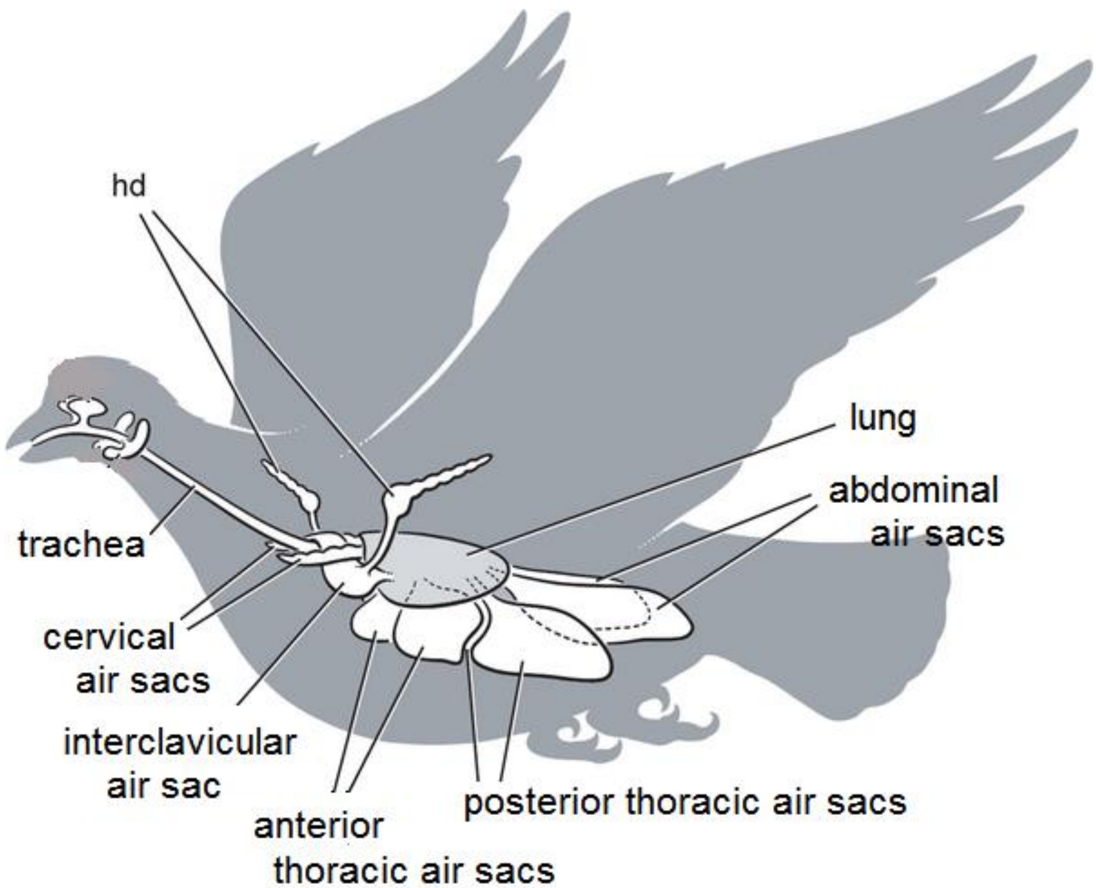
Respiratory System in Birds

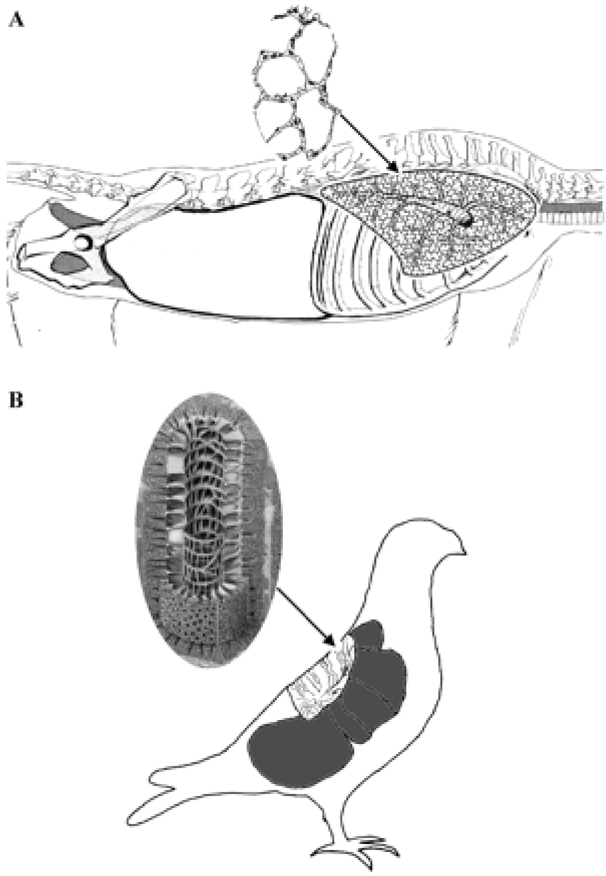
Avian Respiration

The avian respiratory system delivers oxygen from the air to the tissues and also removes carbon dioxide. In addition, the respiratory system plays an important role in thermoregulation (maintaining normal body temperature). The avian respiratory