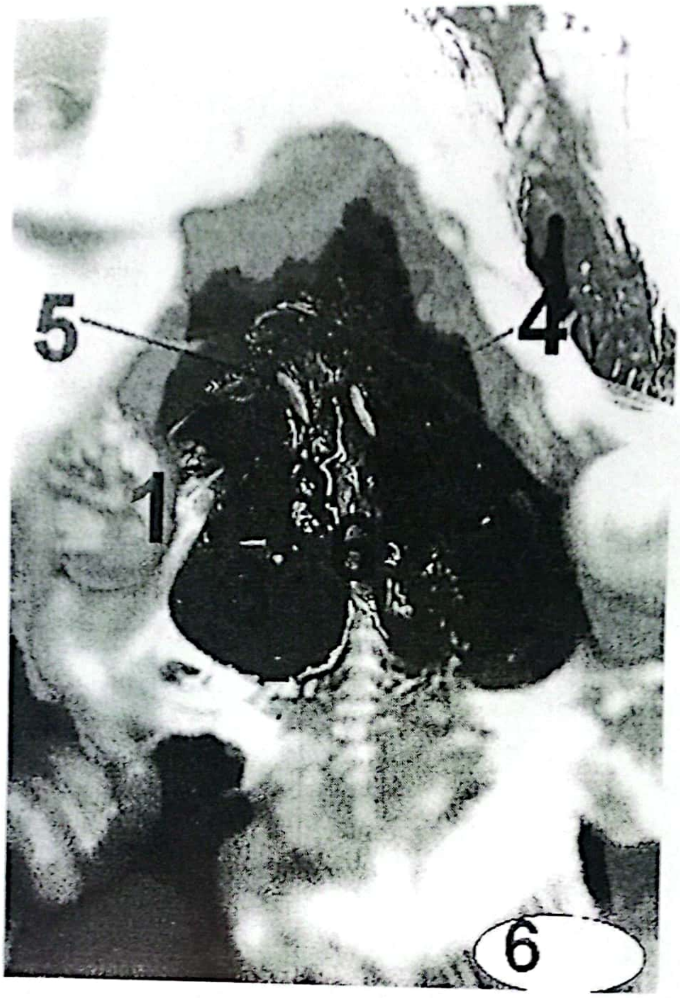


Fig. (6): A photograph of the body cavity of a pigeon (the body wall was longitudinally incised and the gizzard & intestinal tract were cranially displaced)

1- Intestinal tract

2- Left kidney

3- Right kidney

4- Left testis

5- Right testis

6- Synsacrum

7- Transparent wall of the left abdominal air sac (enclosing the kidney and testicle).

Fig. (7): A photograph of the body cavity of a pigeon (the body wall was longitudinally incised and the intestinal tract was displaced)

1- Left lobe of the liver

2- Proventriculus (reflected cranially)

3- Heart

4- Cranial thoracic air sac

5- Pulmonary surface of the right and left caudal thoracic air sacs (extending ventral to the lungs)

6- Right lung

7- Left kidney

8- Right kidney

9- Synsacrum

Fig. (8): A photograph of the body cavity of a pigeon (the body wall was longitudinally incised and the gizzard &proventriculus were displaced).

