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Review

Anatomy of respiratory system in poultry

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ABSTRACT

Respiration is one of the functions that has vital importance for the continuity of metabolism. The level of metabolic activity of a living organism is dependent on the respiratory system which mediates the transport of oxygen to tissues and the accumulation of accumulated carbon dioxide. Naris, cavitas nasalis, larynx, trachea, syrinx, bronchus primarius (mesobronchi), bronchi secundarii, bronchus tertiarius (parabronchi), air capillaries, pulmo, air sacs and pneumatic bones form respiratory tract of a bird. Half of the air taken in inspiration goes to the caudal air sacs, and other half goes to the cranial air sacs over the lungs (leaving oxygen and loading carbon dioxide). In the expiration while the air in the caudal sacs passes through the lungs (leaving oxygen and loading carbon dioxide) to the trachea, the air in the cranial sacs passes to the trachea.

Kanatlı hayvanlarda solunum sistemi anatomisi

ÖZ

Solunum, metabolizmanın devamlılığı için hayati öneme sahip olan fonksiyonlardan birisidir. Bir canlının metabolik faaliyet düzeyi dokularına oksijen taşınmasına ve birikmiş karbondioksitin toplanmasına aracılık eden solunum sistemine bağlıdır. Bir kuşta solunum yolunu naris, cavitas nasalis, larynx, trachea, syrinx, primer bronchi (mesobronchi), sekonder bronchi, tersiyer bronchi (parabronchi), air capillaries, pulmo, air sacs ve pneumatik kemikler oluşturur. İnspiration'da alınan havanın yarısı caudal hava keselerine, diğer yarısı ise akciğer üzerinden (oksijeni bırakıp karbondioksit yüklenerek) cranial hava keselerine gider. Ekspiration'da caudal keselerdeki hava akciğer üzerinden (oksijeni bırakıp karbondioksit yüklenerek) trachea'ya geçerken, cranial keselerdeki hava da trachea'ya geçer.

INTRODUCTION

The numbers of breathing depend on the size of the birds. While a hummingbird breathes 143 times a minute, the turkey changes air 7 times. Naris, cavitas nasalis, larynx, trachea, syrinx, primer bronchi (mesobronchi), secondary bronchi, inferior bronchi, air capillaries, pulmo, air sacs and pneumatic bones form respiratory tract of a bird (1).

1. NARIS (Nostril)

Os nasale and os premaxillae form its skeleton. If the caudal edge of this hole is round holorhinal, slit-shaped schizorhinal and two holes on each side take the name amphirhinal (13,15, 25). In poultry the cartilage leaf in the ventral part of the naris is called lamella verticalis naris (12). This cartilage is not found in duck and goose (15).

1.1. Cavitas nasalis (Nasal cavity)

Os premaxillae in dorsal, os nasale and os lacrimale in dorsolateral, os palatinum and vomer on the base form its skeleton. Cavitas nasalis is divided into two spaces, right and left, through septum nasale, partly bone, partly cartilage (2, 13). Septum nasi is complete in the chicken (10). As right and left nasal cavity are apart from each other in some species including the chicken, it is called nares perviae, in some of the water bird as nasal septum is the hole on the front side it is called nares perviae (13, 24). The conchae in cavitas nasalis clean and warm the air before it enters the respiratory tract. Most birds have three conchae called concha nasalis rostralis, concha nasalis media and concha nasalis caudalis (2). Concha nasalis rostralis is found on the front of the nasal cavity. This concha, which is not found in the quail (23), comes out of the ventral of the naris in the chicken, undertakes the task of changing the direction of the air flow.

Concha nasalis media is the largest concha of the nasal cavity and is found in almost all poultries (2). This concha is clinically important because it is associated with sinus infraorbitalis (the only paranasal sinus in birds). Sinus infraorbitalis is a paranasal sinus, located at the rostral angle of maxillar and nasal bone (24). In addition, sinus infraorbitalis is associated with the cervicocephalic air sac. Sinus infraorbitalis is located in the ventromedial of orbita and has many diverticula (2). Concha nasalis caudalis is a protrusion in regio olfactoria and originating from the lateral wall of the nasal cavity. This concha is important for smelling, filtering particles in the air, water and heat economy (23).

