A Study of the Respiratory System of the Sparrow (*Passer domesticus*)

Ben Peter Arnowitz

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A STUDY OF THE RESPIRATORY SYSTEM
OF THE
SPARROW (PASSE DOMESTICUS)

By

Ben Peter Arnowitz

A Thesis submitted to the Faculty of the
College of Liberal Arts of Marquette University in
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# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Methods and Materials</td>
<td>2</td>
</tr>
<tr>
<td>Gross Anatomy</td>
<td>3</td>
</tr>
<tr>
<td>Diagrammatic drawing of trachea and lungs</td>
<td>4</td>
</tr>
<tr>
<td>Diagrammatic drawing of air sacs and lungs</td>
<td>7</td>
</tr>
<tr>
<td>Embryology</td>
<td>8</td>
</tr>
<tr>
<td>Trachea</td>
<td>8</td>
</tr>
<tr>
<td>Lung buds, Bronchi</td>
<td>8</td>
</tr>
<tr>
<td>Air Sacs</td>
<td>9</td>
</tr>
<tr>
<td>Blood Supply</td>
<td>11</td>
</tr>
<tr>
<td>Lungs</td>
<td>11</td>
</tr>
<tr>
<td>Lymph Supply</td>
<td>13</td>
</tr>
<tr>
<td>Lungs</td>
<td>13</td>
</tr>
<tr>
<td>Nerve Supply</td>
<td>14</td>
</tr>
<tr>
<td>Lungs</td>
<td>14</td>
</tr>
<tr>
<td>Mammalian Histology</td>
<td>15</td>
</tr>
<tr>
<td>Trachea</td>
<td>15</td>
</tr>
<tr>
<td>Lungs</td>
<td>16</td>
</tr>
<tr>
<td>Bronchial Tubes</td>
<td>16</td>
</tr>
<tr>
<td>Bronchi, Bronchioles</td>
<td>17</td>
</tr>
<tr>
<td>Respiratory Bronchioles</td>
<td>18</td>
</tr>
<tr>
<td>Alveolar Ducts, Alveolar Sacs, and Alveoli</td>
<td>19</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>Pages</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Sparrow Histology</td>
<td>21</td>
</tr>
<tr>
<td>Trachea</td>
<td>21</td>
</tr>
<tr>
<td>Syrinx</td>
<td>21</td>
</tr>
<tr>
<td>Bronchi, Bronchioles, Respiratory Bronchioles</td>
<td>22</td>
</tr>
<tr>
<td>Alveolar Ducts, Alveolar Sacs, Alveoli</td>
<td>23</td>
</tr>
<tr>
<td>Physiology</td>
<td>24</td>
</tr>
<tr>
<td>Trachea, Bronchi, Bronchioles</td>
<td>24</td>
</tr>
<tr>
<td>Conclusion</td>
<td>27</td>
</tr>
<tr>
<td>Bibliography</td>
<td>28</td>
</tr>
</tbody>
</table>
Introduction

The respiratory mechanisms of birds, unlike that of mammals, are definitely adapted to the function of flight. Because of this added adaptation, we should expect, therefore, some morphological and perhaps even embryological, physiological, and histological differences. An example of a morphological difference between birds and mammals is the intricate system of air-sacs that are present in birds. This remarkable feature is probably the reason why birds are able to fly as they do.

In this thesis the writer has used the sparrow (Passer domesticus) for the basis of his experiments. This particular bird was chosen in preference to all other birds because very little work has been done on it, that is, in reference to the organization of the material concerning the respiratory system, such as its gross anatomy, embryology, histology, physiology, etc.

At times in the discussion of the respiratory system of the sparrow, the writer has made reference to the chicken (Gallus domesticus) and to the pigeon for purposes of clarification. This is especially noted in the treatment of the gross anatomy and embryology of the bird.
Methods and Materials