1- Gizzard

2- Proventriculus

3- Right lobe of the liver

4- Spleen

5- Left kidney

6- Right kidney

7- Ovary

8- Wall of the left abdominal air sac

9-Synsacrum

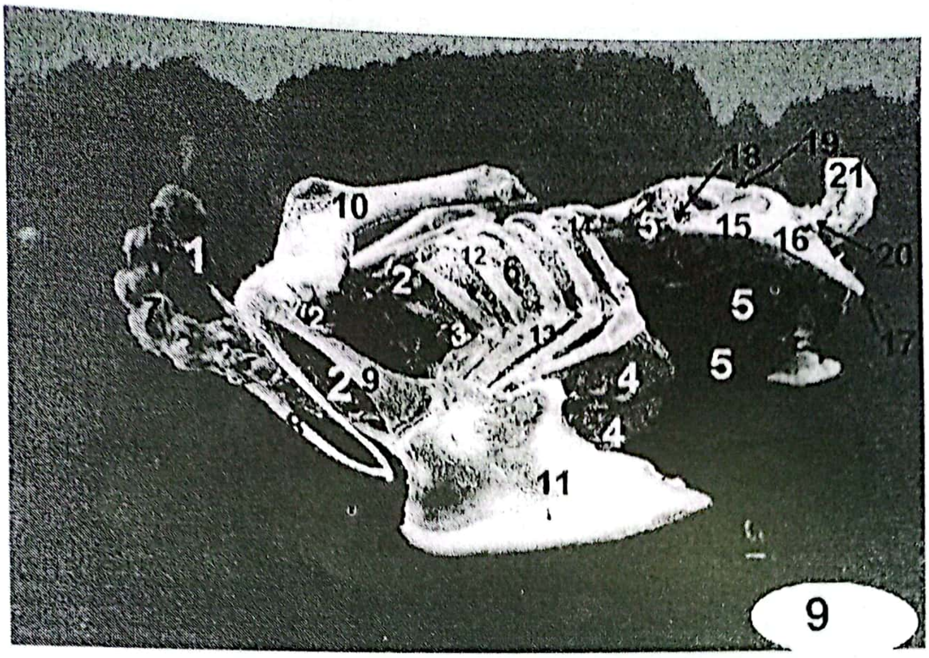


Fig. (9): A photograph of the left lateral view of an adult pigeon showing the skeletal relations of the air sacs

1- Trachea

2 - Interclavicular air sac

'2- Humeral diverticulum of (2)

"2- Axillary diverticulum of (2)

3- Left cranial thoracic air sac.

4- Left and right caudal thoracic air sacs.

5- Left and right abdominal air sac

5'- Diverticulum of the abdominal air sac.

6- Left lung

7- Cervical vertebrae

8- Clavicle (furculum)

9- Coracoid bone

10- Humerus

11- Keel of the sternum

12- Vertebral (dorsal) portion of a rib

13- Sternal (ventral) portion of a rib

14- Last (7^{th}) rib

15- Ilium

16- Ischium

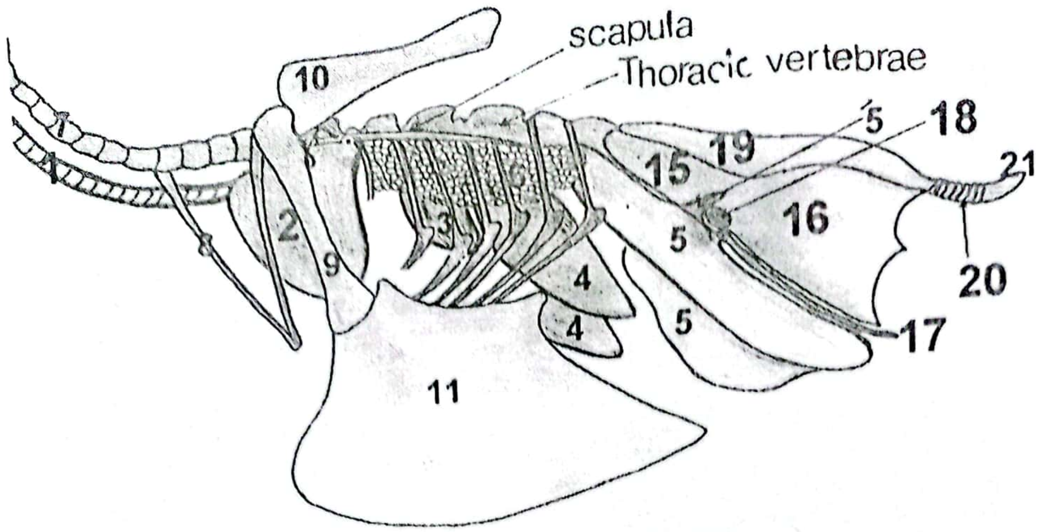
17- Pubis

18- Acetabulum

19- Synsacrum

20- Free caudal vertebrae

21-Pygostyle



A diagrammatic illustration of Fig. (9)