The concha septalis, which is also in the fourth, is a concha

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from the septum nasale and seen in the shearwater. Cavitas nasalis is divided into three regions called regio vestibularis, regio respiratoria and region olfactoria. Among them regio vestibularis is the region where concha nasalis rostralis is and gl. (glandula) nasalis's channel is opened. It is covered with cutaneous mucosa (13). In goose gl. nasalis; a crescent-like structure extending in the dorsal and caudal of the bulbus oculi is a structure which consists of the only lobe (29). Regio respiratoria is the regio where concha nasalis media is located and which is covered by respiratoric mucosa. Regio olfactoria is the area where concha nasalis caudalis is located and which is covered by olfactoric mucosa (13).

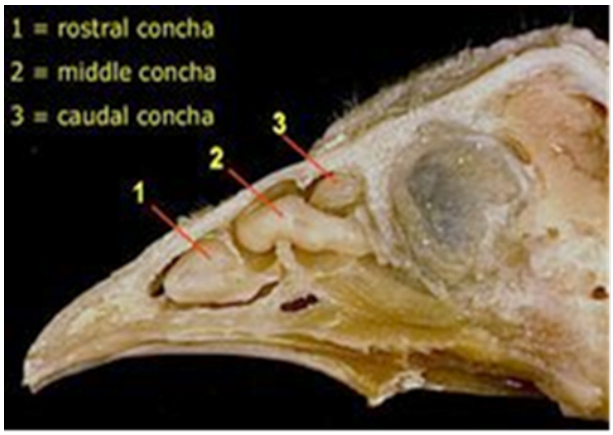

Figure 1 Cross section of the nasal cavity of birds (3)

2. LARYNX

In poultry larynx consists of two parts including larynx cranialis and larynx caudalis. Larynx cranialis is located at the beginning of the trachea and is only responsible for respiratory. Larynx caudalis is located at the end of the trachea and also acts as a sound organ (7, 25). Birds are different from mammals in terms of larynx at the beginning of trachea not having lig. (ligamentum) vocale.

Mons laryngealis; in the base of pharynx and in the caudal of the tongue, is the protuberance shaped by the muscles and cartilages under the larynx cranialis's mucosa (15, 19, 25). Mons laryngealis is seen as prominent due to cart. (cartilago) arytenoideas and muscles under its mucosa. Mons laryngealis is covered with cutaneous mucosa, its spikes include papilla rows which are towards the esophagus as well. The slit-like hole in mons laryngealis and opening to the cavitas laryngealis, the cavity of larynx, is called glottis. In the chicken and in the goose, the sulcus extending from the back end to the back of glottis is called sulcus laryngealis. Cavitas laryngealis is covered with respiratoric mucosa (13).

It was noted that the glottis width, which is the entrance of larynx, is nearly twice as large as in Gerze's cock to the chickens (28). It has reported that there were two transversal papilla rows with rostral and caudal positions whose spikes enabling the transfer of food to esophagus are towards caudal in domestic poultry (15, 25), Denizli rooster (31), long-legged buzzard (19) on mons laryngealis in the shape of tuber, only transversal papilla row in seagulls (16) in the same place. It has been reported that the sharp point of mons laryngealis in the stork is in the shape of a small triangle directing to caudal and there are 1-3 papillas in mons laryngealis (27).

2. 1. Cartilagines laryngeales

Larynx consists of only cart. cricoidea and cart. procricoidea and two cart. arytenoideas, four cartilages in total. Procricoidea with two cart. arytenoidea total of four cartilages are formed (7, 15, 18, 19, 20, 24, 25). There is no cart. thyroidea and epiglottis (23, 24). Cart. cricoidea is in the form of tongs, the bump on the corpus found in the median is called crista ventralis. The thin, flat area extending from corpus to the dorsal takes the name ala. The ala on the right and left side with cart. procricoidea on the dorsomedian shapes the joint (13). It has been determined that cart. cricoidea forms the entire ventral and caudodorsal roof of larynx, is the largest cartilage of larynx and ossified (29).