The sparrow used was killed by etherization. The tissue of the respiratory tract was fixed in Bouin's solution, dehydrated with iso-amyl alcohol and imbedded in paraffin. Cross sections of the structures constituting the respiratory system were made at ten microns in thickness. These sections were stained with Harris's hematoxylin and eosin.
The air enters the nostrils and is taken into the lungs through the glottis by movements of the muscles, so that there is an easy passage through the lungs at all times. The glottis has a good skeletal arrangement of four cricoid and two arytenoid cartilages. The glottis leads into the larynx which is an expanded chamber situated at the top of the trachea. Although the larynx of birds is morphologically the same as the larynx of other vertebrates from which sounds issue, in birds the voice is not produced in the larynx but in another part of the trachea—the syrinx, which is an enlarged chamber located at the point where the trachea forks into the two bronchi. The walls of the syrinx are supported by the last tracheal rings and the first bronchial half-rings. In the dorsal wall of the interior of the syrinx there is a slight vertical fold, the semilunar membrane, supported by a bony ridge, the pessulus. The voice is produced by the vibrations of the pessulus and the tympaniform membranes. Large thickenings in the lateral walls of the syrinx also play a role, and the syringeal and sternotracheal muscles aid by changing the shape of the syrinx. (1)

(1) Hyman, p. 281.
Gross Anatomy

(1) Trachea.
(2) Tracheal muscle.
(3) Syrinx.
(4) Left bronchus.
(5) Right bronchus.
(6) Right lung.
(7) Left lung.

Note

The above diagram illustrating the lungs and trachea of the chicken (Gallus domesticus) was taken from Adams' Introduction to the Vertebrates.
Gross Anatomy

The two bronchi lead into the lungs. The lungs, spongy and much higher in development than those of the reptiles, lie along the back, close to the ribs, protected by a fold of peritoneum. The peculiarity of the birds respiratory system lies in the development of large accessory air sacs that extend to the different parts of the body, thus making it pneumatic. The accessory air sacs consist of six pairs: 1) an interclavicular air sac lying dorsal to the crop in the angle formed by the two halves of the furcula or wishbone—its delicate ventral wall is in contact with the dorsal wall of the crop; 2) a cervical air sac lying dorsal to the interclavicular air sac; 3) an axillary sac between the pectoralis minor in the region of the axilla; 4) a large posterior intermediate air sac inclosed between the anterior and posterior walls of the oblique septum; 5) a small anterior intermediate air sac lying to each side of the heart; and 6) a large abdominal air sac lying on either side of the viscera. These air sacs communicate with the lungs by means of branches of the bronchi. This system not only aids in decreasing the specific gravity of the bird but also insures a more complete exposure
Gross Anatomy

of the lung tissue to the air; for the residual air is retained in the air sacs and not in the lungs as in other vertebrates, and the air in the lungs is consequently completely renewed at each inspiration. (2)

(1) Intercostal air sac.
(2) Cervical air sac.
(3) Axillary air sac.
(4) Posterior intermediate air sac.
(5) Anterior intermediate air sac.
(6) Abdominal air sac.
(7) Dorsal surface of right lung.
(8) Ventral surface of left lung.

Note

The above diagram illustrating the pleurae, bronchi, and air sacs was taken from Krogh's Comparative Physiology of Respiratory Mechanisms. (2) Adams, p. 125-126.
(1) Interclavicular air sac.
(2) Cervical air sac.
(3) Axillary air sac.
(4) Posterior intermediate air sac.
(5) Anterior intermediate air sac.
(6) Abdominal air sac.
(7) Dorsal surface of right lung.
(8) Ventral surface of left lung.

Note

The above diagram illustrating the pigeon lungs and air sacs was taken from Krogh's *Comparative Physiology of Respiratory Mechanisms.*
Embryology

Trachea:

The first indication of the formation of the respiratory system appears in three-day chicks as a mid-ventral groove in the pharynx. Beginning just posterior to the level of the fourth pharyngeal pouches and extending caudad, this laryngo-tracheal groove deepens rapidly and by closure of its dorsal margins becomes separated from the pharynx except at its cephalic (laryngeal) end. The tube thus formed is the trachea, and the opening which persists between the laryngeal end of the trachea and the pharynx is the glottis. The original entodermal evagination gives rise only to the epithelial lining of the trachea, the supporting structures of the tracheal walls being derived from the surrounding mesenchyme.

