which serves to slow airflow. This allows time for the air to be warmed, filtered and humidified. The nasal mucosa is also supplied with a large number of sensory nerve endings. When irritated by inhaled particles, these sensory nerve endings will trigger a sneeze reflex.

The pharynx is commonly termed the 'throat' and is divided (from superior to inferior) into the nasopharynx, the oropharynx and the laryngopharynx. Only air moves through the nasopharynx, whereas both food and air pass through the oropharynx and laryngopharynx. The laryngopharynx is the point of bifurcation which leads to the larynx anteriorly and the oesophagus posteriorly.

The lungs are protected from food substances by the flap-like epiglottis that closes over the larynx during swallowing. The larynx contains the vocal cords and so is essential for voice production. Vocal cord (glottic) function is also essential for an effective cough mechanism.

The trachea, or windpipe, descends from the larynx into the thorax and is situated anterior to the oesophagus. It contains numerous cartilaginous C-shaped rings that support the anterior and lateral aspects of the trachea. These rings help to prevent tracheal collapse during the pressure changes associated with breathing. They are open posteriorly to allow the oesophagus to expand anteriorly as food is swallowed.

THE BRONCHIAL TREE

The branching pattern of airways is often referred to as the 'bronchial tree'. The airways divide and subdivide again. In all, there are approximately 23 generations (divisions) of airway in the human lung (Fig. 1-2).

The trachea bifurcates into the right and left main bronchi, which then supply their respective lungs. This point of bifurcation is termed the 'carina'. The right main bronchus branches off from the trachea at an angle of 20–30 degrees, while the left main bronchus branches off at an angle of 45–55 degrees. As the right main bronchus is more vertical than the left, aspirated food and drink are more likely to end up in the right lung if the person is in an upright position.

Each main bronchus then divides into lobar bronchi: three on the right and two on the left. Each lobar bronchus supplies the lobe of a lung and subdivides into segmental bronchi and then bronchi and bronchioles of ever decreasing size. Finally, terminal bronchioles divide into respiratory bronchioles. Respiratory bronchioles are hybrid structures and are part bronchiole, part alveoli. The respiratory bronchioles then give rise to the 300 million alveoli that are present in a healthy adult.

The structure of the airways changes towards the lung peripheries. The bronchioles lack cartilage but

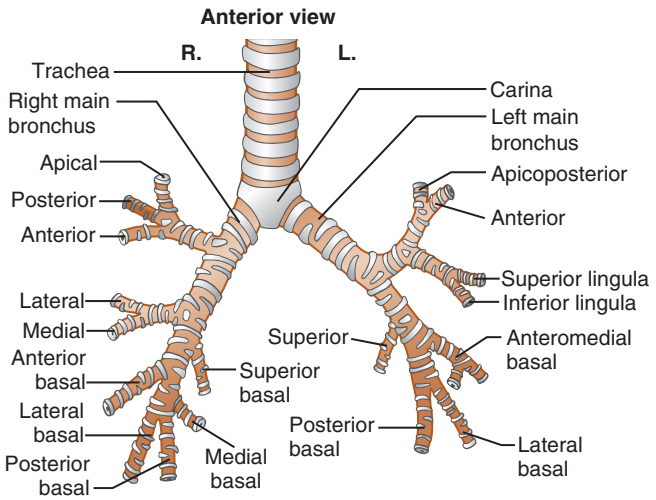

FIGURE 1-2 ■ The bronchial tree.

still have a relative abundance of smooth muscle. Hence the cartilage that maintains airway patency is absent, and constriction of the smooth muscle significantly reduces airway calibre in these small airways.

The calibre of the airways reduces through their generations and the major resistance to gas flow is normally in the upper airway. The larger airways are supported by cartilage, while the smaller airways are held patent by the radial traction of the surrounding lung so that their calibre increases with the volume of the lung. The diameter of these airways is also controlled by neural tone, which is predominantly parasympathetic.

