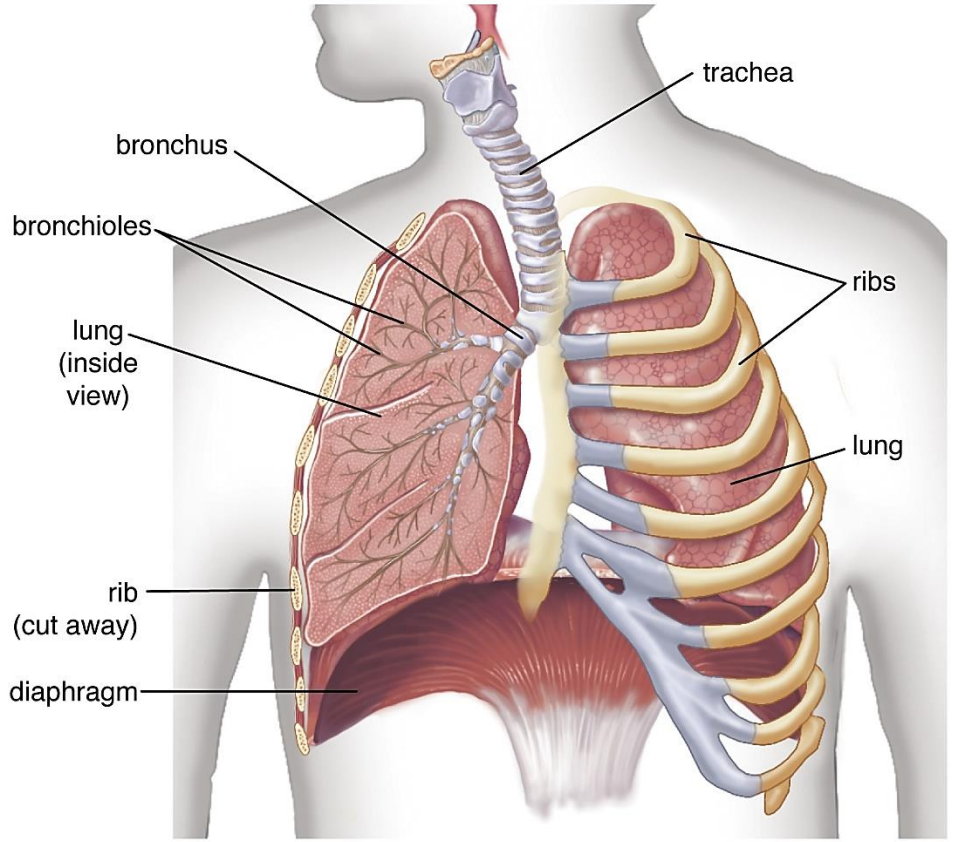
Lungs

Unlike tracheal systems, which branch throughout the insect body, lungs are localized respiratory organs. Representing an infolding of the body surface, they are typically subdivided into numerous pockets. Because the respiratory surface of a lung is not in direct contact with all other parts of the body, the gap must be bridged by the circulatory system, which transports gases between the lungs and the rest of the body. Lungs have evolved both in organisms with open circulatory systems, such as spiders and land snails, and in vertebrates. Among vertebrates that lack gills, the use of lungs for gas exchange varies. Amphibians rely heavily on diffusion across external body surfaces, such as the skin, to carry out gas exchange; lungs, if present, are relatively small. In contrast, most reptiles (including all birds) and all mammals depend entirely on lungs for gas exchange. Turtles are an exception; they supplement lung breathing with gas exchange across moist epithelial surfaces continuous with their mouth or anus. Lungs and air breathing also evolved in a few aquatic vertebrates as adaptations to living in oxygen-poor water or to spending part of their time exposed to air (for instance, when the water level of a pond recedes).