Lung buds, Bronchi:

The tracheal evagination grows caudad and bifurcates to form a pair of lung-buds. As the lung-buds develop they grow into the loose mesenchyme on either side of the mid-line. The adjacent splanchnic mesoderm is pushed ahead of them in their caudal-lateral growth and comes to constitute the outer investment of the lung-buds. The enterdermal buds give rise only to the epithelial lining of the bronchi, and the
Embryology

air passages and air chambers of the lungs. The connective tissue stroma of the lungs is derived from the mesenchyme surrounding the lung-buds, and their pleural covering from the investment of the splanchnic mesoderm.(1)

The primitive entodermal tubes form the primary bronchi, in which two divisions may be distinguished on either side, viz: a part leading from the end of the trachea to the hilum of the lung (extra-pulmonary bronchus) and its continuation within the lung, extending its entire length (mesobronchus).(2)

Air Sacs:

At ninety-six hours, the bronchi arise from the end of the trachea, ventral to the oesophagus and pass back on either side of the latter, describing near their centers a rather sharp curve that brings the dorsal ends to a higher level than the oesophagus. A very slight dilatation at the extreme end of the mesobronchus is usually interpreted as the beginning of the abdominal air sac.

Four evaginations arise on the sixth day from the mesial wall of the anterior division of the mesobronchus, which is otherwise unbranched. These represent the entobronchi; they could also be class-

(1) Patten, p. 167.
(2) Lillie, p. 328-338.
Embryology

ed as secondary bronchi. On the ninth day the first entobronchus has formed a number of branches in the anterior lobe of the lung, and two of its terminal twigs, one in the antero-dorsal the other in the antero-ventral tip of the lung, are slightly dilated and project as primordia of the cervical and inter-clavicular air-sacs respectively. The interclavicular air sac grows out to form the subscapular air-sac and at the time of hatching has approached close to the humerus.

The second entobronchus is also subdivided several times; its terminal branches extending to the dorsal surface of the lung. The third entobronchus bends ventrally, and from its base a narrow canal extends into the pleuroperitoneal membrane, where it expands into the anterior thoracic air-sac, which is much the largest of the air-sacs at this time.

The mesobronchus, which has by this time terminated posteriorly in the small abdominal air-sac, is still contained in the lung substance. Just anterior to this is a slight diverticulum, possibly the primordium of the posterior thoracic air-sac. (3)

(3) Lillie, p. 326-332.
Blood Supply

Lungs:

The lungs like the liver, receive blood from two sources, arterial blood through the bronchial vessels, and venous blood through the pulmonary artery. The bronchial arteries, from one to three for each lung, are much smaller than the pulmonary vessels, and carry blood for the nutrition of the lung. They arise from the aorta or from an intercostal artery and follow the bronchial tubes through the lung, to be ultimately distributed in three ways: 1) They supply the bronchial lymph glands, the coats of the large blood vessels, and the walls of the bronchial tubes, forming in the latter an outer and an inner plexus for the irrigation of the muscle coat and the mucous membrane; 2) they supply the interlobular areolar tissue; and 3) they spread out over the surface of the lung beneath the pleura. The bronchial veins do not have so extensive a distribution because some of the blood supplied by the bronchial arteries returns by the pulmonary veins. The superficial and deep set of bronchial veins unite at the root of the lung to drain on the right side into the large azygos and on the left into the left upper azygos vein.

The pulmonary artery which supplies the venous blood, is a very large vessel that gives branches to
Blood Supply

each lobe of the two lungs. It devides with the bron­
chi and closely accompanies them along their posterior
or superior walls. The corresponding veins pass along
the anterior or inferior walls. (These vessels do not
supply blood to the walls of the bronchi). At the apex
of the pulmonary lobule the pulmonary artery breaks up
into several small twigs, one for each atrium, supply­
ing blood to an extensive capillary plexus that spreads
over the surface of the atria and air sacs. The capil­
larly meshes are very dense and the capillary tubes very
large, so that the intervening spaces are barely wider
than the capillaries themselves.

The pulmonary veins carry blood from the pulmon­
ary capillary plexus. Each venous radicle drains an
area corresponding to several air cells or alveoli.
At first these small veins take an independant course
in the interlobular tissue, but after they have attain­
ed a certain size they accompany the arteries and the
bronchi, and, as a rule, lie along the lower and front
aspect of the latter. At the root of the lung there
are formed two pulmonary veins on each side which open
separately into the left auricle.(1)

Hill, p. 271-274.
Lungs:

The lymphatics of the lung are very extensive and accompany the two blood system. We may therefore divide them into two sets, a bronchial and an alveolar. The bronchial consists of an elaborate and fine plexus that ramifies through the mucosa and submucosa of the bronchial tubes. This set anastomoses freely with a second plexus just external to the smooth circular muscle layer of the bronchi. Lymph nodes are interpolated everywhere in these plexuses. Just beneath the pleura, all over the surface of the lung, lymphatics ramify and drain toward the root of the lung, where they join the lymphatics located in the bronchial walls.