The conducting zone of the lung includes the upper respiratory tract and the airway divisions up to and including the terminal bronchioles. The function of the conducting zone is to transport gas in and out of the lungs. The respiratory zone is where gas exchange takes place and includes the respiratory bronchioles and alveoli (Fig. 1-3).

Disruption of airway function can occur through obstruction to a large airway by, for example, a tracheal tumour. It may also occur because of more widespread disease in asthma, when the calibre of large numbers of smaller airways is affected by episodic alteration of smooth muscle contraction, mucosal oedema and intraluminal secretions. In chronic bronchitis, obstruction occurs by mucosal thickening and mucus secretion, but in emphysema the mechanism is different. Though seldom occurring in isolation from other forms of airway obstruction, the result of parenchymal emphysema is to weaken the elastic structure which maintains radial traction on the airways and allows them to close too early in expiration.

THE LUNGS AND PLEURAE

The cone-shaped lungs are located in the thoracic cage and are positioned vertically around the heart. The two lungs contain millions of alveoli within a fibroelastic matrix. They do not have a very rigid structure and are held in contact with the rib cage by negative pressure between the pleural surfaces. The resting volume of the lung is determined by the outward spring of the rib cage and the inward elastic recoil of the lung matrix. Expansion and contraction of the lung involves the controlled stretching or relaxation of the lung by the respiratory muscles. The position of lung resting volume can be influenced if the lung is stiffer than usual (as in interstitial disease) or if it is more compliant (as when damaged by emphysema).

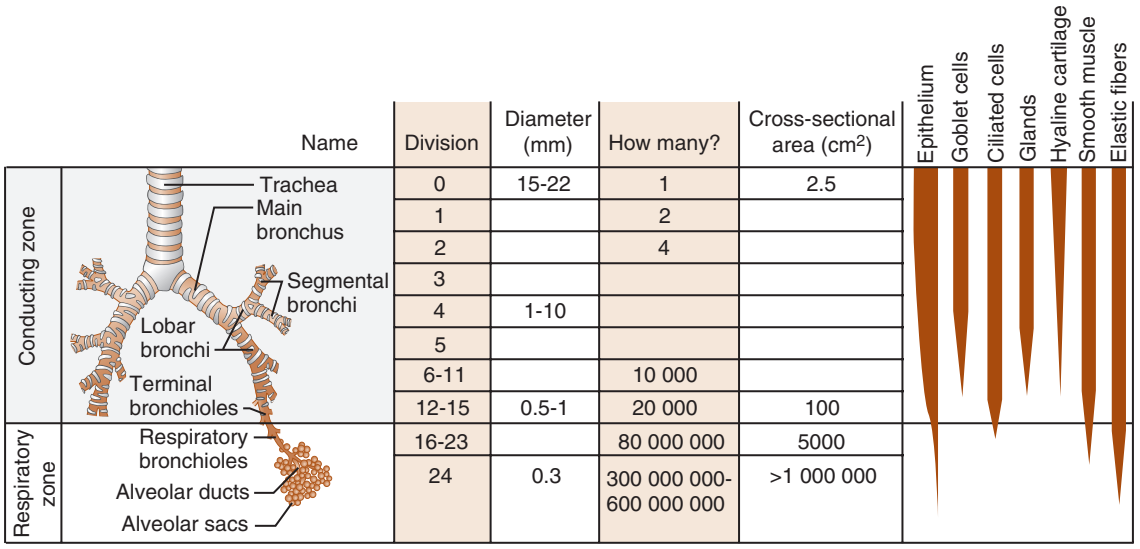

FIGURE 1-3 ■ Conducting and respiratory zones.

The lungs are divided into **lobes** (Fig. 1-4). The right lung is larger and has three lobes: upper, middle and lower. The left lung has just two lobes: upper and lower. The left lung is smaller because the heart is situated to the left of midline and therefore some of the space of the left lung is taken up by the heart (cardiac notch).

