Respiration

Learning outcomes

After studying this section, you should be able to:

describe the actions of the main muscles involved in breathing

compare and contrast the mechanical events occurring in inspiration and expiration

define the terms compliance, elasticity and airflow resistance

describe the principal lung volumes and capacities

compare the processes of internal and external respiration, using the concept of diffusion of gases

describe O_2 and CO_2 transport in the blood

explain the main mechanisms by which respiration is controlled.

The term respiration means the exchange of gases between body cells and the environment. This involves two main processes:

Breathing (pulmonary ventilation)

This is movement of air into and out of the lungs.

Exchange of gases

This takes place:

n the lungs: *external respiration*

n the tissues: *internal respiration*.

Each of these will be considered later in this section.

Breathing

Breathing supplies oxygen to the alveoli, and eliminates carbon dioxide.

Muscles of breathing

Expansion of the chest during inspiration occurs as a result of muscular activity, partly voluntary and partly involuntary. The main muscles used in normal quiet breathing are the *external intercostal muscles* and the *diaphragm*.

Intercostal muscles

There are 11 pairs of intercostal muscles that occupy the spaces between the 12 pairs of ribs. They are arranged in two layers, the external and internal intercostal muscles (Fig. 10.20).

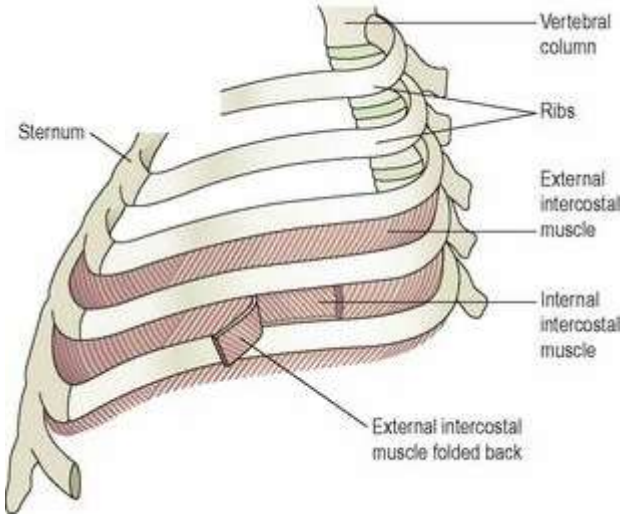

Figure 10.20 The intercostal muscles and the bones of the thorax.

The external intercostal muscles

These extend downwards and forwards from the lower border of the rib above to the upper border of the rib below. They are involved in inspiration.

The internal intercostal muscles

These extend downwards and backwards from the lower border of the rib above to the upper border of the rib below, crossing the external intercostal muscle fibres at right angles. The internal intercostals are used when exhalation becomes active, as in exercise.

The first rib is fixed. Therefore, when the external intercostal muscles contract they pull all the other ribs towards the first rib. Because of the shape and sizes of the ribs they move outwards when pulled upwards, enlarging the thoracic cavity. The intercostal muscles are stimulated to contract by the *intercostal nerves*.

Diaphragm 10.7

The diaphragm is a dome-shaped muscular structure separating the thoracic and abdominal cavities. It forms the floor of the thoracic cavity and the roof of the abdominal cavity and consists of a central tendon from which muscle fibres radiate to be attached to the lower ribs and sternum and to the vertebral column by two crura. When the muscle of the diaphragm is relaxed, the central tendon is at the level of the 8th thoracic vertebra (Fig. 10.21). When it contracts, its muscle fibres shorten and the central tendon is pulled downwards to the level of the 9th thoracic vertebra, lengthening the thoracic cavity. This decreases pressure in the thoracic cavity and increases it in the abdominal and pelvic cavities. The diaphragm is supplied by the *phrenic nerves*.

