TABLE 20.1 Physiological Parameters for Weaning and Extubation of Adults

Parameter	Acceptable Value
Ventilatory Performance and Muscle Strength	
VC	>15 mL/kg (IBW)
$\dot{V}_E$	<10–15 L/min
V_T	>4–6 mL/kg (IBW)
f	<35 breaths/min
f/V_T	<60–105 breaths/min/L (spontaneously breathing patient)
Ventilatory pattern	Synchronous and stable
P_{Imax} (up to 20-s measurement from RV)	< −20 to −30 cm H_2O
Measurement of Drive to Breathe	
$P_{0.1}$	>6 cm H_2O
Measurement and Estimation of WOB	
WOB[a]	<0.8 J/L
Oxygen cost of breathing[a]	<15% of total $\dot{V}O_2$
Dynamic compliance	>25 mL/cm H_2O
V_D/V_T	<0.6
CROP index	>13 mL/breaths/min
Measurement of Adequacy of Oxygenation	
P_aO_2	≥60 mm Hg (F_IO_2 <0.4)
PEEP	≤5–8 cm H_2O
P_aO_2/F_IO_2	>250 mm Hg (consider at 150–200 mm Hg)
P_aO_2/P_AO_2	>0.47
$P_{(A-a)}O_2$	<350 mm Hg (F_IO_2 = 1)
% $\dot{Q}_s/\dot{Q}_t$	<20%–30%

[a]Actual measure of WOB.

CROP, Compliance, respiratory rate, oxygenation, and inspiratory pressure; *f,* respiratory rate; F_IO_2, fractional inspired O_2; f/V_T, rapid shallow breathing index; *IBW,* ideal body weight; $P_{0.1}$, pressure on inspiration measured at 100 msec; P_aO_2, partial pressure of O_2 in the arteries; P_aO_2/P_AO_2, ratio of arterial PO_2 to alveolar PO_2; $P_{(A-a)}O_2$, alveolar-to-arterial partial pressure of O_2; P_aO_2/F_IO_2, ratio of partial pressure of O_2 (PO_2) in the arteries to F_IO_2; *PEEP,* positive end-expiratory pressure; P_{Imax}, maximum inspiratory pressure; % Q_s/Q_t, percent shunt; *RV,* residual volume; *VC,* vital capacity; V_D/V_T, ratio of dead space to tidal volume; $\dot{V}_E$, minute ventilation; $\dot{V}O_2$, O_2 consumption per minute; V_T, tidal volume; *WOB,* work of breathing.

have been found to be reasonably consistent as weaning criteria (see Box 20.4). Although these variables provide information about the patient's potential for liberation from the ventilator, assessments made during a formal, carefully monitored 30- to 120-minute SBT may be the most useful guide for making decisions regarding discontinuation of the ventilation (Key Point 20.2).[2]

***Key Point* 20.2** A properly monitored spontaneous breathing trial is safe and effective; therefore the other assessments listed under Recommendation 2 (see Box 20.4) and in Table 20.1 may generally be unnecessary.[2]

Patient Ventilatory Performance and Muscle Strength

For many years several simple measurements have been used to evaluate a patient's ventilatory muscle function before weaning and extubation. These include vital capacity (VC), $\dot{V}_E$, *f,* spontaneous V_T, and the rapid shallow breathing index (RSBI). VC has not been shown to be a good predictor for ventilator discontinuation, probably because it requires patient cooperation, which is not always consistent. The *f,* V_T, and RSBI can be obtained using a bedside pulmonary function device, a respirometer, or directly through the ventilator. These measurements do not require patient cooperation (see Table 20.1).

The *f* is easy to count and is a fairly reliable guide to a patient's ability to tolerate a ventilatory load.[67] A spontaneous *f* greater than 35 breaths/min in an adult indicates that the patient is not ready to be weaned. Evaluation of the pattern of breathing is also valuable. The clinician should review the patient's sedation history when making these measurements because sedatives can alter breathing patterns.[68]

The RSBI is the most frequently studied and one of the more reliable tests for determining a patient's weaning status. It is calculated by dividing the respiratory frequency (in breaths/min) by the V_T (in liters): f/V_T. This measurement is taken 1 minute after disconnecting the spontaneously breathing patient from the ventilator and O_2. Successful weaning is more likely if the RSBI is less than 105 (normal range, 60–105). Values above 105 suggest that a patient is not ready for weaning and probably will fail a weaning trial (Case Study 20.2).[63,69,70]