The lobes of the lungs are separated by **fissures**. The right lung is divided by the horizontal fissure (separates the upper and middle lobe) and the oblique fissure (separates the lower lobe from the upper and middle lobe). The left lung only has two lobes and therefore just has an oblique fissure (between the upper and lower lobe).

Each lobe of lung is divided into **bronchopulmonary segments**. There are 10 bronchopulmonary segments in the right lung, and eight in the left lung. A bronchopulmonary segment is a functionally and

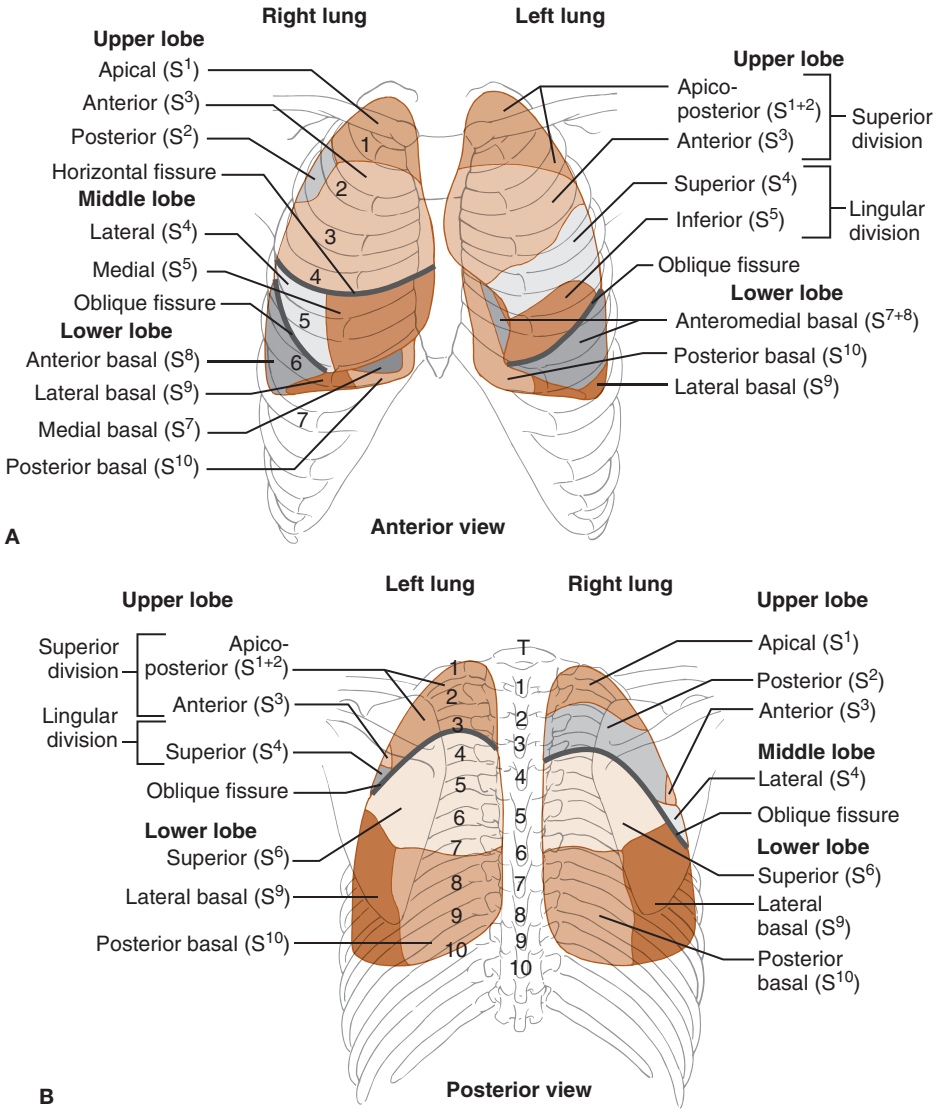

FIGURE 1-4 ■ Lung lobes and fissures. **(A)** Anterior view. (Superior basal segments not visible in anterior view.) **(B)** Posterior view.