Cart. procricoidea is a comma-like small cartilage in the dorsomedian position between cart. cricoidea's ala and cart. arytenoidea. There are corpus at the front and cauda extending towards the back. Cart. arytenoidea is in the form of a sling. Its only protrusion to the front is named proc. (processus) rostralis, its protrusion to the back is named proc. caudalis. The joint-forming part with cart. procricoidea forms the corpus of cartilage (13).

Figure 2 Larynx cranial dorsal view (27)

a: Sulcus laryngealis, b: glottis, c: m. cricohyoideus, arrow: crista ventralis, arrowhead: Papilla's in mons laryngealis

2. 2. Articulationes larynges (Larynx joint)

The synovial joints of larynx are art. procricoarytenoidea, art. procricocricoidea, art. intracricoidea and art. cricoarytenoidea. Art. intracricoidea is formed between ala and corpus of cricoidea. In median plane, the combination of right and left corpus arytenoideas with each other and the combination of right and left ala cricoideas between each other are like articulatio fibrosa (13).

2. 3. Musculi laryngeales (Muscles of larynx)

The inner muscles of larynx are called musculus (m.) dilatator glottidis and m. constrictor glottidis. These muscles are located between cart. cricoidea and cart. arytenoidea. The m. dilatator glottidis is superficially located just below the mucosa (28). M. constrictor glottidis is located further behind, originates from cart. procricoidea, connects to cart. arytenoidea and cart. cricoidea by surrounding glottis as a horseshoe (13). The outer muscles of larynx were specified as m. cricohyoideus, m. cleidotrachealis and m. tracheolateralis. Although m. cricohyoideus was only the outer part of larynx, it was observed that m. cleidotrachealis and m. tracheolateralis were the muscle of trachea at the same time. It has been specified that m. cricohioideus originates from os hyoideum, and is connected to the ventral of the corpus of cart. cricoidea in the form of two right and left muscle bands (28).

3. TRACHEA

The trachea, starting from the caudal of larynx cranialis, is in the ventral of the neck, just below the skin, extends to syrinx. Esophagus is found in its dorsal and is connected to the ventral of the esophagus on the median line (13, 28). The trachea consists of cartilages called cartt. (cartilagines) tracheales, of which the right and left halves are wide but with incisuras in median parts. As it is in shape of a completely closed ring, there are no m. trachealis and lig. anulare (13). The rings in the middle region of the trachea are in contact with the previous or the next ring and have a similar shape to that of " H " in goose (Anser anser domesticus). It is characteristic for the goose the bifurcation of the cartilages similar to " H " in the middle region of the trachea and a complete knitting and ossification of the tympanum (26).

The number of cartilage rings varies depending on the neck length in the poultries. For example, it has been reported that they are 100-130 in chicken (13), 120 in turkey (10), 114-134 in duck (21), 115-134 in gulls (16). As a result of the long neck due to the functional requirement, the trachea in poultry is shaped longer than the mammals. Accordingly, the air current in the trachea meets more resistant than the mammals. However, these problems have been resolved with the large diameter of the trachea (13). While the trachea was leaning against the ventro-medial of ingluves on apertura thoracis cranialis level, it was seen that it ended in the cranial of the basis cordis by dividing into two bronchus (29).

3. 1. Musculi Tracheales

Trachea has four muscles. These are m. tracheolateralis, m. sternotrachealis, m. cleidotrachealis and m. sternohyoideus. M. tracheolateralis; starting from cart. cricoidea of larynx, ends with a narrow tendo on both sides at the beginning of the tympanum (29).

M. sternotrachealis originates from the sternum, m. cleidotrachealis stems from the clavicula. Both muscles end on trachea. M. sternohyoideus is attached to the front end of trachea and larynx after originating from the sternum (13). Musculi (mm.) tracheales is also defined as the extrinsic muscles of syrinx since it indirectly provides the movements of syrinx as well as the movement of trachea (29) .