Measurement of the maximum inspiratory pressure (P_{Imax} [or MIP]), also called negative inspiratory force (NIF), was described in Chapter 4 (see Fig. 4.2). For the purpose of weaning, this parameter must be measured with a specific technique to ensure consistency. P_{Imax} is measured in an occluded airway after 20 seconds.[2] (NOTE: The procedure should be stopped if O_2 desaturation or arrhythmias occur.) A specific value of P_{Imax} that can be used as a predictor of weaning success or failure has not been firmly established. (NOTE: Trending a patient's maximal

BOX 20.7 Requirements of an Ideal Weaning Index

The ideal weaning index should include the following:
- Assessment of the pathophysiological determinants of weaning outcome, including ventilatory muscle function, pulmonary gas exchange (ventilation and oxygenation), and psychological problems
- Accurately evaluate physiological function as it relates to the degree of abnormality present
- Ease of measurement and reproducible measurements
- Minimum patient cooperation
- High positive and negative predictive values

Case Study 20.2

Calculation of Rapid Shallow Breathing Index (RSBI)

Which of the following patients has an RSBI that suggests it is time to begin weaning from ventilatory support?

Patient 1: Spontaneous V_T is 0.4 L; *f* is 10 breaths/min.

Patient 2: Spontaneous V_T is 0.25 L; *f* is 30 breaths/min.

inspiratory force [i.e., MIF] measurements can provide information that can serve as an early indicator of impending respiratory weakness.) The ratio of the inspiratory pressure to P_{Imax} and the ratio of the airway occlusion pressure to P_{Imax} may provide other valuable weaning tools, but further study of these parameters is needed.[63,71-73]

Measurement of Drive to Breathe

The inspiratory drive to breathe is established by measurement of the airway occlusion pressure ($P_{0.1}$ [or P_{100}]). The $P_{0.1}$ can be measured by adding special valve systems to a ventilator system; it is available on some ICU ventilators, such as the Dräger Evita Infinity V500 (Dräger Medical, Telford, PA).

To obtain the $P_{0.1}$, the airway is occluded during the first 100 msec of inspiration and the pressure at the upper airway is measured (Fig. 20.6). The $P_{0.1}$ is thought to reflect both the drive to breathe and ventilatory muscle strength.[2] The normal range is 0 to −2 cm H_2O.

$P_{0.1}$ is reported as an absolute value even though the pressure generated is below baseline. A value close to normal may indicate that the patient is breathing comfortably. However, a low value may indicate either a weak drive to breathe or muscle weakness, which are not good indicators for readiness to wean.[2] Values below −6 cm H_2O may indicate a high drive to breathe and suggest that weaning is not likely to succeed.[73-76] High occlusion pressures may indicate that the patient is uncomfortable.[2] A high drive to breathe in these situations could lead to fatigue during a ventilator withdrawal challenge. On the other hand, a high $P_{0.1}$ may reflect strong respiratory muscles and a vigorous respiratory drive, which are advantageous if the patient has an intact drive to breathe.[2] Additional studies will be required to evaluate the effectiveness of $P_{0.1}$ as a predictor of weaning success.

Work of Breathing

When a patient has received total ventilatory support for several days or weeks, the respiratory muscles may become weak from lack of use. Patients may also be undernourished. As with any other skeletal muscles, lack of nutrition weakens the diaphragm. Proper nutrition is therefore essential for maintaining respiratory muscle strength and ensuring successful weaning from the ventilator.

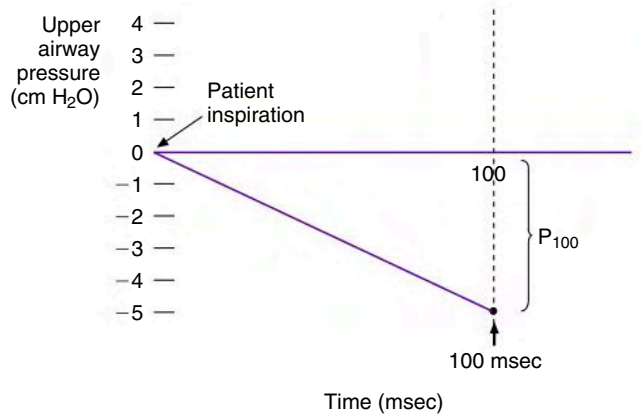

Fig. 20.6 Graphic representation of pressure on inspiration measured at 100 milliseconds ($P_{0.1}$). The airway is occluded after patient inspiration. Pressure at the mouth is measured at 100 msec, and the airway is then opened. The upper airway pressure at 100 msec is the $P_{0.1}$ value, reported as an absolute number.