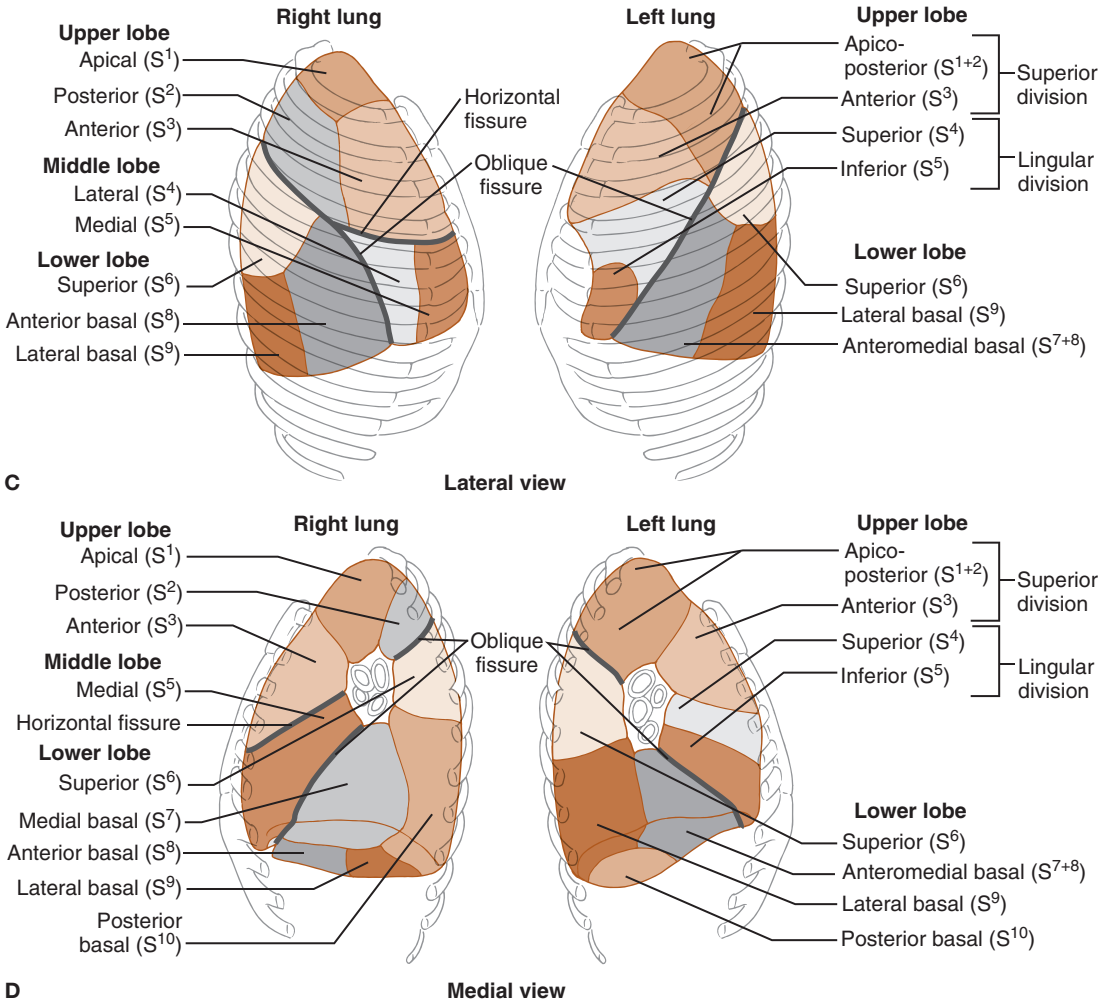

FIGURE 1-4, cont'd ■ **(C)** Lateral view. **(D)** Medial view. S, segment number.