system is different from that of other vertebrates, with birds having relatively small lungs plus nine air sacs that play an important role in respiration (but are not directly involved in the exchange of gases).

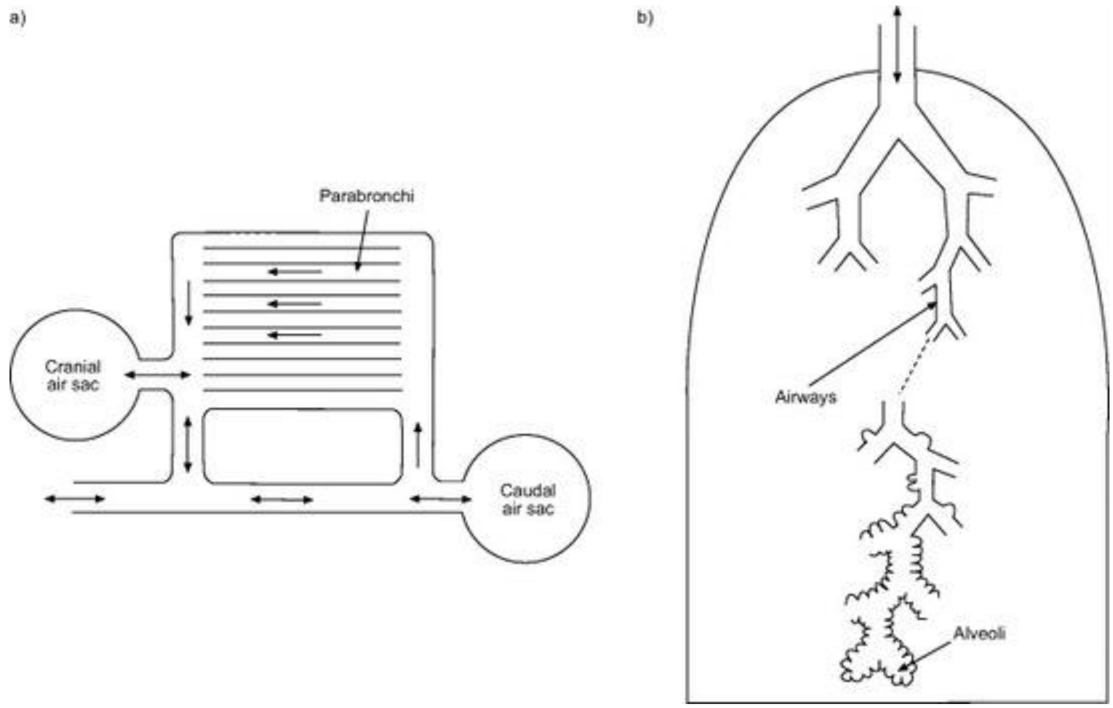


Avian respiratory system
(hd = humeral diverticulum of the clavicular air sac; adapted from Sereno et al. 2008)

