(Fig. 25-4).

Bronchioles are smaller than 1 mm in diameter, they lack cartilage, and they have a simple cuboidal epithelium. Bronchioles are embedded into the connective tissue framework of the lung, and thus their diameter increases and decreases with lung volume. Bronchioles are further subdivided, depending upon their function. Nonrespiratory bronchioles include terminal bronchioles, which serve as conductors of the gas stream, whereas respiratory bronchioles contain alveoli that function as sites of gas exchange. The area from the terminal bronchiole to the alveolus is occasionally called the secondary lobule or acinus (Fig. 25-5). The amazing anatomic feature of this area is that it is only ~5 mm in length, but the total volume of the acini comprises the single largest volume of the lung, at approximately 2500 ml!

The respiratory (gas-exchanging) unit consists of the respiratory bronchioles, the alveolar ducts, and the alveoli, and it is the **basic physiological unit** of the lung. The respiratory bronchioles, as previously mentioned, are the first bronchioles that have alveoli. Each branching of the respiratory bronchioles results in an increased number and size of the alveoli, until the respiratory bronchiole terminates in an opening to a group of alveoli (Fig. 25-6). This terminal opening is called an alveolar duct. In addition to the difference in function between the conducting airways and the terminal respiratory unit, the conducting airways receive their blood supply from the bronchial circulation, whereas the terminal

BLOOD SUPPLY TO THE LUNG

The lung has two separate blood supplies. The first is the pulmonary circulation, which brings deoxygenated blood from the right ventricle to the gas-exchanging units. At the gas-exchanging units, oxygen is picked up and carbon dioxide is removed from the blood before it is returned to the left atrium for distribution to the rest of the body. The second blood supply is the bronchial circulation, which arises from the aorta and provides nourishment to the lung parenchyma. The circulation to the lung is unique in its dual circulation and in its ability to accommodate large volumes of blood at low pressure.

The pulmonary capillary bed is the largest vascular bed in the body. It covers a surface area of 70 to 80 m^2, which is nearly as large as the alveolar surface area. The network of capillaries is so dense that it might be considered to be a sheet of blood interrupted by small vertical supporting posts (Fig. 25-7). The capillary volume in the lung at rest is approximately 70 ml. During exercise, this volume increases and approaches ~200 ml. This increase occurs, in part, through the recruitment of closed or compressed capillary segments as an increased cardiac output raises the pulmonary vascular pressure. In addition, open capillaries can enlarge as their internal pressure rises. This occurs when the lungs fill with blood, as it does in left heart failure, which is associated with an elevated left atrial pressure (see Chapter 16). The pulmonary veins return blood to the left atrium

it (Fig. 25-8). They nourish the walls of the bronchi, bronchioles, blood vessels, and nerves, and they perfuse the lymph nodes and most of the visceral pleura. Approximately one third of the blood returns to the right atrium through the bronchial veins, whereas the remainder drains into the left atrium via pulmonary veins. This deoxygenated blood, which mixes with oxygen-enriched blood in the pulmonary veins, contributes to the small alveolar-arterial oxygen difference in normal individuals. In the presence of diseases such as cystic fibrosis, the bronchial arteries, which normally receive only 1% to 2% of the cardiac output, increase in size (hypertrophy), and they could receive as much as 10% to 20% of the cardiac output. Erosion into these vessels secondary to infection is responsible for the hemoptysis (coughing up blood) that occurs in this disease.