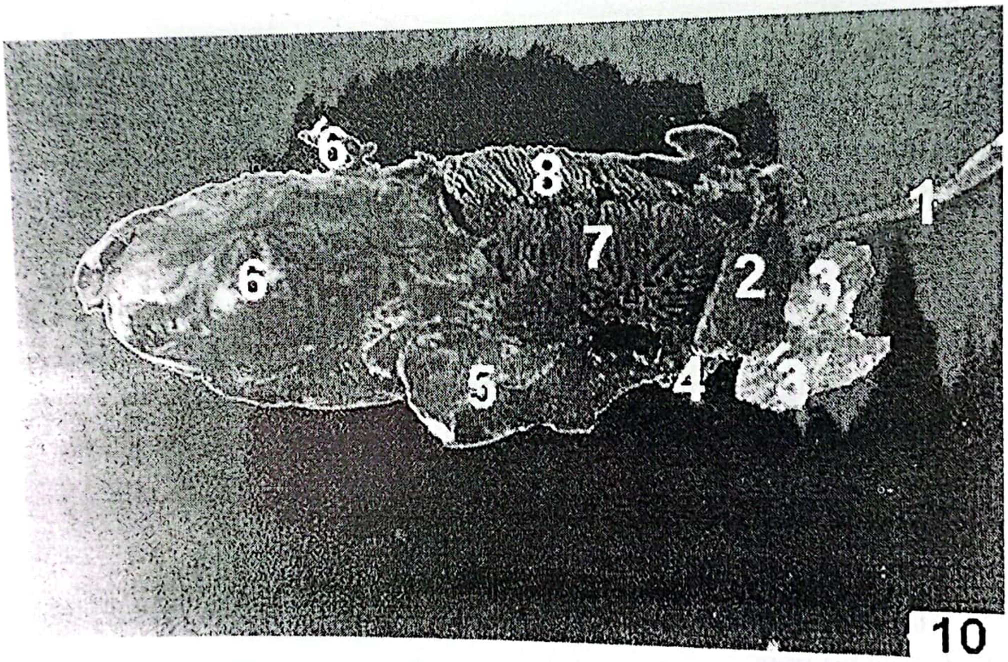


Fig. (10): A photograph of the dorso-lateral view of the air sacs of an adult pigeon showing:

1- Trachea
2- Cervical air sac
3- Axillary diverticulum of the interclavicular air sac
'3- Humeral diverticulum of the interclavicular air sac
4- Right cranial thoracic air sac
5- Right caudal thoracic air sac
6- Right abdominal air sac
'6- Diverticulum of the abdominal air sac
7- Right lung
8- Left lung