Gas exchange

The human gas exchange system links the circulatory system with the atmosphere. It is adapted to:

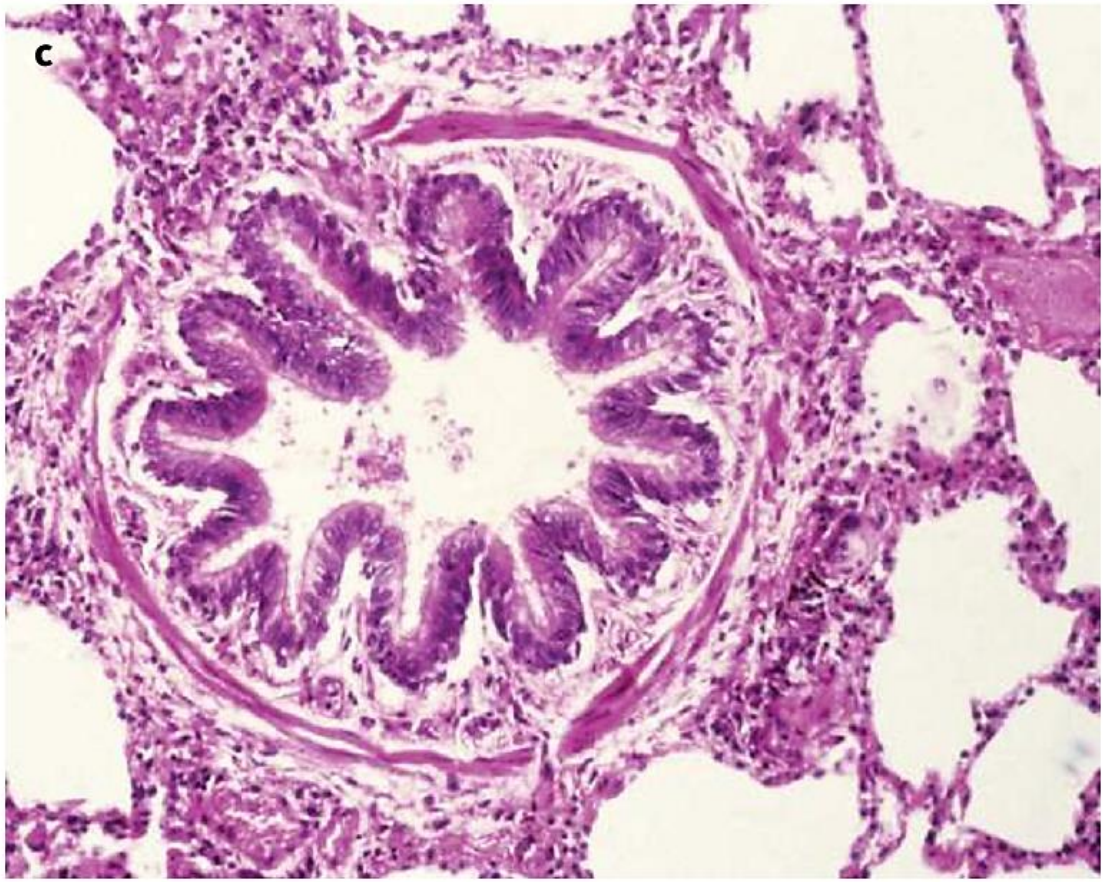
- clean and warm the air that enters during breathing
- maximise the surface area for diffusion of oxygen and carbon dioxide between the blood and atmosphere
- minimise the distance for this diffusion
- maintain adequate gradients for this diffusion.

As air flows through the nose and the trachea, it is warmed to body temperature and moistened by evaporation from the lining, so protecting the delicate surfaces inside the lungs from desiccation (drying out). Protection is also needed against the suspended matter carried in the air, which may include dust, sand, pollen, fungal spores, bacteria and viruses. All are potential threats to the proper functioning of the lungs. Particles larger than about 5–10 µm are caught on the hairs inside the nose and the mucus lining the nasal passages and other airways.

In the trachea and bronchi, the mucus is produced by the goblet cells of the ciliated epithelium. The upper part of each goblet cell is swollen with mucin droplets which have been secreted by the cell. Mucus is a slimy solution of mucin, which is composed of glycoproteins with many carbohydrate chains that make them sticky and able to trap inhaled particles. The rest of the goblet cell, which contains the nucleus, is quite slender like the stem of a goblet. Mucus is also made by mucous glands beneath the epithelium. Some chemical pollutants, such as sulfur dioxide and nitrogen dioxide, can dissolve in mucus to form an acidic solution that irritates the lining of the airways.

Between the goblet cells are the ciliated cells. The continual beating of their cilia carries the carpet of mucus upwards towards the larynx at a speed of about 1 cm min^{-1}. When mucus reaches the top of the trachea it is usually swallowed so that pathogens are destroyed by the acid in the stomach.