BOX 20.8 Physical Signs and Measurements of Increased Work of Breathing

- Use of accessory muscles
- Asynchronous breathing (chest wall−diaphragm asynchrony)
- Nasal flaring
- Diaphoresis
- Anxiety
- Tachypnea
- Substernal and intercostal retractions
- Patient asynchronous with ventilator
- Measured WOB >1.8 kg/m/min or >0.8 J/L
- Measured WOB ≥15% of total O_2 consumption

The WOB and ventilatory muscle fatigue are both important aspects of ventilator dependency. Unfortunately, a universally accepted normal value for the WOB has not been identified as a predictor of weaning success. In addition, measurement of WOB requires a great deal of expertise and can be both invasive and costly.[2,77,78] Box 20.8 lists signs and measures indicating a high WOB.[78]

Previously mentioned parameters, such as spontaneous f and the f/V_T ratio, allow the clinician to gauge a patient's spontaneous WOB. Less obvious contributors to an increased WOB are a high O_2 cost of breathing, an elevated metabolic rate (high CO_2 production [$\dot{V}CO_2$]), a high ratio of dead space to tidal volume (V_D/V_T) (≥0.6), high airway resistance (R_{aw}), and stiff lungs (low respiratory system compliance).[79] The first three factors require special equipment and are difficult to measure. These parameters are seldom used by clinicians because they require too much respiratory work for a patient to maintain for an extended period (Key Point 20.3).[2,59]

***Key Point* 20.3** "More complex weaning parameters focused on physiological measurements, such as muscle strength, respiratory system mechanics, metabolic parameters, and work of breathing, add little to the assessment of individual patients for discontinuation potential."[59]

The index that evaluates compliance, respiratory rate, oxygenation, and inspiratory pressure (CROP index) may provide a good assessment of potential respiratory muscle overload and fatigue. The CROP index is calculated as follows:

$$\text{CROP} = \frac{(\text{CD} \times P_{Imax} \times [P_aO_2/P_AO_2])}{f}$$

where C_D is dynamic compliance, P_{Imax} is the maximum inspiratory pressure, P_aO_2 is the arterial partial pressure of O_2, P_AO_2 is the alveolar partial pressure of O_2, and f is the respiratory rate. CROP values above 13 indicate the likelihood of successful ventilator withdrawal.[2]

Adequacy of Oxygenation

Invasive mechanical ventilation is rarely used specifically to treat hypoxemia. The notable exception to this is ventilation in patients with acute respiratory distress syndrome (see Chapter 13). If a patient receiving mechanical ventilation requires a high F_IO_2 and a high level of PEEP and has low arterial O_2 levels, the underlying pulmonary disease that caused the need for ventilation probably has not resolved sufficiently to allow the patient to breathe without assistance. Several oxygenation parameters can be used to determine whether the underlying disease has resolved; these include the P_aO_2; the ratio of the arterial O_2 partial pressure to the fraction of inspired O_2 (P_aO_2/F_IO_2); the ratio of arterial to alveolar O_2 partial pressure (P_aO_2/P_AO_2); shunt; and the alveolar-to-arterial O_2 partial pressure ($P_{(A-a)}O_2$) (see Table 20.1).[78] Hemoglobin levels must also be sufficient to ensure that O_2 transport is adequate before weaning. Assessment of the patient's hemodynamic status (e.g., blood pressure, heart rate, and cardiac index [CI]) is an important part of the evaluation process.

Recommendation 2: Assessment of Readiness for Weaning Using Evaluation Criteria

The ACCP/SCCM/AARC Task Force's Recommendation 2 states that a formal assessment of the patient should be performed to determine whether the criteria have been met for discontinuation of ventilation.[1] Specific criteria for determining weaning readiness are listed in Box 20.4 and Table 20.1.

