STRUCTURE OF THE RESPIRATORY TRACT

We live at the bottom of a vast sea of air composed primarily of oxygen and nitrogen. By living in air rather than water, we enjoy surroundings 50 times richer in oxygen. By breathing, we give our body fluids access to this reservoir as they continually exchange both oxygen (O_2) and carbon dioxide (CO_2) with air. There are no long-term storage sites for oxygen within the body; they are not necessary, as long as this exchange between body fluids and air remains unimpeded.

RESPIRATORY TRACT BRANCHES MANY TIMES

Alveoli are the final destination of a tortuous path— Efficient contact of body fluids with air is mediated by the *respiratory tract,* which begins in the *nasal* and *oral cavities* and ends in a vast system of microscopic blind-ended sacs called *alveoli* in the deepest recesses of the lungs. During inspiration, air travels from the atmosphere through the nasal (or oral) passages, through the *pharynx,* and into the *trachea.* During this time, it is warmed and takes up water vapor. After passing down the trachea, it flows through the *bronchi, bronchioles,* and *alveolar ducts* and finally reaches the microscopic alveoli, where exchange of oxygen and carbon dioxide takes place. Following a single O_2 molecule along this tortuous route, we find about 23 forks in the path as the airways bifurcate into finer and finer branches. During expiration, the same path is traversed, but in the opposite direction.

Cilia and mucus serve as filters— The widest tubes (trachea and bronchi) contain stiff cartilage together with some smooth muscle. They are lined by a layer of epithelial cells (not shown on opposite page) that often have minute hair-like structures, called cilia, projecting from their surface. These cells also secrete over their surface a *mucus* sheet that floats above a thin saline layer. The mucus is continuously transported like an escalator in an upward direction (away from the lungs) by the coordinated movement of the cilia. This process serves as an efficient filter for dust particles that strike the walls as turbulent air flows in and out of the air passage. Once the upward-traveling mucus reaches the pharynx we unconsciously swallow it.

Failure of this filtering system occurs when cilia are paralyzed by cigarette smoke. The system also fails in the fatal genetic disease *cystic fibrosis,* in which there is a congenital loss of cAMP-activated Cl^- channels in airway epithelial cells. Without this channel, secretion of the thin saline layer between cilia and mucus is grossly impaired. Mucus becomes thicker and cilia, now trapped in the sticky mucus, are no longer able to function. This leads to repeated pulmonary infections and progressive destruction of the lungs. Cystic fibrosis is one of the most common genetic disorders in Caucasians, occurring in about 1 out of 2000 births.

The smaller branches (bronchioles) of the respiratory tract also contain smooth muscle, but no cartilage, cilia, or mucus glands. Particles deposited in the bronchioles and alveoli are removed by wandering alveolar macrophages.

Total alveolar surface area is huge— The extensive branching pattern of the air passages results in an enormous number of alveoli—approximately 300 million. The diameter of each alveolar sphere is only about 0.3 mm, but adding all their surface area together gives a total of about 85 sq. m (close to the size of half a tennis court!) available for gas exchange with blood. Yet this enormous surface is contained within a maximum total volume of only 5 to 6 L, which fits very nicely into the thorax. However, this device is not without problems. The tiny alveoli are at the dead end of narrow bronchial tubes in a complex branching tubular network. Left to itself, air would stagnate within them. This does not occur because the alveoli are intermittently flushed with fresh air as we breathe.

The enlarged view of a single alveolus in the plate shows the actual interface between body fluids and air where *gas exchange* takes place. Alveolar walls, like blood capillaries, are made of extremely thin cells. Despite the fact that O_2 and CO_2 have to traverse two cell layers in passing between alveolus and capillary, the total distance is very short, and diffusion is correspondingly rapid. Efficient gas exchange is also enhanced by the dense supply of capillaries in the lungs, one of the most profuse networks of blood vessels in the body.

LOW PRESSURES IN THE PULMONARY CIRCULATION

Low pressures reduce the work of the right heart and provide protection from edema— The pulmonary circulation that transports blood from the right heart to this alveolar exchange interface also has peculiarities that appear well adapted to its function. Most notably, the pressures in the pulmonary circulation are small; the mean pressure in the pulmonary artery is about 15 mm Hg, only about one-seventh the 100 mm Hg mean pressure in the aorta. Thus, the forces driving blood through the pulmonary circulation are relatively small, and because the blood flows through the pulmonary and systemic circulations are equal, it follows that the resistance of the pulmonary circulation must also be small. Keeping the pulmonary pressures and resistance low so that flow can be maintained reduces the work required of the right heart. In addition, the low pressure in the pulmonary capillary pushing fluids out into the alveolar spaces is overbalanced by the oncotic pressure of the plasma proteins (plate 40) drawing fluids in. The net force favors reabsorption of fluid from the alveolus so that the normal lung has no tendency to fill with fluid. Further, blood vessels in the lungs have an atypical response to low concentrations of O_2 dissolved in blood plasma. Unlike arterioles of the systemic circulation, which dilate, lung arterioles constrict in response to low local plasma O_2 concentrations. This has the advantage of shunting blood away from areas of the lung that are poorly ventilated and cannot serve as adequate sources of O_2.

CN: Use red for A, blue for B, purple for N, and a very light color for L.
1. Begin with the large illustration. The edge of the right lung is colored gray, and the left lung is colored completely gray. Only the bronchi (I) are colored in the right lung.
2. Color the enlargement on the lower left showing circulation to and from the alveoli.
3. Color the enlargement (lower right) of the gas exchange between an alveolus and a lung capillary.
4. Color the schematic diagram (to the left of the large figure) of external and internal respiration.