The alveolar set accompany the pulmonary vessels. These lymphatics have their origin in a plexus that surrounds the respiratory or alveolar portions of the lungs, and then accompanies the pulmonary arteries and veins along the external surfaces of the bronchial tubes to the root of the lungs, where they ultimately unite with the bronchial lymphatics. While lymphatic nodes are present everywhere, they are particularly abundant at the root of the lung.(1)

(1) Hill, p. 274-275.
Nerve Supply

Lungs:

The nerves of the lung come from the pneumogastric and the sympathetic, and are made up of medullated and non-medullated fibers. They enter at the root of the lung and accompany the blood vessels to the terminal air passages, where they arborize about the lung alveoli just external to the epithelial lining. Many nerve ganglia are located along their course and many fine fibers are given off that innervate the musculature and epithelial lining of the bronchial tubes and the walls of the blood vessels. (1)

(1) Hill, p. 275-276.
Trachea:

The trachea is a membranous tube, which is supported by a number of C-shaped cartilaginous plates inserted into the membranous portion of its wall. These cartilages are incomplete posteriorly, the space between their free ends being occupied by fibrous and muscular tissue.

The trachea is lined by a mucous membrane consisting of a pseudostratified, ciliated epithelium, which rests on a well defined basement membrane. Numerous goblet cells are interspersed among the ciliated columnar cells.

External to the basement membrane is a layer of reticular tissue, the tunica propria. Numerous lymphocytes are scattered throughout the layer with, here and there, diffuse aggregations, and small nodules, of lymphoid tissue. The tunica propria is richly supplied with elastic fibers. These fibers form a layer between the tunica propria and the submucosa, which is the equivalent of the muscularis mucosae in the wall of the alimentary canal.

The submucosa consists of loosely arranged collagenous and elastic fibers located between the mucosa and the tracheal cartilages. This tissue becomes condensed about the surfaces of the cartilages, and joins the perichondrium. In addition, it contains small groups of
Mammalian Histology

serous and mucous glands, some of which are so deeply placed that they lie in the tissue between the tracheal cartilages.

Lungs:

The lungs constitute a paired organ occupying a great part of the thoracic cavity and constantly changing in form with the different phases of respiration. The right lung consists of three lobes and the left lung of two, and each lobe receives a branch of the primary bronchi. The outer surface of the lungs is closely invested by a serous membrane called the visceral pleura.

Each of the five lobes of the lungs is divided by thin connective tissue septa into great numbers of roughly pyramidal portions of pulmonary tissue, the lobules. These are so arranged that the apex of each points toward the hilus and the base toward the pleura.

Bronchial Tubes:

The trachea divides into two main branches called bronchi. These tubes enter the substance of the lungs at the hilus, one on each side, and then divide into smaller bronchi. These give rise to still smaller bronchi, from which bronchioles of several orders originate. Each terminal bronchiole continues into one, two, or more
Mammalian Histology

respiratory bronchioles. These break up into 2 to 11 alveolar ducts, from which arise the alveolar sacs and alveoli. Thus, the main successive divisions of the bronchial tree are: primary bronchi, secondary bronchi, bronchioles, terminal bronchioles, respiratory bronchioles, alveolar ducts, alveolar sacs, and alveoli.

Bronchi; Bronchioles:

Before the bronchi enter the lung their structure is practically identical with that of the trachea. But as soon as they enter the lung, the cartilage rings disappear and are replaced by irregularly shaped cartilage plates which completely surround the bronchus. At the same time as the cartilage plates become irregularly distributed around the tube, the muscular layer completely surrounds the bronchus. The cartilages disappear when the diameter of the bronchiole reaches 1 mm.

The pseudostratified epithelium is continued from the bronchi into the bronchioles. As the diameter of the tubes is reduced, the thickness of the epithelium is diminished until, in the smaller bronchioles, it is simple columnar in form. The columnar cells of the epithelium bear cilia throughout the greater part of the bronchial tree.

The epithelium rests on a thin, but well-defined, basement membrane. External to the basement membrane
Mammalian Histology

is a layer of reticular tissue containing lymphocytes, the tunica propria. In the larger bronchioles, lymphoid tissue may be present in the diffuse form and also as small nodules. The nodules appear most frequently at the bifurcation of the tubes.