The air sacs permit a unidirectional flow of air through the lungs. Unidirectional flow means that air moving through bird lungs is largely 'fresh' air & has a higher oxygen content. In contrast, air flow is 'bidirectional' in mammals, moving back and forth into and out of the lungs. As a result, air coming into a mammal's lungs is mixed with 'old' air (air that has been in the lungs for a while) & this 'mixed air' has less oxygen. So, in bird lungs, more oxygen is available to diffuse into the blood (avian respiratory system).



The alveolar lungs of mammals (Rhesus monkey; *A*) and parabronchial lungs of birds (pigeon; *B*) are subdivided into large numbers of extremely small alveoli (A, inset) or air capillaries (radiating from the parabronchi; B, inset). The mammalian respiratory system is partitioned homogeneously, so the functions of ventilation and gas exchange are shared by alveoli and much of the lung volume. The avian respiratory system is partitioned heterogeneously, so the functions of ventilation and gas exchange are separate in the air sacs (shaded in gray) and the parabronchial lung, respectively. Air sacs act as bellows to ventilate the tube-like parabronchi (Powell and Hopkins 2004).

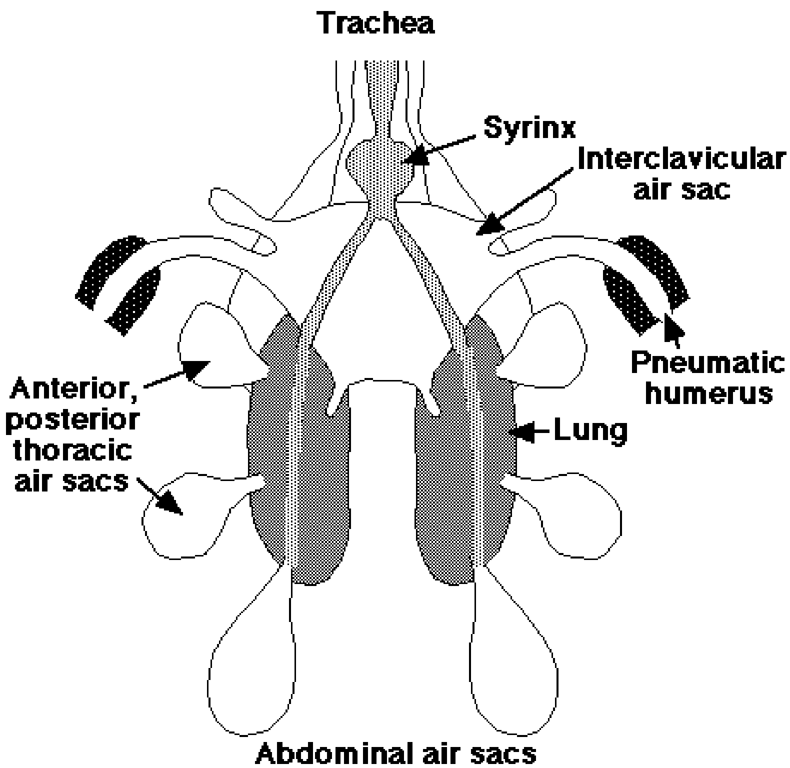


Comparison of the avian 'unidirectional' respiratory system (a) where gases are exchanged between the lungs and the blood in the parabronchi, and the bidirectional respiratory system of mammals (b) where gas exchange occurs in small dead-end sacs called alveoli (From: West et al. 2007).