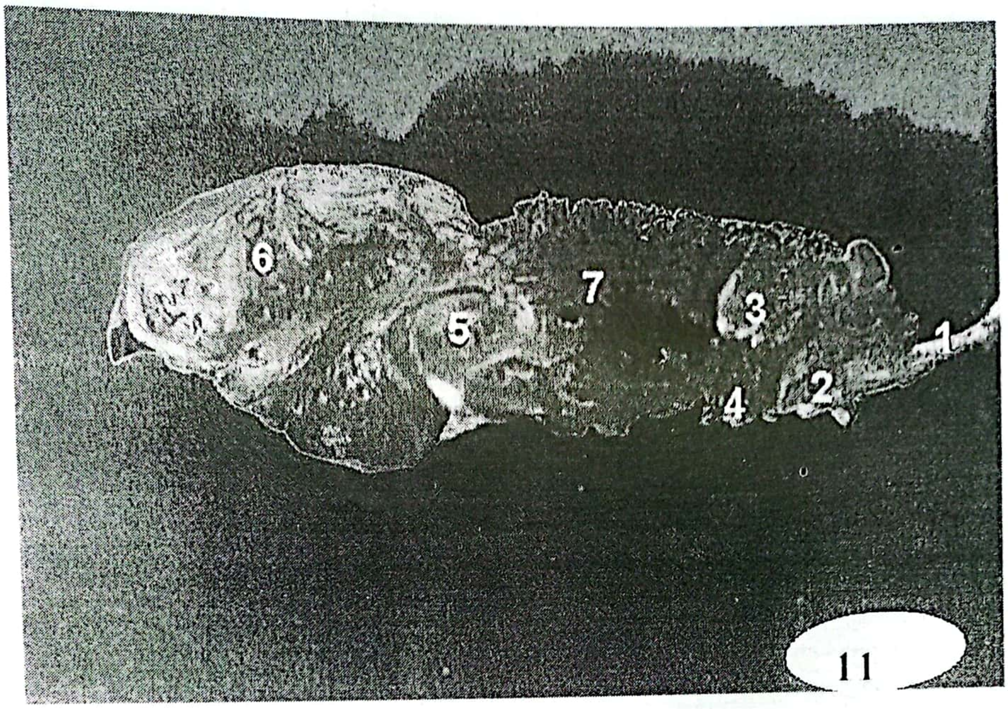


Fig. (11): A photograph of the right lateral view of the air sacs of an adult pigeon showing:

1- Trachea

2- Interclavicular air sac

3- Right cervical air sac

4- Right cranial thoracic air sac

5- Right caudal thoracic air sac

6-Right abdominal air sac

7-Right lung

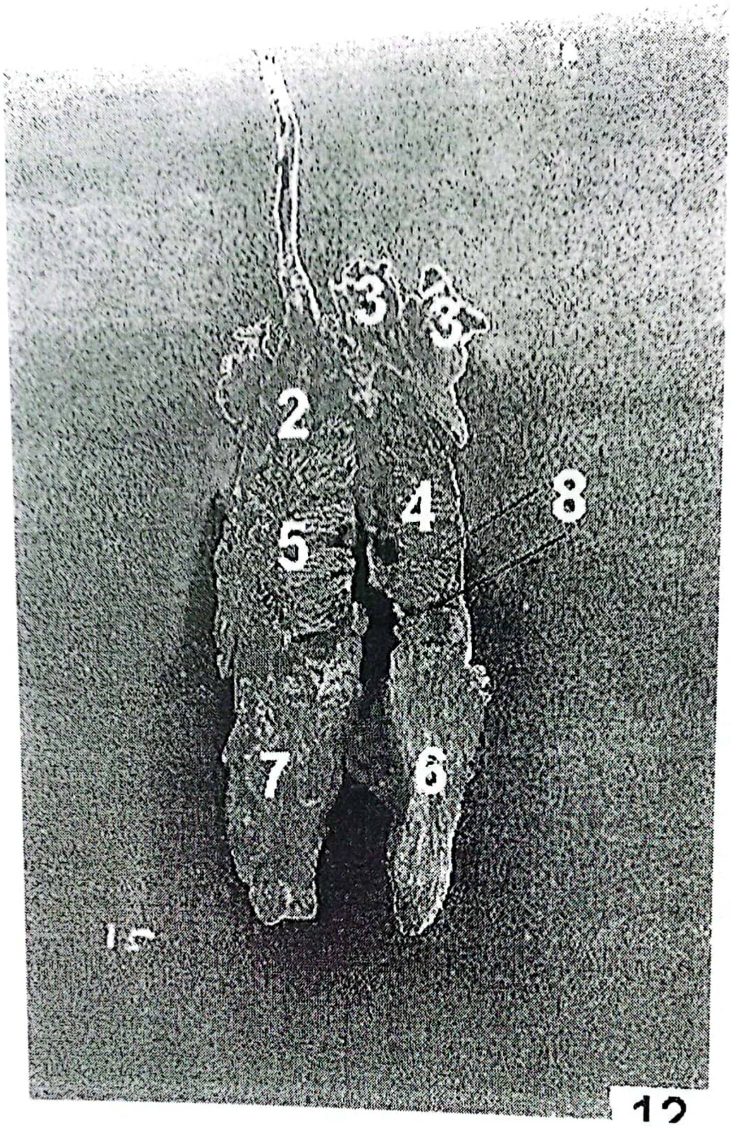


Fig. (12): A photograph of the dorsal view of the air sacs of an adult pigeon showing:

1- Trachea

2- Cervical air sac

3- Axillary diverticulum of the interclavicular air sac

'3- Humeral diverticulum of the interclavicular air sac

4- Right lung

5- Left lung

6- Right abdominal air sac

7- Left abdominal air sac

8- Impressions of the ribs on the lung

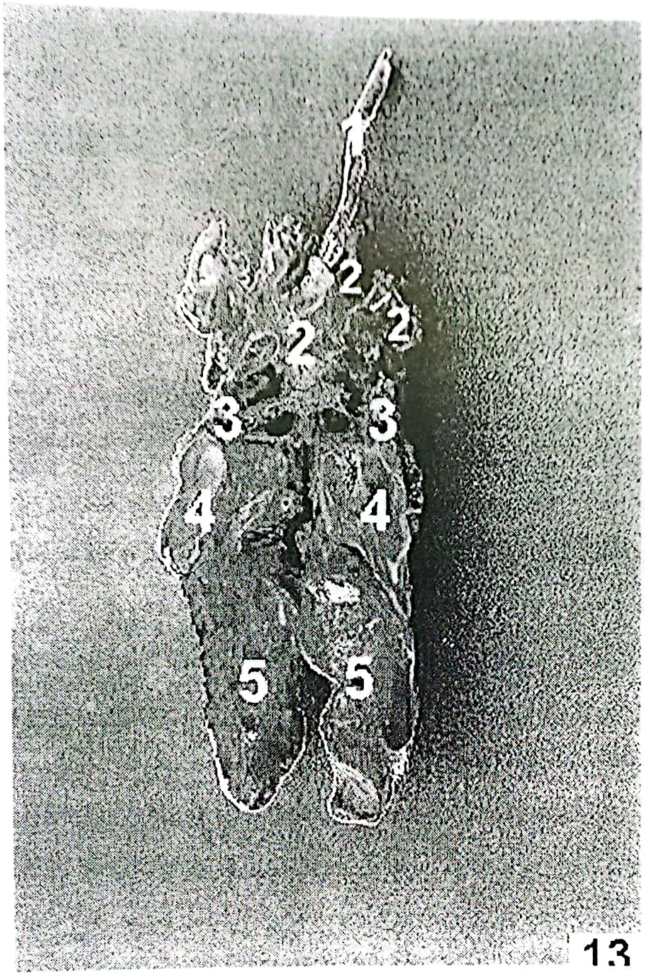


Fig.(13) : A photograph of the ventral view of the air of an a dult pigeon showing:

1- Trachea.

2 - Axillary diverticulum of (2)

'2- Humeral diverticulum of (2)

"2- Axillary diverticulum of (2)

3- Right and left cranial thoracic air sacs

4- Right and left caudal thoracic air sacs

5- Right and left abdominal air sacs

DISCUSSION

There is considerable interest today in birds as food producers, as models for biological research, or simply as objects of pleasure in aviaries and in the wild (Mc Lelland, 1990).

It is well known that air sacs are one of the main characteristics of the respiratory apparatus of birds. They are blind- ending tubes that have been entirely eliminated from the bronchi and extend outside the lungs (Nickel et al.,1977). The explanation for functions of the air sacs was provided by many authors. They are thermoregulatory, dissipating excess heat produced by muscles during flight; act as bellows to ventilate the lungs and also responsible for decreasing the density of the bird's body during flight (Nickel et al., 1977; Kent & Carr, 2001 and Dyce et al., 2002). Furthermore, Robert, Susan, Gerry and Katherine (1997) stated that when the air sacs are affected ,the birds cannot properly breathe and so even moderate exercise is tiring and race fitness cannot come.