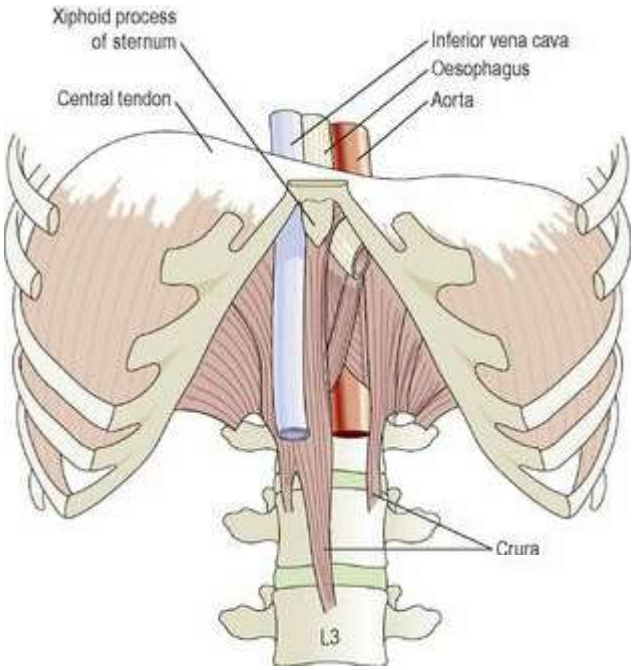

Figure 10.21 The diaphragm.

Quiet, restful breathing is sometimes called *diaphragmatic breathing* because 75% of the work is done by the diaphragm.

The external intercostal muscles and the diaphragm contract simultaneously, enlarging the thoracic cavity in all directions, that is from back to front, side to side and top to bottom (Fig. 10.22).