OXYGEN$_A$ OXYGENATED BLOOD$_{A'}$
CO$_{2\,B}$ DEOXYGENATED BLOOD$_{B'}$

RESPIRATORY TRACT
NASAL CAVITY$_C$
ORAL CAVITY$_D$
PHARYNX$_E$
EPIGLOTTIS$_F$
LARYNX$_G$
TRACHEA$_H$
BRONCHI$_I$
BRONCHIOLE$_J$
ALVEOLAR SAC
ALVEOLAR DUCT$_K$
ALVEOLUS$_L$
EPITHELIUM$_M$

LUNG CAPILLARY$_N$
DIAPHRAGM$_O$

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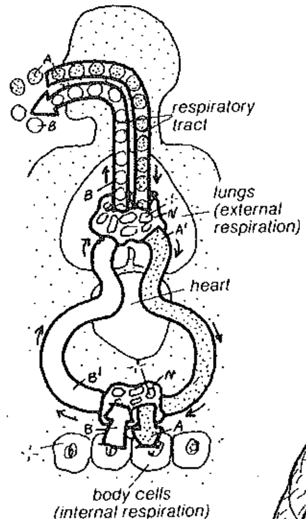
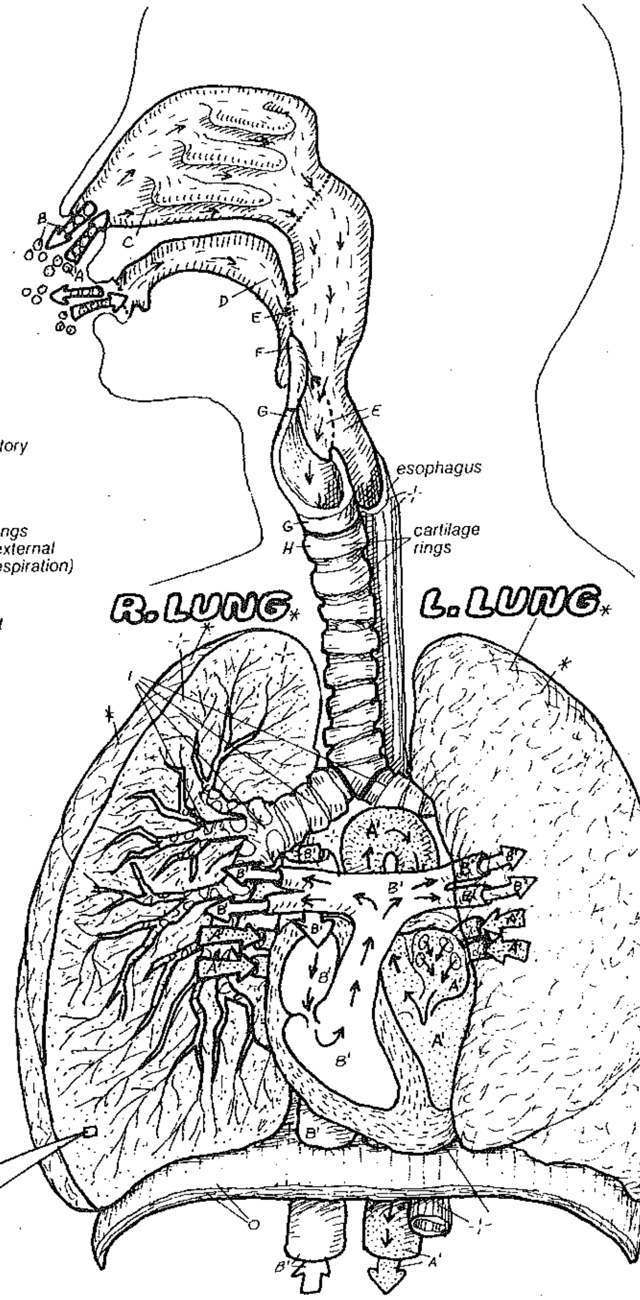
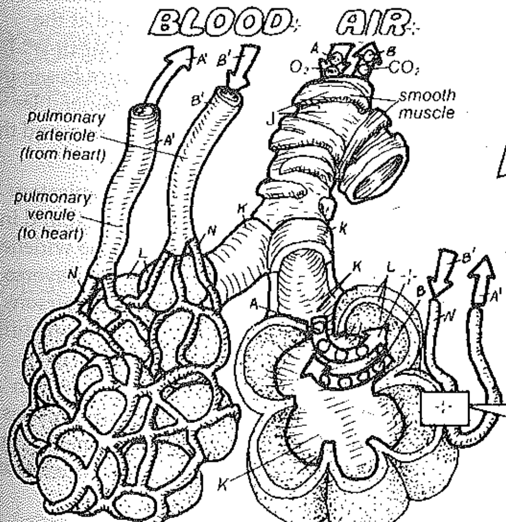


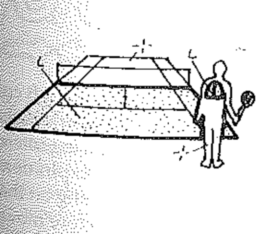


BLOOD AIR



Alveolar sacs (left) are microscopic clusters of individual spherical outpouchings called alveoli. Each cluster is embedded in a network of blood capillaries.

GAS EXCHANGE



The extensive branching pattern of the air passages results in an enormous number of alveoli—approximately 300 million. Adding the surface area of each of these gives a total alveolar surface area of about 85 sq m (close to the size of half a tennis court!) available for gas exchange with blood. An enlarged view of a single alveolus (right) shows that the walls, like blood capillaries, are made of extremely thin cells. Despite the fact that O_2 and CO_2 have to traverse two cell layers in passing between alveolus and capillary, the total distance is very short; diffusion is rapid.