The current study revealed that an adult pigeon possessed an unpaired interclavicular air sac and four paired sacs; namely, the cervical, cranial thoracic, caudal thoracic and abdominal air sacs.

This was in an accordance with that reported by Chiasson (1972) in the same bird; Nickel et al. (1977); Selianski (1986); Shively (1987) in the chicken as well as King (1966) and Robert et al. 1997) in most avian species. Otherwise, King (1966) and Bone (1982) revealed the presence of two subcutaneous sacs in addition to the above listed nine sacs in pelicans, cormorants, grebes, penguins, cranes and storks. However, species variations in the number of air sacs were reported by many other authors. In this respect, the definitive number of air sacs identified by King and Kelly (1956); King (1957); Akester (1960); King (1975); King and Mc Lelland (1975); Heath and Olusanya (1985); Mc Lelland (1990) and Dyce et al. (2002) in the chicken and duck and Bezuidenhout (1986) in the ostrich was eight (a single cervical, a single clavicular or interclavicular, and the three remaining pairs formed the paired cranial thoracic, caudal thoracic and abdominal air sacs).

Moreover, King and Atherton (1970); King and Mc Lelland (1984) and Mc Lelland (1990) described only seven sacs in the turkey, where the caudal thoracic sacs are completely absent. In addition, the fused cervical sacs blended with the primordial pair of lateral clavicular sacs, forming a single cervico-clavicular sac and the primordial pair of medial clavicular sacs persisted throughout life as very small separate sacs. At the same time, El-Mahdy (1994) in the adult quails and Kent and Carr (2001) in most birds identified five pairs of air sacs (cervical, clavicular, cranial thoracic, caudal thoracic and abdominal). The latter authors added the presence of a pair of less common axillary sacs, which lay on each side between the major elevator muscle (Supacoracoideus) and the major depressor muscle (Pectoralis major).

The cervical air sacs of the pigeon in the current investigation aerated nearly the vertebrae starting from the 3rd or 4th cervical up to the 2nd thoracic, however, King and Kelly (1956); King (1975); Nickel et al. (1977); Selianski (1986) and Shively (1987) reported that these sacs in the adult chicken aerated from the 3rd or 4th thoracic up to the 2nd cervical vertebrae in addition to the first two vertebral ribs. The touch observed between the two cervical sacs in the pigeon was also observed by Akester (1960) in the duck. Furthermore, Cover (1953c) in the turkey stated that the tube-like cervical diverticula passed cranially along the cervical vertebrae and extended caudally as far as the 4th caudal vertebra and these diverticula apparently aerated the cervical, thoracic, synsacral and caudal vertebrae, as well as every vertebral rib.

The two diverticula (humeral and axillary)of the interclavicular air sac seen in the current results were also observed in the chicken and turkey by Duncker (1971); Nickel et al. (1977) and Dyce et al. (2002). The latter authors added that ,therefore, compound fractures of the humerus might introduce infection to the air sacs and lungs. However, King (1975) also in the chicken reported the presence of three diverticulae given off from the clavicular sac (pectoral, humeral and axillary), which lay between the muscles of the shoulder joint. While, an axillary diverticulum was only given off from each clavicular sac in the quail (El-Mahdy,1994) which aerated the bones of the pectoral girdle. Moreover, Cover (1953c) reported that the cervico- clavicular sac of the turkey aerated the sternum and humerus. On the other hand, Shively (1987) described the axillary diverticula in some species of chicken to be derived from the cranial thoracic sacs. Robert et al. (1997) added that the pressure exerted from the interclavicular sac upon the syrinx is essential for vocal sound production in most birds.