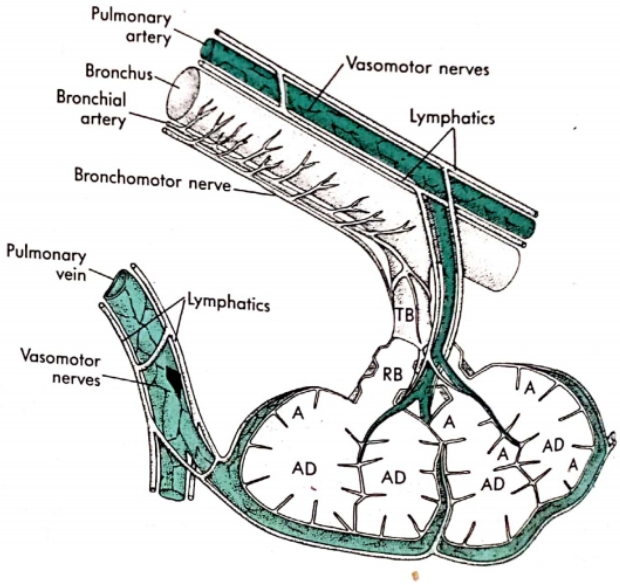
MUSCLES OF RESPIRATION

The muscles of respiration are skeletal muscles. Their structure and function are identical to those of other skeletal muscles; that is, their force of contraction increases when they are stretched, and it decreases when the muscles are shorter. Thus, the force of contraction of respiratory muscles increases with increasing lung volume.

The lungs are located within the thoracic cavity, and they are in intimate contact with the chest wall. Dividing the thoracic cavity from the abdominal cavity is the diaphragm, the major muscle of respiration. The diaphragm is a thin, musculotendinous, dome-shaped sheet of muscle that is inserted into the lower ribs, and it separates the thoracic from the abdominal cavity (Fig. 25-9). The zone of opposition is the region where the diaphragm is in direct contact with the lower ribs. This zone of opposition enhances the transmission of the abdominal pressure across the diaphragm directly to the rib cage. The diaphragm is innervated by the right and left phrenic nerves, which have their origins at the third to fifth cervical segments of the spinal cord (C3 to C5). The arterial blood supply to the diaphragm originates from branches of the intercostal arteries, and the veins drain into the inferior vena cava. Contraction of the diaphragm forces the abdominal contents downward and forward. This increases the vertical dimension of the chest cavity, and creates a pressure difference between the thorax and abdomen. In addition, the rib margins are lifted and moved out, which increases the transverse diameter of the thorax. The 12 ribs on either side articulate with the thoracic vertebrae. The ribs can rotate only upward, which increases the transverse diameter of the thorax. The curvature of the diaphragm, when it is contracted, results in a substantial increase in thoracic volume.

In adults, the diaphragm can generate airway pressures up to 150 to 200 cm H_2O during a maximal inspiratory effort. During quiet breathing (tidal breathing), the diaphragm moves approximately 1 cm. However, during vital capacity (deep breath) maneuvers, the diaphragm can move as much as 10 cm. If the diaphragm is paralyzed, it moves higher up in the thoracic cavity during inspiration, because of the fall in intrathoracic pressure. This paradoxical movement of the diaphragm can be demonstrated by fluoroscopy.

The other significant muscles of inspiration are the external intercostal muscles, which pull the ribs upward and forward during inspiration. This causes an increase in both the lateral and the anteroposterior diameters of the thorax (Fig. 25-10). Innervation of these muscles originates from the intercostal nerves that arise from the same level of the spinal cord. Paralysis of these muscles has no significant effect on respiration, because of the importance of the diaphragm.



■ **Fig. 25-8** The anatomic relation between the pulmonary artery, the bronchial artery, the airways, and the lymphatics. *TB,* Terminal bronchioles; *RB,* respiratory bronchioles; *A,* alveoli; *AD,* alveolar ducts.

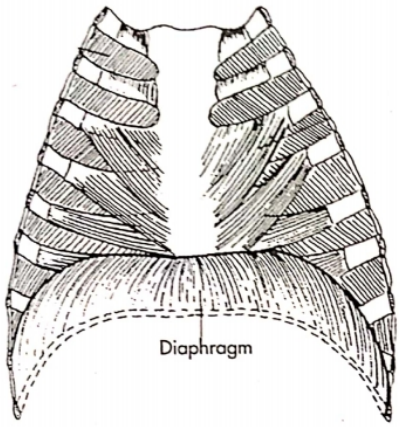
This is why individuals with high spinal cord injuries can breathe on their own. It is only when the injury is above C3 that individuals are completely ventilator dependent.