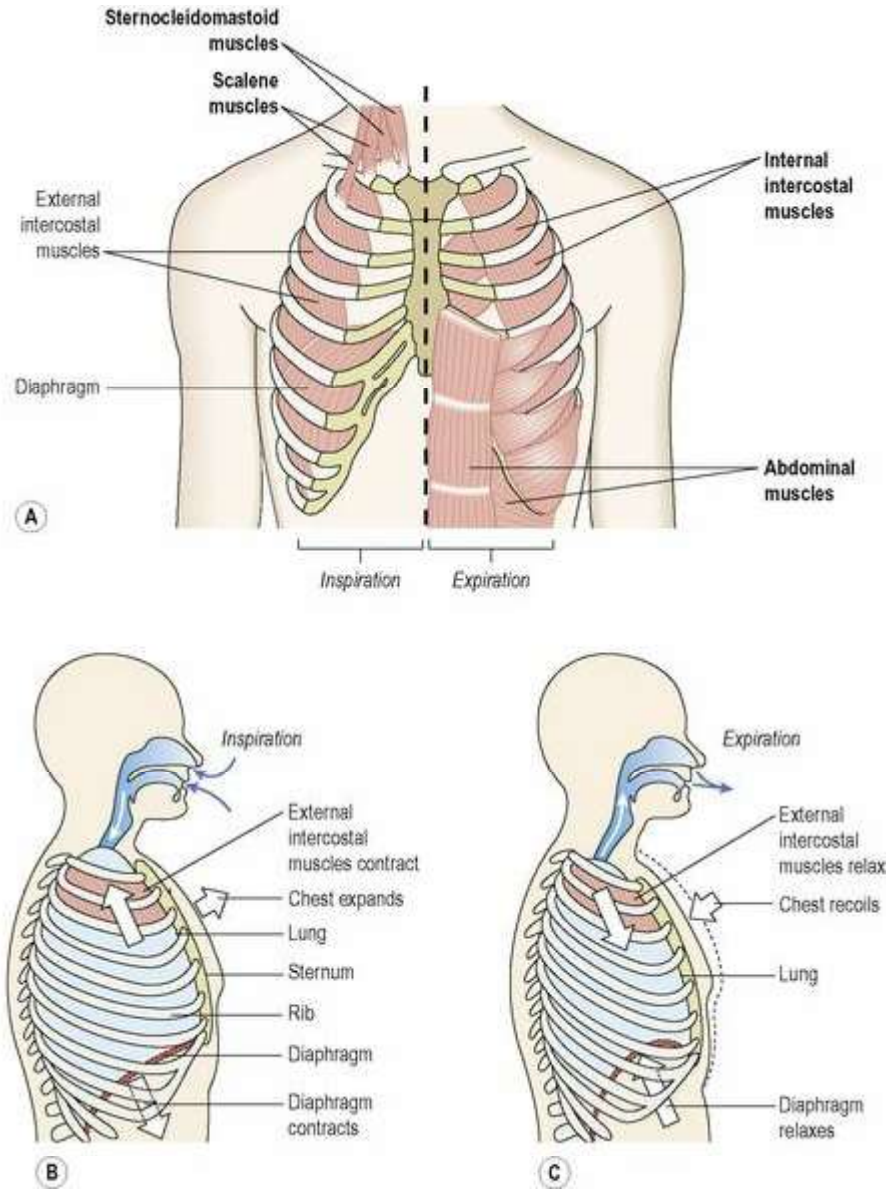

Figure 10.22 **Changes in chest size during inspiration. A.** Muscles involved in respiration (accessory muscles labelled in bold). **B, C.** Changes in chest volume.

Accessory muscles of respiration

When extra respiratory effort is required, additional muscles are used. Forced inspiration is assisted by the *sternocleidomastoid* muscles (p. 414) and the *scalene* muscles, which link the cervical vertebrae to the first two ribs, and increase ribcage expansion. Forced expiration is helped by the activity of the internal intercostal muscles and sometimes the abdominal muscles, which increase the pressure in the thorax by squeezing the abdominal contents.

Cycle of breathing 10.8

The average respiratory rate is 12 to 15 breaths per minute. Each breath consists of three phases:

nspiration

xpiration

ause.

As described previously, the visceral pleura is adherent to the lungs and the parietal pleura to

the inner wall of the thorax and to the diaphragm. Between them is a thin film of serous fluid (p. 243).

Breathing is dependent upon changes in pressure and volume in the thoracic cavity. It follows the underlying physical principle that increasing the volume of a container decreases the pressure inside it, and that decreasing the volume of a container increases the pressure inside it. Since air flows from an area of high pressure to an area of low pressure, changing the pressure inside the lungs determines the direction of airflow.

Inspiration

Simultaneous contraction of the external intercostal muscles and the diaphragm expands the thorax. As the parietal pleura is firmly adherent to the diaphragm and the inside of the ribcage, it is pulled outward along with them. This pulls the visceral pleura outwards too, since the two pleura are held together by the thin film of pleural fluid. Because the visceral pleura is firmly adherent to the lung, the lung tissue is, therefore, pulled up and out with the ribs, and downwards with the diaphragm. This expands the lungs, and the pressure within the alveoli and in the air passages falls, drawing air into the lungs in an attempt to equalise the atmospheric and alveolar air pressures.

The process of inspiration is *active*, as it needs energy for muscle contraction. The negative pressure created in the thoracic cavity aids venous return to the heart and is known as the *respiratory pump*.

At rest, inspiration lasts about 2 seconds.

Expiration

Relaxation of the external intercostal muscles and the diaphragm results in downward and inward movement of the ribcage (Fig. 10.22) and elastic recoil of the lungs. As this occurs, pressure inside the lungs rises and expels air from the respiratory tract. The lungs still contain some air, and are prevented from complete collapse by the intact pleura. This process is *passive* as it does not require the expenditure of energy.

At rest, expiration lasts about 3 seconds, and after expiration there is a pause before the next cycle begins.

Physiological variables affecting breathing

Elasticity

Elasticity is the term used to describe the ability of the lung to return to its normal shape after each breath. Loss of elasticity of the connective tissue in the lungs necessitates forced expiration and increased effort on inspiration.

Compliance

This is a measure of the stretchability of the lungs, i.e. the effort required to inflate the alveoli. The