anatomically independent unit of lung which has its own segmental bronchus, artery and vein. Segments are separated from one another by connective tissue septa. This means that if an isolated tumour or disease is present in one bronchopulmonary segment, it can be surgically removed (segmentectomy), causing minimal disruption to adjacent segments of lung. Respiratory physiotherapists should be familiar with the names of the bronchopulmonary segments and the anatomical position of each segmental bronchus. This anatomical knowledge is required in order to perform gravity-assisted positioning (GAP), which is used to promote drainage of excess bronchopulmonary secretions. Specific segmental bronchi are positioned perpendicular to gravity in order to drain the affected bronchopulmonary segment (see Fig. 1-2).

The lungs are covered with a thin double-layered serous sac called the **'pleural membrane'.** The outer layer of the membrane is the **parietal pleura** and the inner layer is the **visceral pleura** (Fig. 1-5). The parietal pleura lines the inner surface of the thoracic wall and the superior surface of the diaphragm. The visceral pleura covers the outer surface of the lungs and also lines the fissures. The potential space between the parietal and visceral pleurae is the pleural cavity, and this contains a small amount of pleural fluid which is

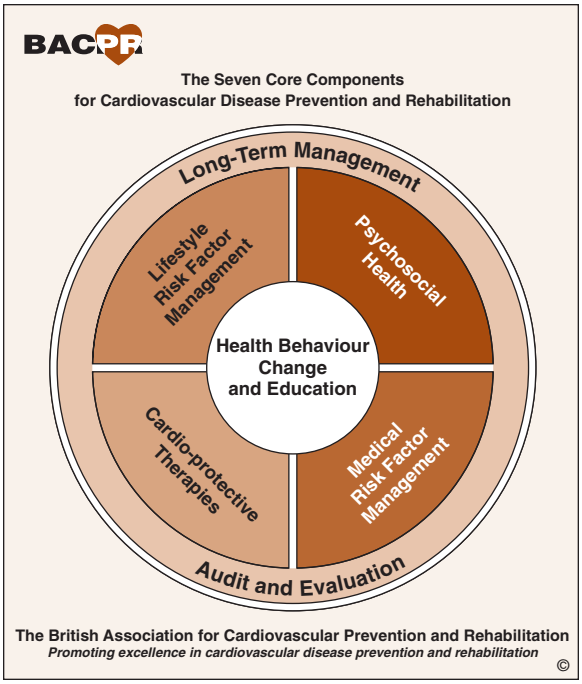

FIGURE 12-3 ■ Definition and core components of cardiac rehabilitation. *(Reproduced with permission from BACPR.)*

cardiac rehabilitation is tailored to a patient's medical condition, risk factor evaluation, and vocational status.

> ***What Is Cardiac Rehabilitation?***
> *'The coordinated sum of activities required to influence favourably the underlying cause of cardiovascular disease, as well as to provide the best possible physical, mental and social conditions, so that the patients may, by their own efforts, preserve or resume optimal functioning in their community and through improved health behaviour, slow or reverse progression of disease.'*
>
> *(BACPR 2012a)*

Although there are class IA recommendations for cardiac rehabilitation in the American Heart Association (AHA) and American College of Cardiology (ACC) management guidelines and performance measures, only around 20% of eligible patients are apparently referred (Menezes et al 2014). Earlier studies from multiple countries reported an average referral rate of approximately 30% in Canada, the United States and the United Kingdom and a little higher at around 50% in the rest of Europe (Aragam et al., 2011). Even among patients who are appropriately and/or automatically referred to cardiac rehabilitation, participation rates remain concerningly low. Surveys across nine European countries show within 1 and 6 months after acute MI, only 29% and 48% of referred patients participated in cardiac rehabilitation (EUROASPIRE I and II, 2001). Predictors of suboptimal participation include poor functional status, higher BMI, tobacco use, depression, low health literacy and long travel distances (Menezes et al 2014). Further, international data show unacceptable levels of modifiable risk factors at follow-up in the majority of people with CHD and other vascular disease (Kotseva et al 2009, Steg et al 2007). Moreover, non-attendees are less likely to believe that rehabilitation is necessary (Cooper et al 2007) yet have higher baseline risk and poorer risk factor knowledge than those who attend (Redfern et al 2007).