4. SYRINX

In the poultry syrinx is located at the 2nd or 3rd thoracal vertebral level, between the trachea and bronchus primarius (13) and on the basis of the heart (28). It is surrounded by clavicular air sac (24). By knitting and ossifying of the last 3-4 cartilage rings forming the trachea, the tympanum is formed (13). The tympanum is formed from 4 C-shaped cartilaginous rings in duck (34), 3-4 in gallinacean (15), 4 in denizli cock (31), 3 in ostrich (33) and 2 in goose (29). The cartilage which divides the air flow into two in Syrinx and directs to the bronchus primarius and is found in the median is called pessulus. The cranial side of the pessulus is covered by membrane semilunaris (13). This section, which forms the beginning of the syrinx, then continues with flattened syringeal rings. One end of the syringeal cartilage is free and the other end attaches to the pessilus (30). It was seen that pessulus in duck was partly in a bony structure and extended into cavum syrinx as wedge-shaped (34). According to the origin it has taken, it is divided into three classes as tracheobronchial syrinx, tracheal syrinx and bronchial syrinx. As it originates from both trachea and bronchial cartilage, tracheobronchial syrinx type is found in most birds. Syrinx is shaped from cartilages called cartt. syringeales. From these cartilages the ones originating from the trachea as shape and origin are called cartt. tracheales syringis and there are about 8 in chickens. The cylindrical part as result of the adherence of the first cart. trachealis syringis to each other, which are the continuation of the trachea, is called tympanum. The cartilages which are in the cranial of bronchus primarius and originate from this formation are cartt. bronchiales syringis. These are C-shaped. Membrana tympaniformis medialis is the part which vibrates to produce sound in the poultry. On the outer side of the same formation, membrane tympaniformis lateralis connects the cartilaginous rings to each other. One-sided extension, which originates from cartt. bronchiales syringis and is in bone or membranous structure is called bulla syringealis (13).

4. 1. Musculi syringeales

M. tracheobronchialis, m. tracheobronchialis brevis, m. tracheobronchialis ventralis, m. syringealis dorsalis and m. syringealis ventralis are syrinx muscles. Membranes called membrane tympaniformis medialis and membrane tympaniformis lateralis are controlled by these muscles and sound is produced (6). The syrinx's function is to create sound. When the syrinx muscles contract, the tension of the tympanic membranes held on to the inner surface of the trachea changes. The air passing through these tympanic membranes provides the formation of sounds specific to the poultry (32).

5. SACCI AEROPHORI

They are thin-walled with sac-like appearance structures of the respiratory system. They were formed as a result of extrapulmonary extensions of the bronchus (10,13). The ability to transmit gas is very low in the air sacs as the vascularization is not good and they only serve as airway (32). Air sacs do not fully swell with air. They are not in direct contact with each other (10). They associate with the lungs through the bronchus. Some of them pneumatize some of the bones with diverticula

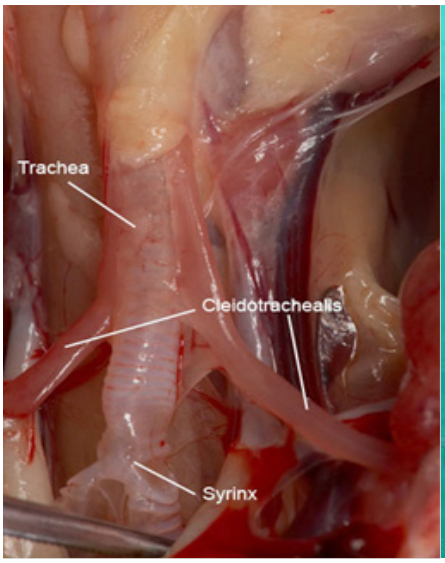

Figure 3 Normal syrinx (4)

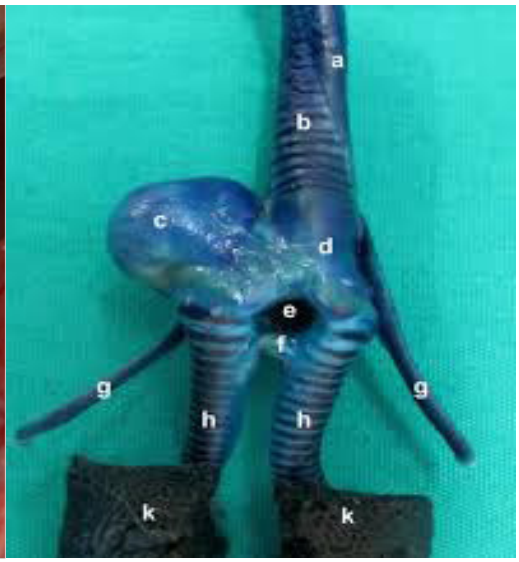

Figure 4 Dorsal aspect of syrinx in male duck (34)

a: m. tracheolateralis b: trachea c: bulla syringealis d: tympanum e: foramen interbronchiale f: lig. interbronchiale g: m. sternotrachealis h: right ve left primer bronchi k: lung