Small groups of mucous glands are present in the submucosa connective tissue between the muscular layer and the cartilage. The glands diminish in number as the bronchioles become smaller, and are not found, as a rule in those bronchioles from the cartilages have disappeared.

The outermost layer of the bronchial wall consists of dense connective tissue which contains many elastic fibers. It surrounds the plates of cartilage and continues into the connective tissue of the surrounding pulmonary tissue and into that accompanying the large vessels.

With the progressive decrease in the size of the bronchi and bronchioles as they proceed from the trachea, the layers of their walls become thinner and some of them fuse into one layer. The smooth muscle, however, is distinct up to the end of the respiratory bronchioles and even continues in the walls of the alveolar ducts.

Respiratory Bronchioles:

The respiratory bronchioles are relatively short tubes, lined in their first part with a ciliated columnar epithelium which contains no goblet cells. A short dis-
Mammalian Histology

tance down the bronchiole, the ciliated columnar epithelium loses its cilia and becomes low cuboidal. These bronchioles have walls composed of collagenous connective tissue in which bundles of interlacing smooth muscle and elastic fibers course. They lack cartilage. A few alveoli bud off from the side of the respiratory bronchiole opposite that along which the branch of the pulmonary artery runs. These alveoli are the first of the respiratory structures of the lung and are responsible for the term "respiratory bronchiole." These bronchioles soon branch and radiate cone-like into 2 to 11 alveolar ducts which extend for relatively long distances.

Alveolar Ducts, Alveolar Sacs, and Alveoli:

The walls of these structures are greatly distended when filled with air. They are supported by an investment of collagenous fibers, among which numerous elastic fibers are present. This form of structure provides for the expansion and contraction of these spaces in the act of breathing. Bands of smooth muscle also extend over, and between, the air cells, and appear in small, knob-like enlargements about the mouths through which the air cells open into the alveolar sacs. By means of this arrangement the alveoli can be closed against irritating elements which enter the lungs in the act of breathing.
The pulmonary alveoli lie close to one another, their polyhedral form being due to mutual pressure. As the wall of one alveolus is pressed against that of another, the connective tissue, by which they are invested, forms a sort of septal partition between them. The connective tissue cells, especially certain types of wander cells (macrophages), which are present in this tissue, are known as septal cells. The air-spaces are lined by a peculiar type of epithelial structure; namely, flattened, non-nucleated protoplasmic plates among which small groups of cuboidal cells, containing nuclei, may be present. The blood capillaries, with which the lungs are richly supplied, form a closely meshed network in the fibrous tissue between the alveoli. (1)

(1) Lambert, p. 300-308.
Trachea:

The trachea of the sparrow, like that of the mammal, is a membranous tube which is supported by a number of C-shaped cartilaginous plates inserted into the membranous portion of its wall. These cartilages are incomplete posteriorly.

As in the mammal, the trachea is lined by a mucous membrane consisting of a pseudostratified, ciliated epithelium which rests on a well-defined basement membrane. The tunica propria and submucosa, unlike that of the mammal, is somewhat lacking. Only very minute quantities of these layers are recognizable.

Another differentiating characteristic of the sparrow's trachea is the size of its cartilaginous discs. The cartilage in the mammal is much thicker and its lacunae are more numerous. In both mammals and birds we have the hyaline type of cartilage.

Syrinx:

At the point where the trachea forks into the two bronchi, an expanded chamber, the syrinx, is present. It is supported by cartilage and contains a membrane operated by skeletal muscle.

As in the trachea, there is a mucous membrane consisting of a pseudostratified, ciliated epithelium.
Sparrow Histology

which rests on a well defined basement membrane. Unlike the trachea, however, the cartilaginous structures are entirely enveloped by a thick mass of striated muscle. Furthermore, there are predominantly more glandular organs in the trachea.

Bronchi, Bronchioles, Respiratory Bronchioles:

The bronchi, as in mammals, are identical in structure to that of the trachea except for the fact that their walls are somewhat thinner. Only when the bronchi enter the lungs does differentiation appear. Here, like that of the mammals, the cartilage rings disappear and are replaced by irregularly shaped cartilaginous plates which completely surrounds the bronchus.