Recommendation 3: Assessment During a Spontaneous Breathing Trial

Perhaps the best approach to determining a patient's readiness to wean is a carefully supervised SBT.[1,2] As stated under Recommendation 3 (see Box 20.4), a formal assessment is made during spontaneous breathing rather than while the patient is mechanically ventilated. An initial SBT is typically conducted when the basic assessment findings suggest that the patient is ready to be weaned, but the clinician nonetheless is uncertain about the patient's ability to sustain breathing without mechanical support. The patient is allowed to breathe spontaneously for a few minutes to determine his or her ability to perform a more extended SBT. This initial effort is considered a screening phase and is usually conducted before a decision is made to continue an SBT.

During the SBT the patient's ability to tolerate unsupported ventilation is determined by observing his or her respiratory pattern, adequacy of gas exchange, hemodynamic stability, and subjective comfort (see the next section). A patient is considered ready for ventilator discontinuation and assessment for extubation when the person can tolerate an SBT for 30 to 120 minutes (Key Point 20.4). Studies have demonstrated that 77% to 85% of patients who pass an SBT can be successfully weaned and extubated without requiring reintubation.[59,63,80,81]

Key Point 20.4 "The best indicator of ventilator discontinuation potential is the clinical assessment of patients during the 30- to 120-minute spontaneous breathing trial (e.g., respiratory rate, blood pressure, heart rate, comfort/anxiety, oxygenation, S_pO_2)."[59]

SBTs typically last at least 30 minutes but not longer than 120 minutes.[1,2,80] The SBT can be accomplished using a low level of CPAP (e.g., 5 cm H_2O), a low level of PSV (e.g., 5–8 cm H_2O), ATC, or simply a T-piece.[81,82] Although all these techniques have been shown to be effective for SBTs, it has been suggested that low levels of PSV shorten the length of time on the ventilator and ICU stays compared with a T-tube trial.[83]

The SBT is well established as a key index of a patient's ability to wean from the ventilator and of successful extubation. Studies have shown that successful completion of an SBT reduces ventilatory time, and therefore the cost of patient care, compared with cases in which the 2-hour SBT was not performed.[78,84] Close monitoring of patients undergoing an SBT is critical. Unnecessary prolongation of a failed SBT can result in muscle fatigue, hemodynamic instability, discomfort, or worsening gas exchange. There are no studies suggesting that SBTs contribute to any adverse outcomes if the trial is terminated promptly when signs of failure are recognized. In short, the patient should not be allowed to experience extreme exhaustion during the trial.

A variety of signs, symptoms, and monitored parameters allow clinicians to evaluate patients during the SBT. Patients who are not tolerating the process may show signs of dyspnea, fatigue, pain, anxiety, diaphoresis, pallor or cyanosis, drowsiness, restlessness, or use of accessory muscles. Box 20.9 lists clinical signs and symptoms that should be monitored during an SBT.[81-85] These physical findings provide evidence that some underlying problem is preventing a successful weaning process.

Recommendation 4: Removal of the Artificial Airway

When a patient can breathe spontaneously (i.e., has performed an SBT successfully) and ventilator support has been discontinued, a decision must be made about removal of the artificial airway. This decision is based on assessment of airway patency and the patient's ability to protect the airway.[59]

BOX 20.9 Clinical Signs and Symptoms Indicating Problems During a Spontaneous Breathing Trial

1. Respiratory rate exceeding 30 to 35 breaths/min (clinicians also should watch for increases of more than 10 breaths/min or fewer than 8 breaths/min).
2. Tidal volume (V_T) decreasing below 250 to 300 mL.
3. Blood pressure changing significantly, as demonstrated by:
   - A drop of 20 mm Hg systolic *or*
   - A rise of 30 mm Hg systolic *or*
   - Systolic values above 180 mm Hg *or*
   - A change of 10 mm Hg diastolic (e.g., rise >90 mm Hg)
4. Heart rate increasing more than 20% or exceeds 140 beats/min.
5. Sudden onset of frequent premature ventricular contractions (more than 4–6/min).
6. Diaphoresis.
7. Clinical signs that indicate deterioration of the patient's condition or that demonstrate the patient is anxious, not ready for weaning, and must be returned to ventilatory support.
8. Deterioration of arterial blood gas values and O_2 saturation measured by pulse oximeter (S_pO_2).[85]

Some practitioners equate ventilator liberation with extubation, which adds to the confusion of defining terms with regard to readiness for discontinuation of ventilation versus readiness for extubation. In most cases, discontinuation of ventilatory support and extubation are a single process. However, in some cases, such as a patient with upper airway burns or one with copious secretions and a weak cough, the artificial airway may need to be maintained for an extended period after discontinuation of mechanical ventilatory support.