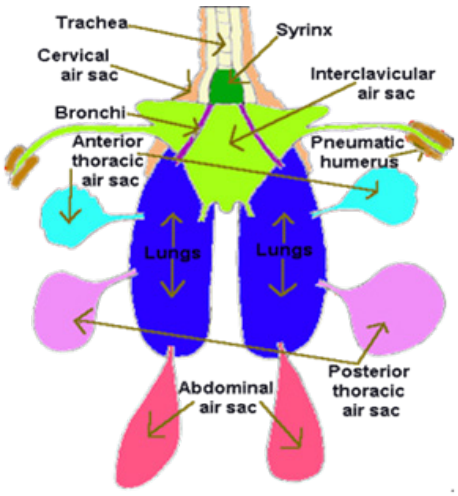

Figure 4 Schematic representation of the air sacs (5)

they have formed. Some diverticula also insert between the internal organs and muscles. The air filled in the air sacs promotes the flight by increasing the volume of the poultry without increasing body weight and pneumatizing some bones. In birds with good flying ability, air sacs are more advanced. Air sacs also help to provide balance among body parts. They are also reported that they play an important role in thermoregulation, and at the same time, they have the effect of strengthening the sound in songbirds. The embryo has six pairs of air sacs, two of which later combine in the median and form saccus claviculares (13). First abdominal, then respectively; saccus cervicalis, saccus thoracicus cranialis, saccus thoracicus caudalis, and saccus interclavicular develop (10). In the domesticated poultry and some birds, another pair of sacs join to form another median air sac, saccus cervicalis. Other sacs stay as pair. For this reason, an adult poultry mostly has eight air sacs. It has also been reported that there are subcutaneous air sacs in storks, pelicans, crane and herons (13). Saccus cervicalis, saccus claviculares and saccus thoracicus cranialis originate from seconder bronchi, which separates from the first intrapulmonary primer bronchi. These sacs are considered as a group called cranial air sacs due to the similarity in the concentration of oxygen and carbon dioxide. Saccus thoracicus caudalis and saccus abdominalis, which are called caudal air sacs originate from the second and third separated bronchus from the seconder bronchi and from the continuation of intrapulmonary primer bronchus. The concentration of oxygen is higher and the concentration of carbon dioxide is lower in the caudal air sacs than the cranial air sacs (14).

5. 1. Saccus cervicalis

They are found on cranial thoracal air sacs, in the cranial of the lungs. Both sacs contact with each other in medial and median makes a septum. There are two arteria carotis communis in this septum. It starts from ventrobronchus cervicalis via ostium cervicale and the connection with the lung is enabled in this way. They are in the appearance of diverticula system between the trachea and the dorsal of the esophagus and the lungs, lying in the ventrolateral of the neck muscles. Each sac has ductus intertransversarius consisting of cervical vertabrae in the neck and lying in canalis transversarius. They pneumatize neck vertebrae (10). One of the diverticula it has shaped are diverticula vertebralia, which are tubular structures inside the columna vertebralis and the other in the outside lying forward and backward. The part lying outside reaches the axis in the cranial. It surrounds the vertebrae and pneumatizes them (13).

However, the first four vertebrae were not found to be pneumatized in the long-legged buzzard (17). Some birds also have diverticula called diverticula intermuscularia. These diverticula cover the neck muscles and accompany the branches of plexus brachialis (29).