In efforts to increase participation there is recognition of the need to 'rebrand and reinvigorate' cardiac rehabilitation (Sandesara et al 2015). Efforts include reducing specific barriers to referral and participation, offering choice (e.g. home-based, evening sessions etc.) and the use of modern technologies (Internet, phone and other communication tools). Commencing programme orientation within 10 days of discharge and initiating structured activity early are associated with increased uptake and improved patient outcomes (Aamot et al 2010, Haykowsky et al 2011, Pack et al 2013). Regarding the use of innovative strategies to bring exercise-based cardiac rehabilitation to more patients, new delivery models must be adopted, especially for patients at low or low-to-intermediate risk. These include the use of telemedicine as well as Internet-based, home-based (including smartphone–based home-care models) and community-based programmes to provide alternatives to conventional, medically supervised, facility-based programmes (Clark et al 2015, Varnfield et al 2014). Moving traditional cardiac rehabilitation out of the hospital setting and into community-based venues may increase accessibility and provides an environment removed from acute illness, thereby promoting health and well-being. Consequently, it is essential for physiotherapists and the MDT to also be equipped to deliver and rigorously

(Berlowitz et al 2005, Burns et al 2000, Leduc et al 2007, Stockhammer et al 2002, Tran et al 2010). In the general population, untreated sleep disorders are associated with cardiovascular disease and impaired cognition (Punjabi 2008). Neurocognitive impairments including decreased memory and attention have also been linked to nocturnal hypoxia in tetraplegic individuals with untreated OSA (Sajkov et al 1998). Studies in chronic SCI have found a positive correlation with age, body mass index (BMI) and neck circumference (Burns et al 2000, McEvoy et al 1995, Stockhammer et al 2002). In contrast, Berlowitz et al (2005) noted that the usual risk factors for OSA do not appear to be important in acute tetraplegia. An individual with acute tetraplegia and undiagnosed or untreated OSA may struggle to participate in the demanding process of rehabilitation. Ongoing cognitive impairment will also be of significance for an individual whose future employment opportunities are skewed towards computer and desk-based tasks.

RESPIRATORY ASSESSMENT

Assessment is discussed in Chapter 2; Post SCI; particular note should be made of the following:

1. Neurological examination: Determines respiratory muscle innervation and hence likely function (Roth et al 1997).
2. Associated injuries: Rib fractures, flail segments, pneumothorax and pulmonary contusions are often associated with thoracic SCI. Patients involved in diving accidents may aspirate. Thoracic and intra-abdominal trauma or complications such as paralytic ileus, acute gastric dilatation or gastrointestinal bleeding will require modification of the techniques used by the physiotherapist, especially manually assisted coughing.
3. Visual assessment of breathing pattern: Identifies paradoxical or unequal movement of the chest wall. Determines whether intercostal activation present by way of lateral ribcage movement.
4. Assessment of diaphragm function: View the patient in supine from the foot of the bed to assess symmetry. Inspect and palpate the upper abdomen. Ask the patient to sniff which selectively recruits the diaphragm.
5. Cough: Listen to the sound of the cough and observe the abdomen for signs of muscle activity. Assess ability to take a deep breath, hold and then expel forcefully; note what components are affected.
6. Lung function testing: Forced vital capacity (FVC) should be measured at the time of admission and subsequently to monitor for signs of respiratory deterioration. Forced expiratory volume in 1 second (FEV_1) will identify any obstructive impairment and peak cough flow should be measured to quantify cough strength.
7. Psychological state: Major psychological adjustment is required by the patient with SCI, not only to the injury itself but also to the necessary treatment procedures. Sensory deprivation, enforced immobilization, fragmented sleep and limited communication can lead to anxiety or contribute to delirium.