Accessory muscles of inspiration (the scalene muscles that elevate the sternocleidomastoid, the alae nasi that cause nasal flaring, and the small muscles in the neck and head) do not contract during normal breathing. However, they do contract vigorously during exercise and when airway obstruction is significant, and they actively pull up on the rib cage. During normal breathing, they anchor the sternum and upper ribs. All of the rib cage muscles are voluntary muscles that are supplied by intercostal arteries and veins and that are innervated by motor and sensory intercostal nerves.

The upper airway must remain patent during inspiration. Therefore, the pharyngeal wall muscles (the genioglossus and arytenoid muscles) are also considered to be muscles of inspiration.

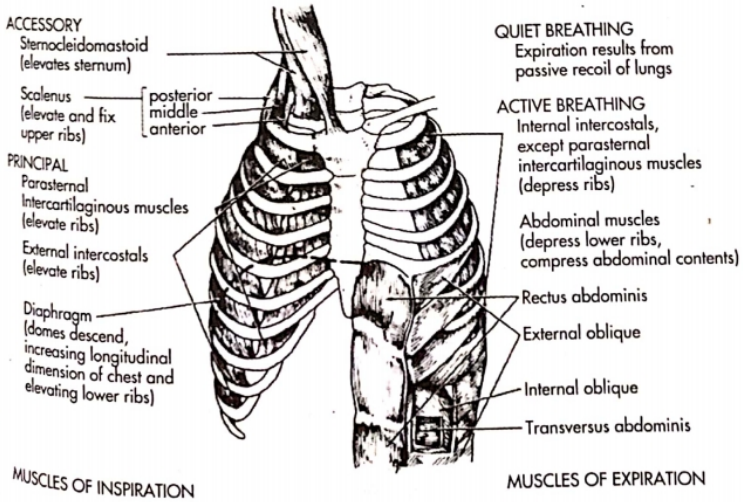
Exhalation during normal breathing is passive, but it becomes active during exercise and hyperventilation. The most important muscles of exhalation are those of the abdominal wall (rectus abdominus, internal and external oblique, and transversus abdominus) and the internal intercostal muscles that oppose the external intercostal muscles (i.e., they pull the ribs downward and inward). Maximal lengthening of the respiratory muscles at high lung volumes and maximal shortening of the respiratory muscles at low lung volumes limit maximal inspiratory and maximal expiratory volume, respectively.

The inspiratory muscles do the work of breathing. During normal breathing, work is low and the inspiratory muscles have significant reserve. Respiratory muscles can be trained to do more work, but there is a finite limit to the work they can perform. Respiratory muscle fatigue is a major factor in the development of respiratory failure.



■ **Fig. 25-9** The diaphragm. Diagram illustrating the position of the diaphragm in the thorax. View from the inside of the thorax. (From Fishman AP: *Pulmonary diseases and disorders,* ed 2, vol 1, New York, 1988, Mc Graw-Hill, p. 68.)

Because respiratory muscles provide the driving force for ventilation, diseases that affect the mechanical properties of the lung affect the muscles of respiration. For example, in chronic obstructive pulmonary disease, the work of breathing secondary to airflow obstruction is increased. Exhalation is no longer passive, but it requires active, expiratory muscle contraction. In addition, the total lung capacity (TLC) is increased. The greater TLC forces the diaphragm downward, shortens the muscle fibers, and decreases the radius of curvature. As a result, the function and efficiency of the diaphragm are decreased. In addition,



■ **Fig. 25-10** Muscles of respiration. Diagram of the anatomy of the major respiratory muscles. *Left side,* inspiratory muscles; *right side,* expiratory muscles. (From Garrity ER, Sharp JT. In *Pulmonary and critical care update,* vol 2, Park Ridge, Ill, 1986, American College of Chest Physicians.)

Mechanism of Breathing

Breathing is simply defined as the physical process in which oxygen is taken into the body and carbon dioxide is forced out from the body.