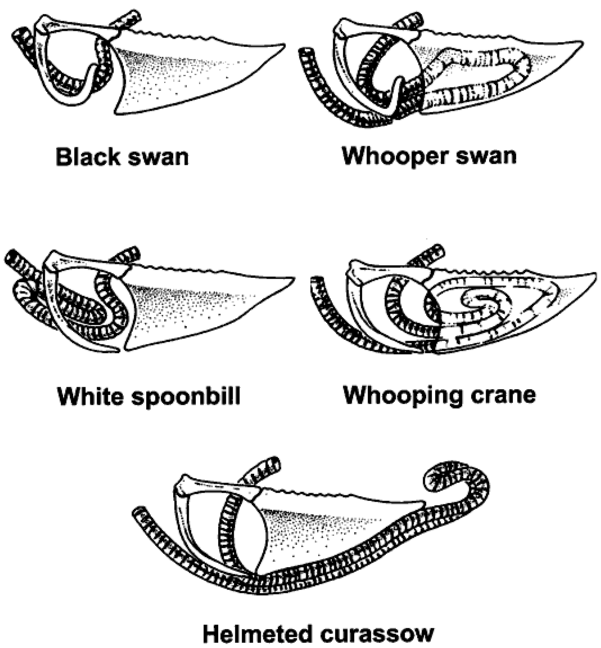
Most birds have 9 air sacs:

- one interclavicular sac
- two cervical sacs
- two anterior thoracic sacs
- two posterior thoracic sacs
- two abdominal sacs

Functionally, these 9 air sacs can be divided into anterior sacs (interclavicular, cervicals, & anterior thoracics) & posterior sacs (posterior thoracics & abdominals). Air sacs have very thin walls with few blood vessels. So, they do not play a direct role in gas exchange. Rather, they act as a 'bellows' to ventilate the lungs (Powell 2000).