Phagocytic white blood cells known as macrophages patrol the surfaces of the airways scavenging small particles such as bacteria and fine dust particles. During an infection, the macrophages are joined by other phagocytic cells which leave the capillaries to help remove pathogens.



c A light micrograph of a small bronchiole in TS (×135). Surrounding the epithelium is smooth muscle. There is no cartilage. Around the bronchiole are some alveoli.

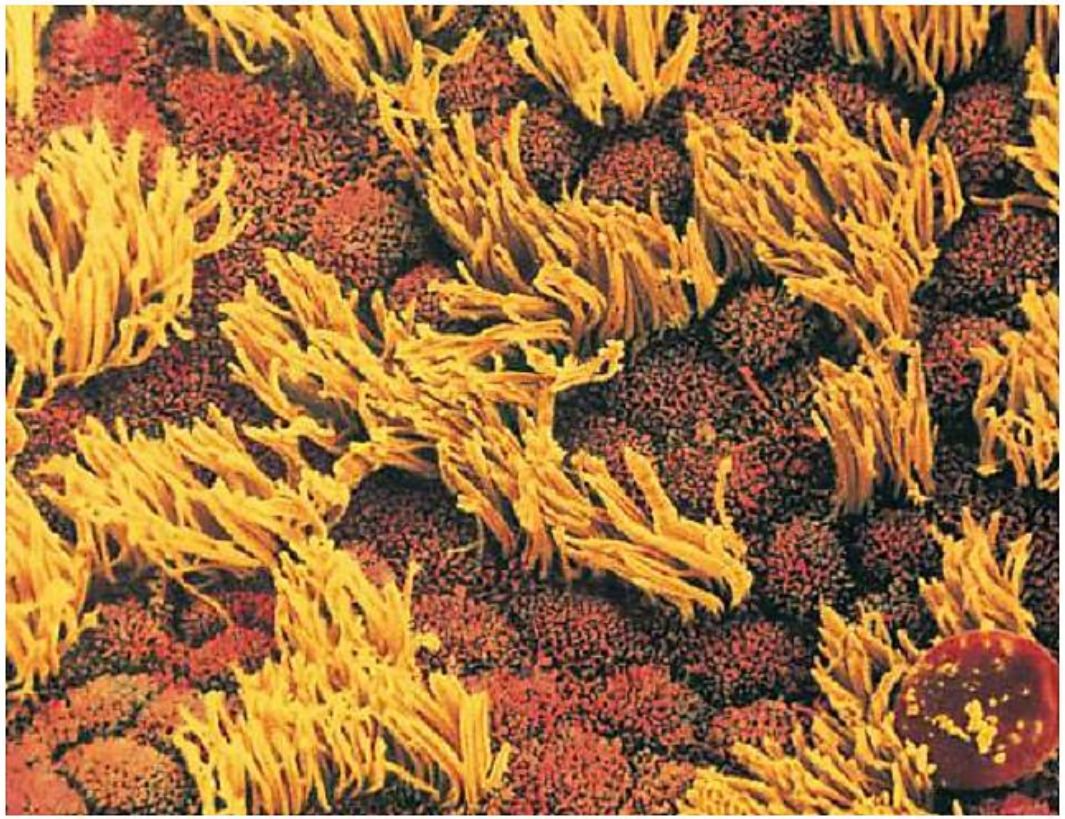


Figure 9.4 False-colour scanning electron micrograph of the surface of the trachea, showing large numbers of cilia (yellow) and some mucus-secreting goblet cells (red) (×2600).

Mammalian Respiratory Systems

In mammals, branching ducts convey air to the lungs, which are located in the thoracic cavity, enclosed by the ribs and diaphragm. Air enters through the nostrils and is then filtered by hairs, warmed, humidified, and sampled for odors as it flows through a maze of spaces in the nasal cavity. The nasal cavity leads to the pharynx, an intersection where the paths for air and food cross. When food is swallowed, the larynx (the upper part of the respiratory tract) moves upward and tips the epiglottis over the glottis, which is the opening of the trachea, or windpipe. This allows food to go down the esophagus to the stomach. The rest of the time, the glottis is open, enabling breathing.

From the larynx, air passes into the trachea. The cartilage that reinforces the walls of both the larynx and the trachea keeps this part of the airway open. Within the larynx of most mammals, the exhaled air rushes by a pair of elastic bands of muscle called vocal folds or, in humans, vocal cords. Sounds are produced when muscles in the larynx are tensed, stretching the cords so that they vibrate. High-pitched sounds result from tightly stretched cords vibrating rapidly; low-pitched sounds come from looser cords vibrating slowly.