Breathing is brought about by two sets of muscles-

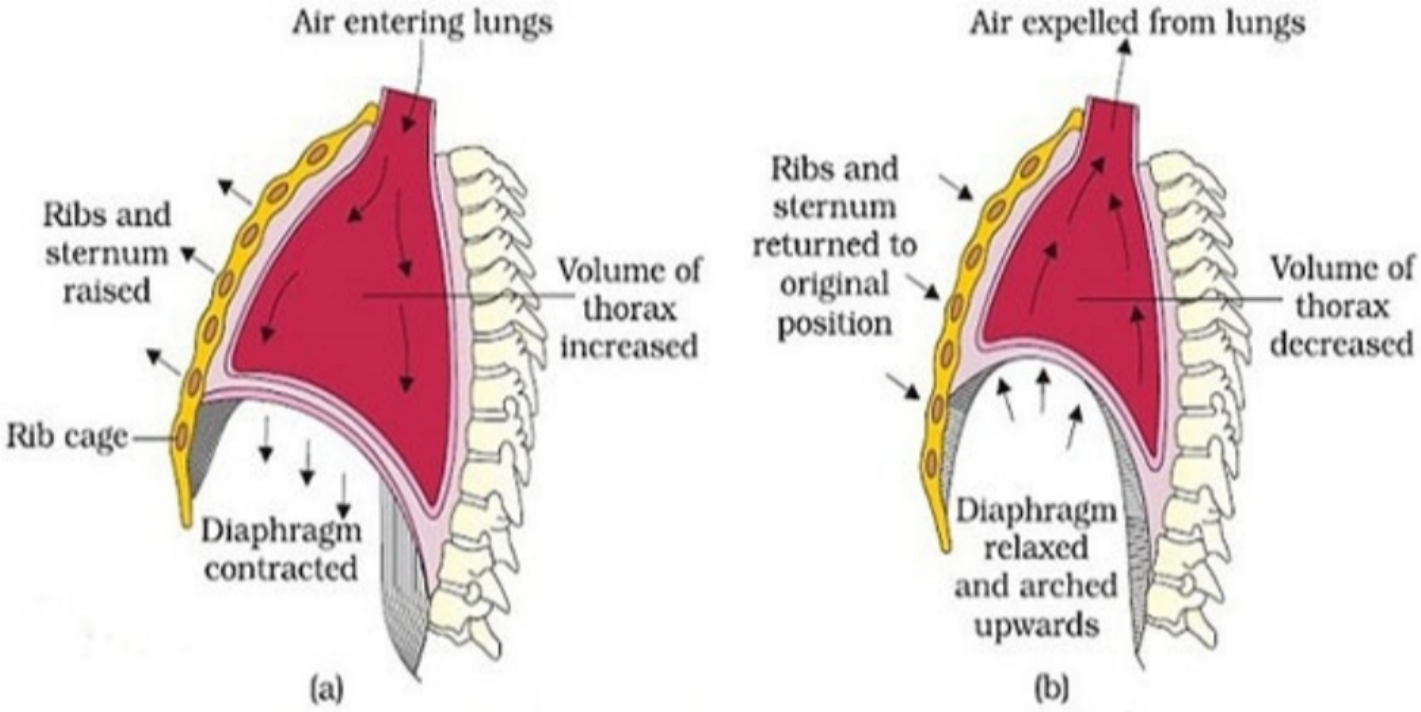
i. Internal intercoastal muscles

ii. External intercoastal muscles

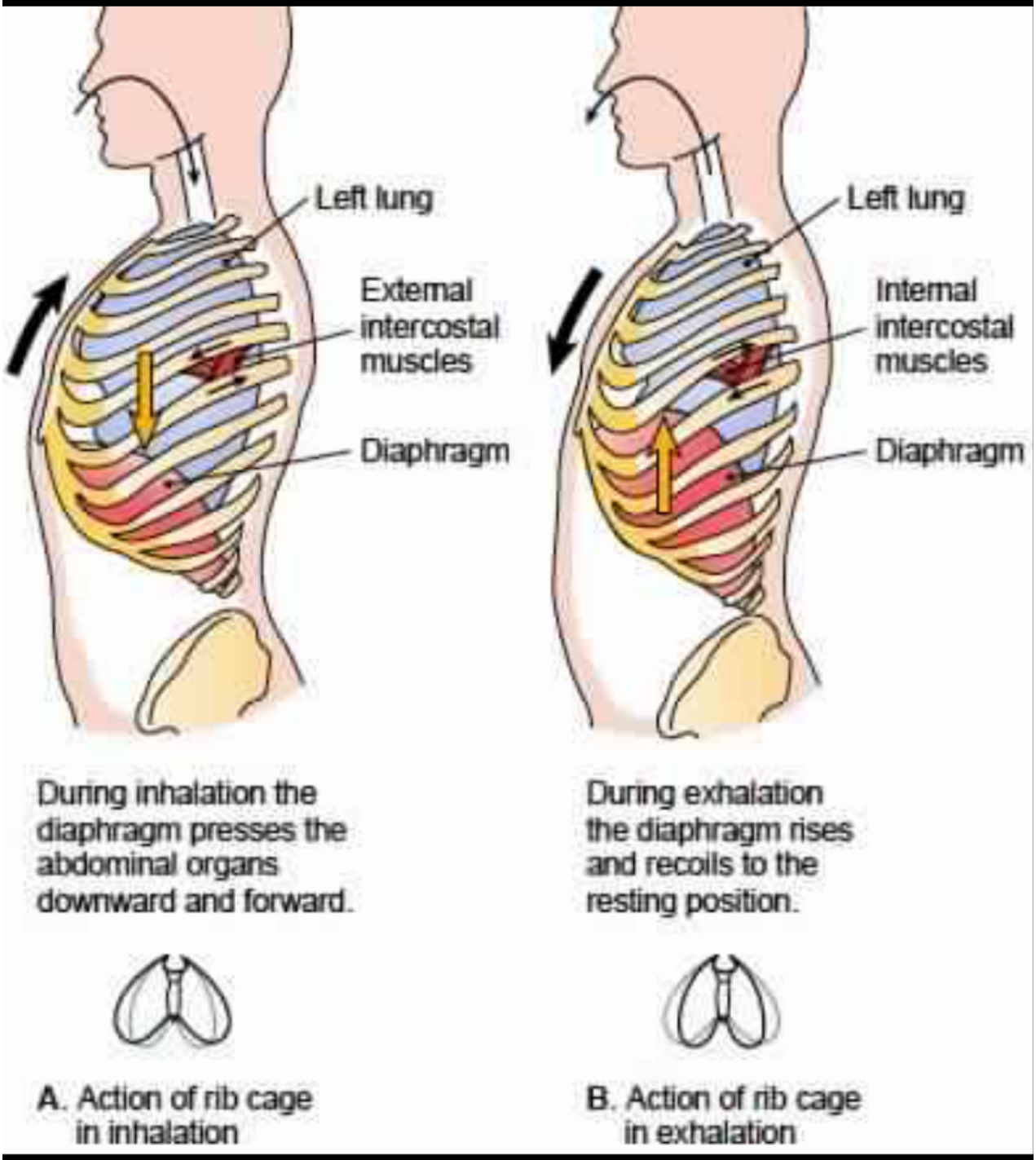
Besides these muscles, diaphragm and abdominal muscles help in breathing.

The process of breathing involves two phases:

1. Inspiration/ Inhalation
2. Expiration/ Exhalation



Mechanism of Breathing
a. Inspiration
b. Expiration


Left lung
External intercostal muscles
Diaphragm
Left lung
Internal intercostal muscles
Diaphragm
During inhalation the diaphragm presses the abdominal organs downward and forward.
During exhalation the diaphragm rises and recoils to the resting position.
A. Action of rib cage in inhalation
B. Action of rib cage in exhalation

Mechanism of Respiration :-

Respiration involves the following steps :-

① Breathing : By which atmosphric air is drawn in and CO_2 rich air is released out.

② Diffusion of O_2 & CO_2 across the alveolar membrane.

③ Transport of O_2 & CO_2 by the blood.

④ Diffusion of O_2 & CO_2 b/w blood and tissue

⑤ Utilisation of O_2 by the cells for catabolic reactions and release of CO_2

Mechanism of Breathing

Inspiration :- Diaphragm and External intercostal muscles play an important role in inspiration.