5. 2. Saccus clavicularis

Initially it consists of four sacs in total, one pair of lateral and one pair of medial. From these sacs those belonging to the same side first combine among each other. Then the right and left sacs combine on the median line and become a single sac (13). In the ostrich, the lateral clavicular air sac is like the other birds except for the absence of diverticulum humerale (8). Saccus clavicularis creates diverticula intrathoracica and diverticula extrathoracica. Diverticula intrathoracica consists of diverticula sternalia extending along the sternum, diverticula cardiaca around the heart, and diverticula intrapulmonale in two right and left parts between two lung lobes in the dorsal of the syrinx (29). Diverticula extrathoracica includes diverticulum subscapulare extending between scapula and thorax, diverticulum subpectorale under mm. pectorales, diverticulum suprahumerale covering caput humeri and associating with diverticulum subscapulare and diverticulum axillare, diverticulum axillare dispersed among the muscles in shoulder region and diverticulum humerale shaped by diverticulum axillare in most species and pneumatizing humerus (13). It has also been reported that a large diverticulum gastrica originating from the median compartment of the saccus clavicularis and covering the caudal part of the proventriculus is found in the ostrich (8).

Esophagus, the trachea and accompanying vessels and nerves and syrinx and its related muscles are hung either among the loops of saccus clavicularis or between the clavicular and cervical sacs. Diverticulum esophagotracheale is between the esophagus and the trachea. Diverticulum costalia is found between sternal ribs and the heart (10).

5. 3. Saccus thoracicus cranialis

They are usually double (13). In the ostrich they are also found equal in size as right and left (8). The ostium intermedium located in the caudomedial where the main bronchus enters originates from ventrobronchus caudalis in en lateral via intermedium craniale. It is located in ventral of the lungs and lateral of the heart. They reach up to the last rib in caudal (13). The visceral face of the saccus thoracicus cranialis was found to be adjacent to the caudal of the heart, the cranial of the liver and the caudal end of the esophagus (29). They do not shape diverticula (8, 13, 29).

5. 4. Saccus thoracicus caudalis

They are usually double (13). In the ostrich they are found equal in size as right and left (8). They originate from bronchus intermedius caudalis via ostium intermedium caudalis. This sac where there are traces belonging to the last ribs of its facies lateralis extends in the caudal of saccus thoracicus cranialis right and left in dorsolateral position (29). The one on the left extends more to the caudal than the one on the right and partly covers the stomach. For this reason, the right and the left sacs are asymmetric. The sacs are also in touch with the lung, the liver, sacci abdominales and intestines (13). They do not shape diverticula (8, 13, 29).

5. 5. Sacci abdominales

They are usually double. It's the continuation of the main bronchus. It starts from ostium caudale. It is the most voluminous in air sacs. It partially covers the abdominal organs by getting into the abdominal cavity in the dorsal. As the development of the left one is blocked by the stomach, the one in the right is more voluminous than the one on the left (13). In the ostrich, the left abdominal air sac was found to be significantly larger than the right (8). The left abdominal air sac in the duck is in two parts, cranial and caudal. It was specified that the caudal part ventilated the last three ribs and synsacrum and was larger and wider than the cranial sac (11). They shape some diverticula. These diverticules enter among some of the abdominal organs and between these organs and the abdominal wall (13). These sacs are in contact with the cock testicles. Although the testicles are in the abdomen, spermatogenesis is regulated by cold air coming to these sacs (10). Most birds have diverticula perirenalia extending laterally along apertura pelvis cranialis adjacent vertebrae and kidneys and diverticula femoralia pneumatizing pelvis and femur (13). Diverticula perirenalia extends from the beginning of diverticula femoralia as cranial and caudal (The two diverticula also originate from the funnel shaped space in the sacci abdominale) (8).

6. PULMONES (LUNGS)

The poultry have two bright red and remarkably small lungs (15, 24). They are not divided into lobes as in mammals. The dorsal side of the lungs is blunt and parallel to columna vertebralis. The ventral side is sharp and approximately attached to the costosternocostal joint level. Pleural space is absent (24).