Common risks associated with extubation include potential airway obstruction, aspiration, and inability to clear secretions. Successful extubation is likely if a patient has a strong cough and is able to mobilize secretions, does not have excessive secretions, and has a peritubular leak on cuff deflation (successful cuff leak test).[86]

The cuff leak test is a means of testing for postextubation airway patency. Note that to qualify for this test, the patient must no longer need ventilatory support. To perform this test, the patient is disconnected from the ventilator, the cuff is deflated, and the ET or TT is obstructed. A leak around the cuff (peritubular leak) during spontaneous breathing suggests that the airway caliber is adequate and successful extubation is likely. A leak of less than 110 mL (average of three values on six consecutive breaths) indicates a high risk for postextubation stridor. Recent guidelines suggest initiation of treatment with systemic steroids at least 4 hours before extubation is indicated for patients who fail the cuff leak test but otherwise are ready for extubation.[60,87,88] It is important to recognize that a successful cuff leak test does not guarantee that postextubation difficulties will not arise. Patients without such leaks, however, must be watched more closely.[87,89,90]

Some clinicians are concerned that their extubation attempts might have a high rate of failure and require reintubation. Reported reintubation rates range from as low 4% to as high as 33%. Higher reintubation rates are more common in patients who demonstrate mental status changes and neurological impairment.[55,91,92] An acceptable reintubation rate has not been determined.[88,93,94] A low reintubation rate (5%) might suggest that clinicians are too conservative in their attempts at extubation and overly exacting in their use of extubation criteria; this gives rise to the risks associated with prolonged intubation (e.g., VAPs, ventilator-induced lung injury, damage to the airway). Conversely, a high percentage of extubation failure (>30%) might indicate that clinicians are too aggressive and too liberal with extubation criteria; this presents the risks associated with reintubation. It has been suggested that an extubation failure rate of 10% to 19% may be clinically acceptable.[62] Box 20.10 lists some of the factors that contribute to extubation failure.[59,91,95]

Reintubation is marked by an eightfold higher risk for the development of nosocomial pneumonia and a 6-fold to 12-fold increase in the mortality rate.[55,80,91,92] The risks of continued use of an artificial airway must be weighed against the risks for extubation and its possible failure (Key Point 20.5). Interestingly, up to 80% of patients who intentionally self-extubate do not require reintubation.[62]

Key Point 20.5 Clinicians are often reluctant to remove an ET for fear of having to reintubate the patient.

Box 20.11 briefly outlines the extubation procedure and lists the required equipment. Box 20.12 summarizes some of the key points of the AARC Clinical Practice Guideline for removal of the ET.[96] Table 20.1 provides a list of physiological parameters that can be used to assess readiness for extubation.

BOX 20.10 Factors That May Contribute to Extubation Failure

- Type of patient (i.e., medical vs. surgical)
- Older age
- Severity of illness at weaning onset
- Repeated or traumatic intubations
- Use of continuous intravenous sedation
- Duration of mechanical ventilation
- Female gender
- Anemia (hemoglobin <10 mg/dL or hematocrit <30%)
- Need for transport out of the intensive care unit
- Initial severity of illness
- Indication for mechanical ventilation (e.g., cause of acute respiratory failure)
- Duration or number of individual spontaneous breathing trials before extubation
- Mode of ventilator support before extubation
- Protocol-directed weaning

Postextubation Difficulties

Hoarseness, sore throat, and cough are common after extubation. Other postextubation problems include subglottic edema, increased WOB from secretions, airway obstruction, and postextubation laryngospasm.[65]

Postextubation glottal edema can result in partial airway obstruction, causing stridor. This potentially serious condition is commonly treated with a cool aerosol supplemented with O_2 and nebulized racemic epinephrine (0.5 mL, 2.25% epinephrine in 3 mL normal saline). Helium-oxygen mixtures (e.g., 70% He/30% O_2), administered through a nonrebreathing mask, also reduce WOB through the partly obstructed airway. This technique, known as heliox therapy, provides a low-density gas that may aid spontaneous breathing, thus relieving the effects of stridor and temporarily supporting gas exchange. This may allow time for medical treatment (e.g., racemic epinephrine and steroids) to take effect and prevent reintubation.[97] Reintubation may be necessary to prevent the development of respiratory distress if postextubation edema and stridor are severe and refractory to treatment.