Role of Diaphragm :- The contraction of muscles of diaphragm causes it to become flat and lowered down increasing the volume of thoracic cavity

↓

Increase in volume of thoracic cavity

Leads to ↓

Increase in volume of pulmonary cavity

causes ↓

Decrease in pressure within the pulmonary cavity

causes ↓

Entry of air from atmosphere to lungs

Role of External intercostal muscles :-

* This muscles are present b/w the ribs. The contraction of this muscles lift the sternum and ribs up and outward causing the increasing of volume of thoracic cavity.

Expiration

Role of Diaphragm :- The relaxation of the diaphragm causes it to come to to normal position which reduces the volume of the thoracic cavity

↓

Decrease in volume of thoracic cavity

leads to ↓

Decrease in volume of pulmonary cavity

causes ↓

Increase in pressure of pulmonary cavity

causes ↓

Expulsion of air from lungs to the atmosphere

Role of External intercostal muscles :-

Relaxation of the muscles leads to pulling of ribs and sternum downward and inward resulting in decreasing the volume of thoracic cavity.

Muscles of inspiration

Accessory

Sternocleidomastoid (elevates sternum)

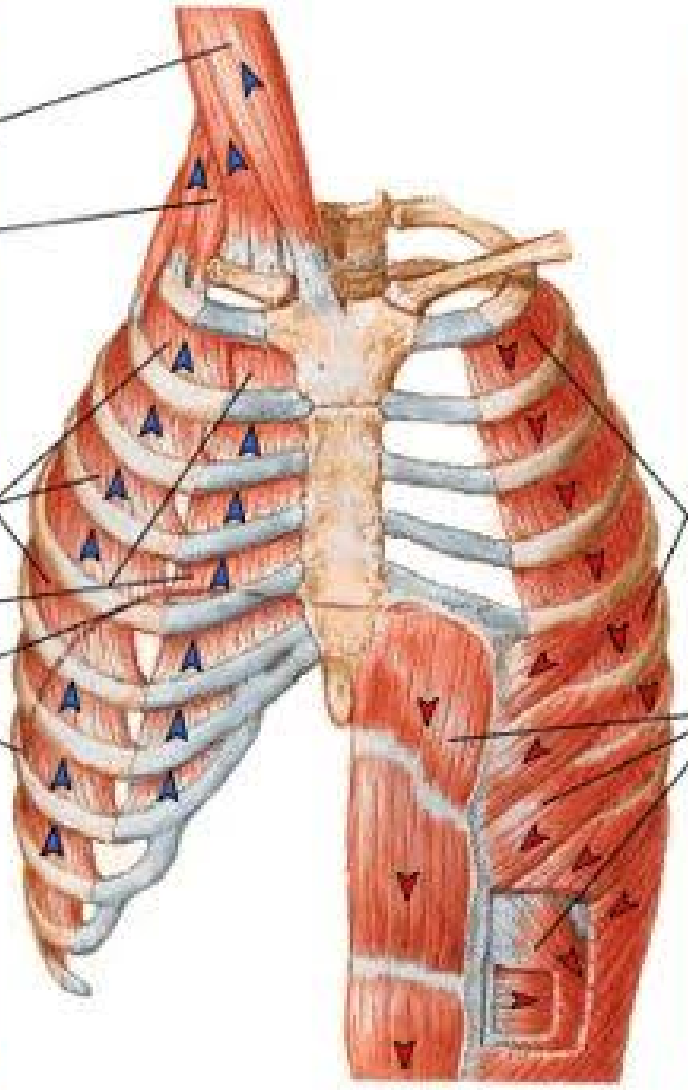
Scalenes Group (elevate upper ribs)

Not shown:
Pectoralis minor

Principal

External intercostals
Interchondral part of internal intercostals (also elevates ribs)

Diaphragm (dome descends, thus increasing vertical dimension of thorac cavity; also elevates lower ribs)



Muscles of expiration

Quiet breathing

Expiration results from passive, elastic recoil of the lungs, dib cage and diaphragm

Active breathing

Internal intercostals, except interchondral part (pull ribs down)

Abdominals (pull ribs down, compress abdominal contents thus pushing diaphragm up)

Note shown:
Quadratus lumborum (pulls ribs down)

Reference :—

1) Anatomy Bidogy
(Pratiksha Pokhrel)

2) Physiology
(Brene and Levy)