The trachea branches into two bronchi (singular, bronchus), one leading to each lung. Within the lung, the bronchi branch repeatedly into finer and finer tubes called bronchioles. Terminal bronchioles divide to form even narrower respiratory bronchioles that supply the alveoli with air.

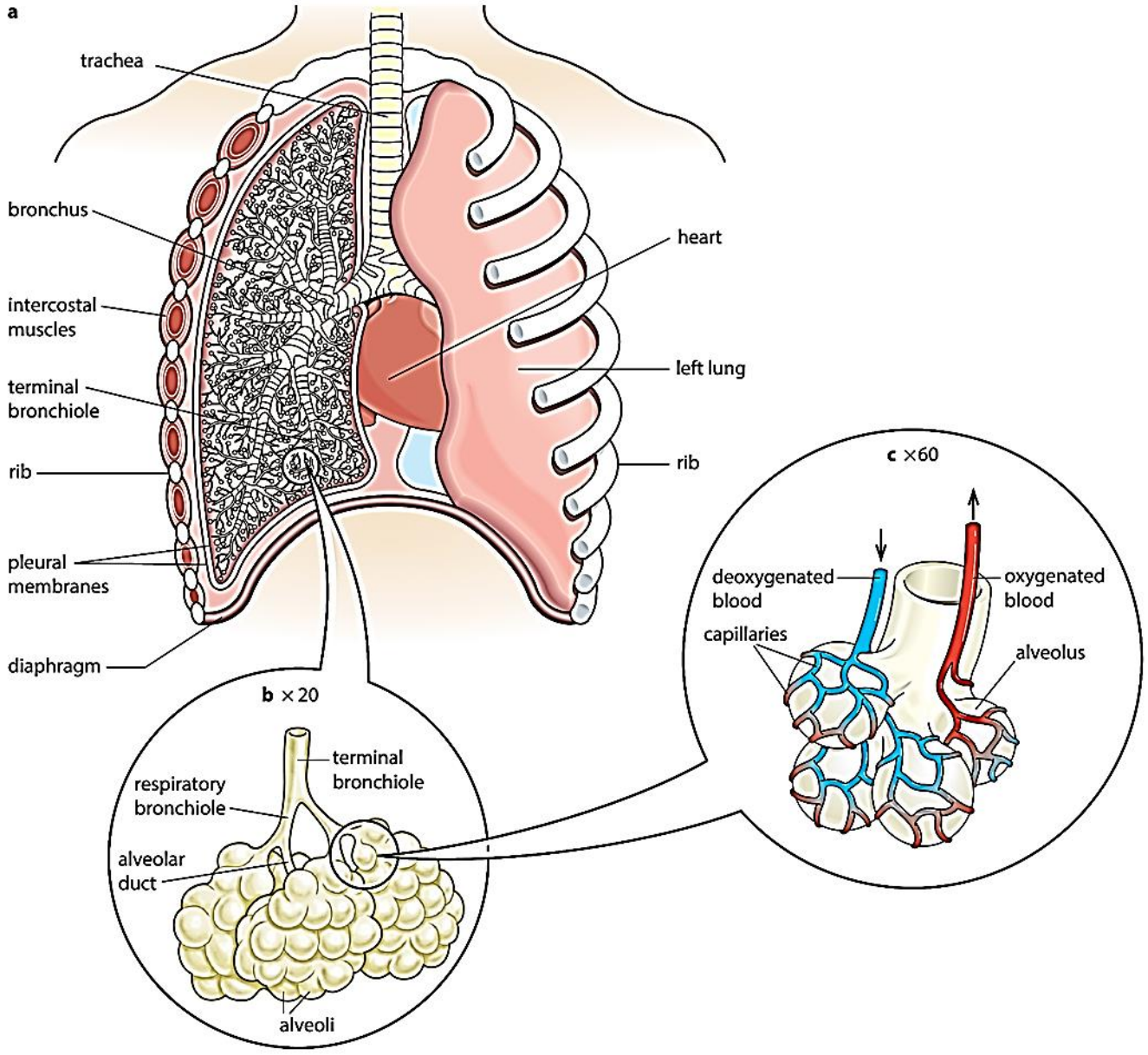


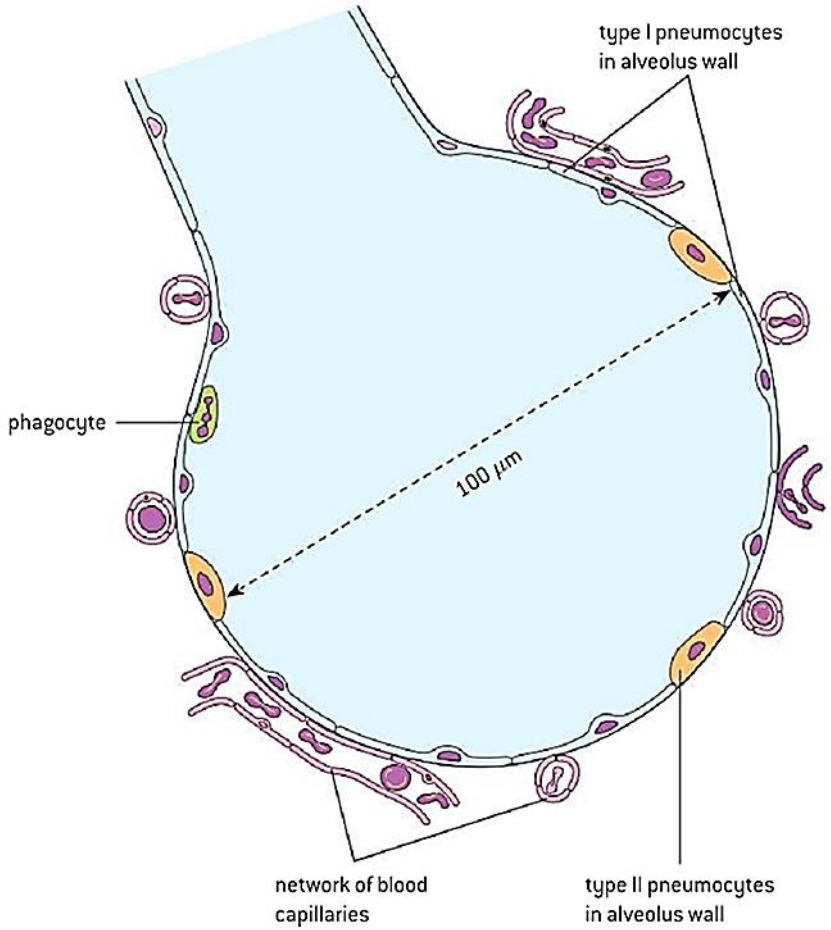
Figure 9.2 The human lungs. Air passes through **a** the trachea and bronchi to supply many branching bronchioles **b** which terminate in alveoli **c** where gas exchange occurs. A gas exchange surface of around 70 m^2 fits into the thoracic cavity, which has a capacity of about 5 dm^3.

Mammalian Respiratory Systems

The epithelium lining the major branches of this respiratory tree is covered by cilia and a thin film of mucus. The mucus traps dust, pollen, and other particulate contaminants, and the beating cilia move the mucus upward to the pharynx, where it can be swallowed into the esophagus. This process, sometimes referred to as the “mucus escalator,” plays a crucial role in cleansing the respiratory system.

In the trachea, there is a regular arrangement of C-shaped rings of cartilage; in the bronchi, there are irregular blocks of cartilage instead. Bronchioles are surrounded by smooth muscle, which can contract or relax to adjust the diameter of these tiny airways. During exercise, the muscles relax to allow a greater flow of air to the alveoli. The absence of cartilage makes these adjustments possible.

Ventilation maintains concentration gradients of oxygen and carbon dioxide between air in alveoli and blood flowing in adjacent capillaries.



Airway	Number	Approximate diameter	Cartilage	Goblet cells	Smooth muscle	Cilia	Site of gas exchange
trachea	1	1.8 cm	yes	yes	yes	yes	no
bronchus	2	1.2 cm	yes	yes	yes	yes	no
terminal bronchiole	48 000	1.0 mm	no	no	yes	yes	no
respiratory bronchiole	300 000	0.5 mm	no	no	no	a few	no
alveolar duct	9×10^6	400 µm	no	no	no	no	yes
alveoli	3×10^9	250 µm	no	no	no	no	yes

Table 9.1 The structure of the airways from the trachea to the alveoli. The various airways are shown in Figure 9.2.