As the bronchioles become smaller in size, the character of their walls changes. The cells of the lining epithelium become less and less crowded until in the terminal bronchioles they appear as low columnar or cuboidal ciliated cells. As the tunica propria decreases in thickness, its elastic tissue becomes more abundant than the white fibrous tissue. Smooth muscles too become more abundant. In the terminal bronchioles no cartilaginous tissue is observed.

The respiratory bronchioles of the sparrow are
Sparrow Histology
also similar in structure to that of the mammal. They
differ as do the bronchi and bronchioles in that their
walls are thinner.

Alveolar Ducts, Alveolar Sacs, Alveoli:
The alveolar ducts, alveolar sacs, and alveoli are
more numerous in the sparrow than they are in the mam­
mal. Furthermore, each alveolus of the bird are more
highly vascularized. These modifications are expected
since birds have a high metabolic rate and therefore
need a large amount of respiratory surface.
Trachea, Bronchus, Bronchioles:

Cartilaginous discs serve to keep the air tubes from collapsing. In the trachea they are incomplete; perhaps this is an adaptive feature for facilitating the expansion of the esophagus against a yielding surface when food is swallowed. In the bronchioles, cartilaginous rings are lacking; these bronchioles dilate during inspiration.

Elastic tissue is well developed throughout the respiratory system, except in the nasal passages and sinuses where there can be no stretching downward or upward on account of the bony framework. With each swallow the trachea is jerked upward, and with each inspiration there is a stretching downward. After the food has passed, the trachea resumes its original shape, and after inspiration the air is expelled and the length of the conductile tubes is reduced. Most of the elastic fibers of the tunica propria are disposed longitudinally. (1)

The trachea is lined by mucous membrane and has a ciliated epithelium upon its inner surface. The mucous membrane which also extends into the bronchi keeps the internal surface of the air passages free from impurities; the sticky mucous entangles particles of dust.

(1) Cowdry, p. 356-357.
and other matters breathed in with the air, and the incessant movements of the cilia continually sweep this dirt-laden mucous upward and outward. (2)

In addition to the ciliated cells, there are also goblet cells and deep mucous and serous glands found in the trachea. According to Carleton and Wells (1832) the goblet cells respond to local irritation and the deep glands to nerve stimulation. In the bronchioles there is an abrupt change characterized by a loss of goblet cells and of deep glands with the ciliated cells, however, more abundant. Hence, the mucous sheet for entangling air-borne foreign particles is absent. The cilia in this region probably beat effectively in a watery fluid, the amount and the source of which has not been definitely determined. It would seem, however, that some of it comes from the respiratory bronchioles, perhaps even from the alveoli. Finally, in the respiratory bronchioles, ciliated cells are gradually replaced by cuboidal cells, except in the small alveoli which are lined with thin respiratory cells. If we consider drainage in the reverse order, beginning with the alveoli, we can picture the diffusion through the epithelium of a watery fluid of hematogenous origin.

Physiology

Transverse muscle fibers join the free ends of the cartilagenous rings in the trachea. Contraction of these fibers decrease the lumen slightly. The transverse fibers are shifted toward the lumen in the bronchi and are disposed in circles or spirals. In the bronchioles, where we have the complete disappearance of cartilage, the circular muscle is proportionally most highly developed and most effective. Here contraction may obliterate the lumen. In the respiratory bronchioles, which are relatively short, the amount of muscle is reduced, partly because the wall is interrupted by bulging alveoli. Contraction of the muscle fibers aids in expiration, which may be spasmodic and protective, decreasing airborne toxic substances; or peristaltic and expulsive in character, supplementing evacuation by ciliary action. Bronchoconstriction results from stimulation of the vagus nerve, while broncho-dilation is brought about by stimulation of the sympathetic fibers, by ephedrine, atropine and other drugs. (3)

(3) Cowdry, p. 358-360.
Conclusion

Thus, the writer, by presenting a study of the respiratory system of the sparrow (Passer domesticus) with reference to its gross anatomy, embryology, histology, and physiology, has shown the differences and similarities that exist between birds and mammals. Perhaps the most distinguishing characteristic is the elaborate system of air sacs that are present in birds. These air sacs, as we have seen, are scattered throughout the body and are connected to the respiratory system at the bronchial tubes.

In addition to being a comparative study of birds and mammals, this thesis is also an attempt to present the material concerning the respiratory system of the sparrow in an organized manner.
Bibliography


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