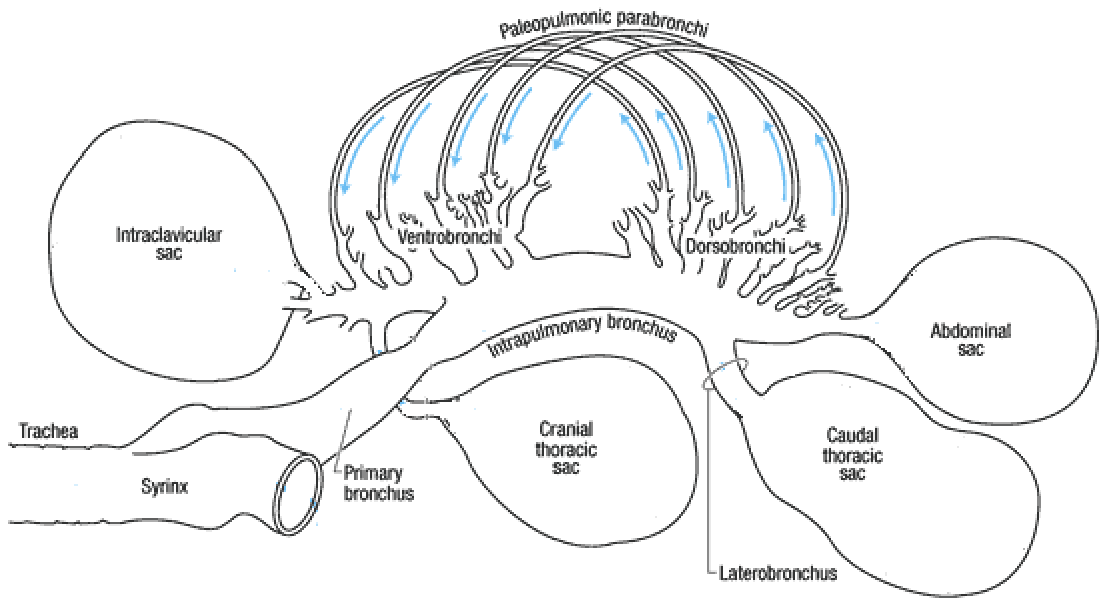


The typical bird trachea is 2.7 times longer and 1.29 times wider than that of similarly-sized mammals. The net effect is that tracheal resistance to air flow is similar to that in mammals, but the tracheal dead space volume is about 4.5 times larger. Birds compensate for the larger tracheal dead space by having a relatively larger tidal volume and a lower respiratory frequency, approximately one-third that of mammals. These two factors lessen the impact of the larger tracheal dead space volume on ventilation. Thus, minute tracheal ventilation is only about 1.5 to 1.9 times that of mammals (Ludders 2001).



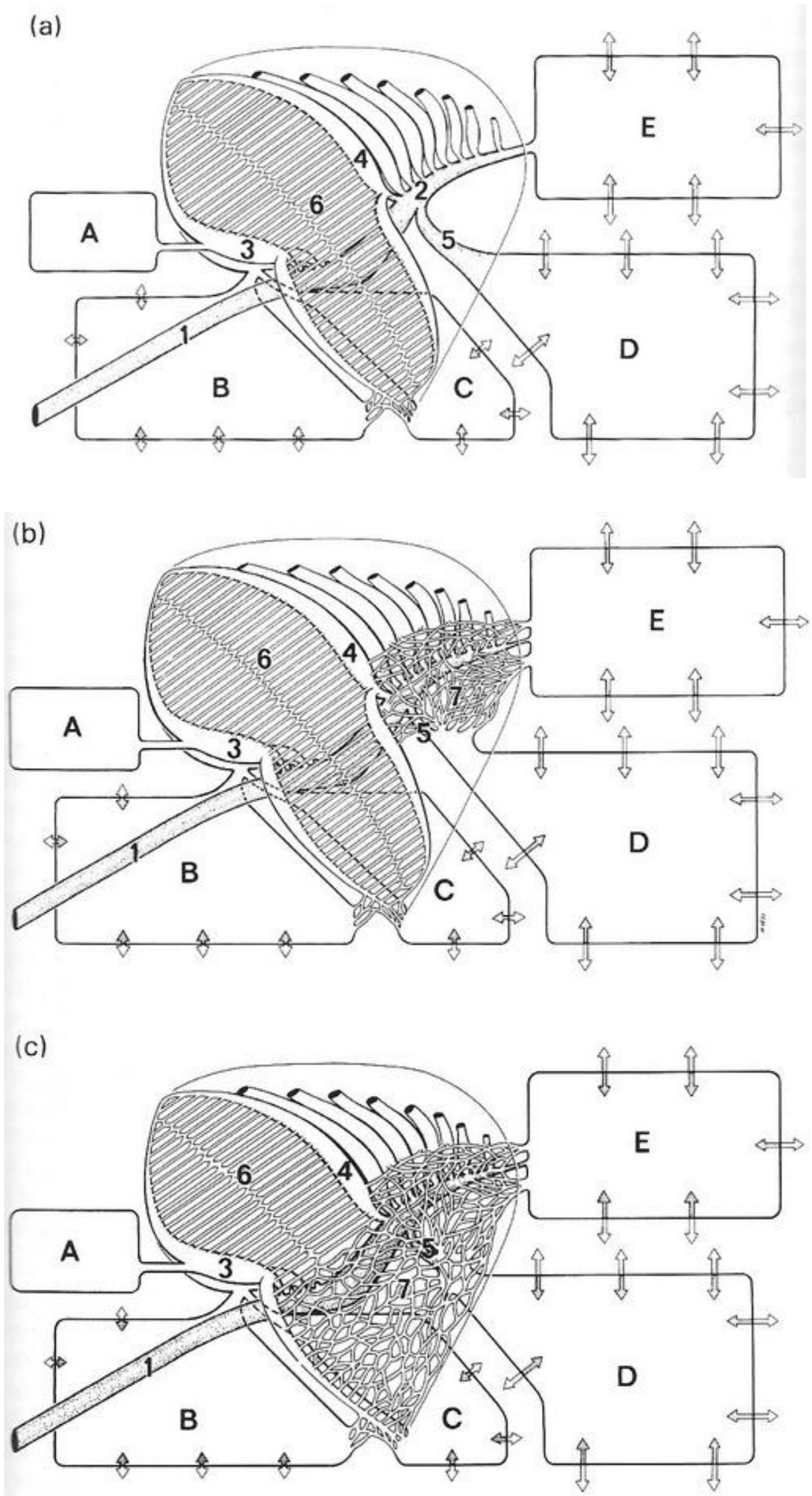
Examples of tracheal loops found in Black Swans (*Cygnus atratus*),Swans (*Cygnus cygnus*), White Spoonbills (*Platalea leucorodia*), Helmeted Curassow (*Crax pauxi*),and Whooping Cranes (*Grus americana*).