PHYSIOTHERAPY TREATMENT

Until the mid 90s, traumatic cervical SCI was managed with skull tongs, traction and bed rest. The past 20 years have seen early surgical stabilization of the spine being widely adopted (Fehlings et al 2010, 2012). Patients are intubated for surgery and admitted to intensive care postoperatively on ventilation. Once surgically stabilized, patients are cleared to sit out of bed. Upright positioning while a patient is in spinal shock may lead to increased work of breathing and hypotension. Use of an abdominal binder and antihypotensive medication may to some extent counteract this, but the physiotherapist must proceed cautiously, monitoring for signs of fatigue and dizziness.

Secretion and ventilation management of individuals with acute cervical SCI differs from that required by individuals with pulmonary dysfunction secondary to non-neurological injuries (Wong et al 2012). Secretions accumulate secondary to increased production (Bhaskar et al 1991), poor cough and, in some instances, aspiration of saliva. Atelectasis leads to impaired aeration, infection and pneumonia (Berlly & Shem 2007). A literature review of respiratory management during the first 6 weeks following cervical SCI showed a protocol using a combination of techniques which may include IPPB, manually assisted

coughing, respiratory muscle resistance training, non-invasive ventilation (NIV) and/or a clinical pathway is most likely to provide positive outcomes (Berney et al 2011a).

Injuries above the level of C5 with AIS A classification have the highest incidence of intubation and ventilation with rates of up to 90% (Como et al 2005, Hassid et al 2008). Early intervention with a non-invasive ventilatory technique may avoid progression of respiratory failure and the need for sedation, intubation and invasive mechanical ventilation (Bach 2012, Tromans et al 1998). However, failure to intubate in a timely way in the presence of tetraplegia can lead to the need for emergency airway intervention (Ball 2001, Como et al 2005) or catastrophic airway loss and death (Hassid et al 2008). In a generalist unit not familiar with SCI specific management, intubation and invasive ventilation followed by the use of a tracheostomy to facilitate weaning from ventilation, may provide the safest option for the patient.

Physiotherapy goals for treatment of the ventilated patient are the same as those for the non-ventilated patient. Treatment may include postural drainage, volume augmentation with manual or VHI, and suction or exsufflation to remove secretions (Berney et al 2011a, b, Wong et al 2012). Patients requiring ventilation due to complications from SCI are often not sedated and a system of communication must be established before physiotherapy is started.

Frequent brief treatments are desirable, as acutely injured patients will tire quickly. Treatment must be effective, using two physiotherapists if necessary. Where possible, linking with planned position changes will optimize efficiency and allow rest between procedures.

Secretion Clearance

Assisted Coughing

A large inspiratory effort followed by a quick and forceful expiration is required in order to achieve a successful cough. Utilizing techniques to increase inspiratory volume outlined in the following paragraphs will allow more efficient airway clearance. Expiratory assistance is provided by the application of a compressive force directed inwards and upwards under the diaphragm and compression of the ribcage, thus replacing the work of the abdominal and internal intercostal muscles (Fig. 13-15). The sound of the resultant cough is the best indicator of the force required. Pressure directed down through the abdomen must be avoided in the acute patient, in the presence of abdominal injury or with paralytic ileus. Care should also be taken in the presence of rib fractures or other chest injuries and therapists should position their hands away from the problem area to perform an assisted cough.