The independency of the cranial thoracic air sacs in the present study was in an agreement with the findings of King (1975); Nickel et al. (1977); King and Mc Lelland (1984) and Dyce et al. (2002) in the domestic fowl. Moreover, the connections observed in the current work of the cranial thoracic sacs with the interclavicular sac, cervical sacs and caudal thoracic sacs were not reported in other species of birds. In view of our study, this might facilitate the air flow in them, thus improving the performance of functions of the air sac system in the pigeon.

Observations of the recent investigation showed that the caudal thoracic sacs were cone-shaped and extended from the 3rd or 4th rib up to about 1cm. ventral and caudal to the last rib and were much bigger than the cranial thoracic sacs. It was also reported by Akester (1960) in the duck as well as El-Mahdy (1994) in the quail that the caudal thoracic sacs were larger than the cranial thoracic ones and those of the quail were rectangular in shape and extended from the 2nd to 6th ribs. Controversy, King (1975) and Mc Lelland (1990) in the chicken described the caudal thoracic sacs as a pair of flattened ear-shaped sacs which were much smaller than the cranial thoracic ones. Moreover, the caudal thoracic air sacs in the turkey were completely absent even in the early embryo (King and Atherton, 1970).At the same time, contrary to that observed in the pigeon, each caudal thoracic sac in the chicken as recorded by King (1975) was entirely excluded from direct contact with the viscera because it was covered medially by the cranial thoracic and abdominal sacs.

Regarding the abdominal sacs, the recent findings in the pigeon simulated those described in the chicken and duck (King, 1975; Nickel et al.,1977; Selianski, 1986; and Dyce et al., 2002), the turkey (King and Atherton, 1970) as well as in the quail (El-Mahdy, 1994) in that such air sacs were paired, occupying either side of the body cavity from the lungs cranially to the synsacrum and pelvic bones caudally and surrounded the abdominal and pelvic viscera. In this connection, Cowles and Nordstrom, (1946) and Kolda and Komarek, (1958) stated that the juxtaposition of the abdominal air sacs and the testicles might cool them. In addition, Fowler, (1991) recorded that the femur is the only pneumatized bone in the ostrich and emu via a femoral diverticulum of the abdominal air sac; such a diverticulum was neither discovered in our results nor in the chicken by King (1975). Furthermore, the recent investigation described a single diverticulum given from each abdominal sac which aerated the synsacrum and the pelvic bone, while King (1975) in the chicken ascertained the presence of a pelvic group consisting of 3 perirenal diverticula, aerating the pelvic girdle and the synsacrum, in addition to the very small femoral group of diverticula from each abdominal sac. At the same time, our results revealed the nearly equal right and left abdominal sacs , as observed from corrosion casts, however, Nickel et al.(1977) in the chicken and El-Mahdy (1994) in the quail, declared the greater volume of the right sac than the left one.

Unfortunately, the volumes of the lungs and individual air sacs in the present study were not estimated, however, the amount of the injected cast material used (70-80 ml) for each bird might indicate the capacity of the respiratory tract in the pigeon. In this respect, Chiasson (1972) recorded that the various air sacs of such bird contained about 82% of the total volume of air in the body, about 17% contained in the lungs and about 1% in the trachea and added that, compared to most other species of birds, the pigeon had a high ratio of lungs to air sac volume. Also, measured from casts, the maximum capacity of the whole tract in heavy breeds of chicken was about 500- 550 ml (in the males) and 275-300 ml (in the females) as recorded by King and Payne (1962). While, the total volume of the respiratory tract of live white leghorn hens about 1 year old and weighing about 1.6 kg was about 170 ml as given by Scheid and Piiper (1969).Furthermore, Dehner (1946) gave the total respiratory volume in the duck as being 277 ml in the male and 198 ml in the female.

It is worthy to mention that the variations in the number and shape of the air sacs in different species of birds might be due to the difference in the nature and power of flight among such birds. Moreover, it seemed more likely that air sac volume might not directly correspond with the flying ability of the bird.

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