The **trachea** bifurcates (or splits) into two primary bronchi at the **syrinx**. The syrinx is unique to birds & is their 'voicebox' (in mammals, sounds are produced in the larynx). The **primary bronchi** enter the lungs & are then called **mesobronchi**. Branching off from the mesobronchi are smaller tubes called **dorsobronchi**. The dorsobronchi, in turn, lead into the still smaller parabronchi. **Parabronchi** can be several millimeters long and 0.5 - 2.0 mm in diameter (depending on the size of the bird) (Maina 1989) and their walls contain hundreds of tiny, branching, & anastomosing **'air capillaries'** surrounded by a profuse network of blood capillaries (Welty and Baptista 1988). It is within these 'air capillaries' that the exchange of gases (oxygen and carbon dioxide) between the lungs and the blood occurs. After passing through the parabronchi, air moves into the **ventrobronchi**.



Avian respiratory system showing the bronchi located inside the lungs. Dorsobronchi and ventrobronchi branch off of the primary bronchus; parabronchi extend from the dorsobronchi to the ventrobronchi. Light blue arrows indicate the direction of air flow through the parabronchi. The primary bronchus continues through the lung and opens into the abdominal air sac.

Birds exhibit some variation in lung structure and, specifically, in the arrangement of parabronchi. Most birds have two sets of parabronchi, the paleopulmonic ('ancient lung') and neopulmonic ('new lung') parabronchi. However, the neopulmonic region is absent in some birds (e.g., penguins) and poorly developed in others (e.g., storks [Ciconiidae] and ducks [Anatidae]). In songbirds (Passeriformes), pigeons (Columbiformes), and gallinaceous birds (Galliformes), the neopulmonic region of the lung is well-developed (Maina 2008). In these latter groups, the neopulmonic parabronchi contain about 15 to 20% of the gas exchange surface of the lungs (Fedde 1998). Whereas airflow through the paleopulmonic parabronchi is unidirectional, airflow through the neopulmonic parabronchi is bidirectional. Parabronchi can be several millimeters long and 0.5 - 2.0 mm in diameter (depending on the size of the bird) (Maina 1989) and their walls contain hundreds of tiny, branching, and anastomosing air capillaries surrounded by a profuse network of blood capillaries.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Differences among different birds in the development of the neopulmonic region of the lung. (a) Penguin lungs are entirely paleopulmonic. (b) Some birds, such as ducks, have a relatively small neopulmonic region. (c) Songbirds have a well-developed neopulmonic region. 1, trachea, 2, primary bronchus, 3, ventrobronchus, 4, dorsobronchus, 5, lateral bronchus, 6, paleopulmonic parabronchi, 7, neopulmonic parabronchi; A, cervical air sac, B, interclavicular air sac, C, cranial thoracic air sac, D, caudal thoracic air sac, E, abdominal air sac. The white arrows indicate changes in volume of the air sacs during the respiratory cycle (From: McLelland 1989).