Frownfelter and Massery (2006) describe various methods of achieving assisted cough. The technique needs to be relatively forceful and it is advisable for the therapist to lower the bed to gain the most advantageous position from which to perform the technique. The spinal stability of the patient must be carefully considered and a shoulder hold should be used to counter any movement of an unstable cervical spine (see Fig. 13-15D and E). The therapist must synchronize the applied compressive force with the expiratory effort of the patient. Once the cough is completed, pressure must be lifted momentarily from the ribs and abdomen, enabling the patient to initiate the next breath. Patients should be encouraged to cough 3–4 times per day or more where indicated, with nursing staff and/or family involved in this process. Patients should also be taught self-assisted coughing when in a wheelchair (Figs 13-15F and 13-16).

Mechanical Aids for Assisted Coughing

Mechanical insufflation–exsufflation devices to assist coughing have been documented in the literature as being effective with patients with neuromuscular disorders and respiratory muscle weakness (Bach 1993, Chatwin et al 2003, Sancho et al 2004, Vianello et al 2005, Whitney et al 2002). Whitney et al (2002) suggest using pressures in the range of +25 cmH_2O positive pressure and −30 cmH_2O negative pressure, while Chatwin & Simonds (2002) have reported effective coughs at pressures of +10 to +30 cmH_2O and −10 to −30 cmH_2O. Winck et al (2004) and Tzeng & Bach (2000) have suggested that pressures of 40 cmH_2O or more may be required.

The range of cough assistance devices has recently expanded (Fig. 13-17) (Porot and Guerin 2013). Much lighter and with an internal battery, the Philips E70 device has inspiratory and expiratory oscillation modes and a memory card for data management. It

FIGURE 13-15 ■ Assisted cough variations. **(A, B)** Two-person assisted cough. **(C, E)** Two-person assisted cough with shoulder stabilization. **(D)** One-person assisted cough. **(F)** Assisted cough with carer providing abdominal compression.

FIGURE 13-16 ■ Self-assist cough.

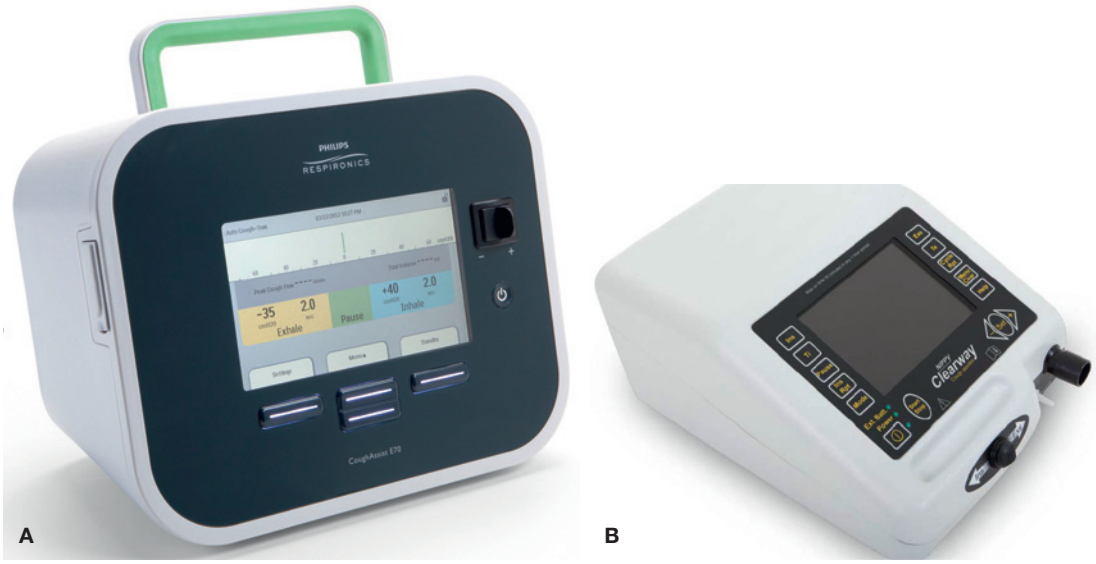

FIGURE 13-17 ■ Cough assistance devices.