There are sulcus costalis on facies costalis looking to costae for ribs. Since there is no pleura for the lungs as in the mammals, the poultry lung is connected to the surrounding tissues via fibrous tissue (6). Between two sulcus costalis is called torus intercostalis. Angulus craniodorsalis has torus marginalis cranialis, angulus caudodorsalis has torus marginalis caudalis. Tori intercostales and tori marginales are called tori pulmonales. The cranial side of the lung is called margo cranialis, the caudal side is called margo caudalis, the side separating facies costalis from facies vertabralis is called margo costoseptalis, the side separating facies vertabralis from facies septalis is called margo vertabroseptalis (13).

Bronchus primarius has 4 groups of bronchi secundarii. There are anterior and posterior bronchi secundarii, which join together to several large tertial bronchial roots. The anterior group; each containing four channels which are associated with the dorsal surface of the primary bronchus immediately after entering the lung. The posterior group contain approximately sixteen channels, eight or nine of which are associated with the dorsal face of primordial bronchus and seven or eight of which are associated with its ventral faces (1).

6. 1. Bronchus primarius

After the trachea has entered the chest cavity, it shapes the

syrinx and then is separated into two main bronchus. These parts enter from hilus of the lungs in ventral direction with a horizontal section together with blood vessels (15, 24). It moves as intrapulmonary bronchus primarius within pulmonary paranchyma and when it reaches approximately half of the lung, an extension called vestibulum occurs (15). Four secondary bronch which branch on the ventral surface of the lung and called ventrobronchi are seperated from the wall of the vestibulum in the main bronchus (24).

6. 2. Bronchi secundarii

The main bronch, called mesobronch, rising gently to the dorsal in pulmonary paranasal, extends to the caudal border of the lungs and continues until the abdominal air sacs (24). Bronchus primarius give four groups of bronchi secundari according to the regions they have spread throughout the course in the pulmones (7,15).

6. 2. 1. Bronchi medioventrales

They originate from the dorsomedial of the cranial part of intrapulmonary primer bronchus. They are usually four and have dispersed in medial and ventral regions of the lung with parabronchus (22,29). Cranial air sacs are associated with 1st, 2nd and 3rd bronchi medioventrales (29).

6. 2. 2. Bronchi mediodorsales

They originate from the dorsal wall of the caudal side of the intrapulmonary primer bronchus. They are located in the medial and dorsal areas of the lung with parabronchus (13, 29). They are composed of ten branches arranged in a row. No direct association of these bronchuses with the sacci pneumatici has been observed (29).

6. 2. 3. Bronchi lateroventrales

They originate from the opposite of bronchial mediodorsales which is the ventral wall of the side of the caudal of intrapulmonary primer bronchus. There are ten in number in geese (29). They are associated with saccus thoracicus caudalis (22). The polygonal chambers which carry air from the bronchi secundarii and parabronchi to pneumocapillaris are called atria. But they are not the same as mammalian lungs. At the base of each atrium there are holes called infundibula which open to pneumocapillaris (13).

6. 2. 4. Bronchi laterodorsales

Bronchi laterodorsales has been reported to be dispersed in the lateral part of the lung by originating between bronchi mediodorsales and bronchi lateroventrales and from the lateral of mesobronchus (29). Intrapulmonary primary dorsomedial portion of the bronchus 7-10 laterodorsal secondary bronch start from dorsomedial part of intrapulmonary primary bronchus (22).

6. 3. Bronchus tertius

The bronchus which are the continuation of the bronchi secundarii and in the case of its sub-branches are called parabronchus. The number of parabronchus varies from species to species, but it is more in better flying birds (1). Atria and infundibula, which are curved narrow tubes, winding and narrow air capillaries are called pneumocapillares (13, 29). Pneumocapillares are tightly wrapped around the blood vessels and gas exchange takes place here (13). The diameter of pneumocapillares differs according to the poultry species (15). The funnel-shaped, single and large bronchus, which collects a large number of parabronchi, is called saccobronchus (13, 24). The unique features of the respiratory system in birds, shortly; air crossovers are the large surface on the parabronchus with a continuous and unidirectional air flow in the parabronchus for gas exchange and a very thin air-to-air barrier (9).

RESULT

Respiratory tract in poultry exhaled air reaching right up to parabronchus starting nares are described with differences in animal species. When compared to domestic mammals, we believe that the greatest difference between the systems is in the respiratory system.

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