Postextubation laryngospasm may occur and is usually transient. Persistent laryngospasm may respond to positive pressure delivered with O_2 (e.g., bag-mask device). If it continues, a neuromuscular blocking agent and reintubation may be necessary.[91]

The risk for aspiration is another potential problem after extubation. Aspiration is associated with an inability to protect the airway, and it is not unusual in patients with central neurological injury. (NOTE: In patients who have a neuromuscular or spinal cord injury, a peak cough flow greater than 160 L/min may predict successful extubation or decannulation [removal of the TT].)[1,59] Other factors that may increase the risk for aspiration after extubation include the following:

- Use of muscle relaxants (may also impair the ability to protect the airway)

BOX 20.11 Extubation Equipment and Procedure

Equipment

- Electrocardiogram monitor
- Resuscitation bag, O_2 source, and O_2 mask
- Suctioning equipment, including suction kits and Yankauer suction
- Laryngoscope and additional endotracheal tubes for intubation (if necessary)
- Racemic epinephrine and a small-volume nebulizer (in case postextubation stridor develops)
- A 5-mL unit dose of normal saline or 5-mL syringe for irrigation with normal saline during suctioning (if necessary)
- 10-mL syringe for deflating endotracheal (ET) tube cuff

Procedure

- Position the patient in semi-Fowler or high Fowler position.
- Explain the procedure to the patient.
- Administer 100% O_2 to the patient with a manual resuscitation bag.
- Suction the patient's mouth and pharynx above the cuff. Oxygenate after suctioning.
- Suction the patient to clear the airway as much as possible, and then loosen the tape supporting the tube.
- Squeeze the resuscitation bag while deflating the cuff to force secretions into the mouth from above the cuff for suctioning (some clinicians cut the pilot balloon). Having the patient cough also helps move the secretions into the mouth.
- Oxygenate and hyperinflate the patient, withdrawing the ET tube when pressure is built up in the lungs at peak inspiration (maximum abduction of vocal cords). An alternative technique is to have the patient breathe in deeply and cough; the tube is removed as the patient coughs (coughing opens the vocal cords). A deep inspiration before cuff deflation, followed by a cough, also helps force secretions into the mouth.
- Have the patient cough after the tube has been removed.
- Administer the same fraction of inspired O_2 (F_IO_2) as before extubation. Some clinicians administer a cool mist after extubation and increase O_2 delivery by 10% if the patient was weaned with PEEP in use.
- Monitor the patient while encouraging coughing and deep breathing. Listen to the breath sounds, particularly in the neck area. Frequently measure the respiratory rate, heart rate, blood pressure, and O_2 saturation by pulse oximeter (S_pO_2) for 30 minutes.
- Monitor the patient for changes over the next hour. It may be desirable to obtain an arterial blood gas measurement at this time to confirm that the patient's oxygenation and ventilatory status is stable.

- Presence of a gastric tube (feedings tubes must be discontinued for 4–6 hours before extubation)
- Abnormal paraglottic sensations (usually begin 4–8 hours after extubation and can last as long as 8 hours after extubation)
- Inability to close the glottis mechanically (may be impaired after extubation)[7]
- Excessive amounts of secretions (e.g., cystic fibrosis)
- Inability to clear secretions effectively (e.g., inadequate neurological or muscular function)

Noninvasive Positive Pressure Ventilation After Extubation

Noninvasive positive pressure ventilation (NIV) may be beneficial after extubation for patients who require some degree of ventilatory support to ease the transition from invasive mechanical ventilation to spontaneous breathing. NIV after extubation appears to have the following benefits[98-103]:

- Improves survival
- Lowers the mortality rate
- Reduces the risk for VAP
- Lowers the incidence of septic shock
- Shortens the ICU and hospital stays

Box 20.13 lists potential criteria for the use of NIV after extubation for patients requiring transitional ventilator support.[103] NIV can be administered temporarily for postextubation subglottic edema to give medications that reduce swelling (e.g., corticosteroids) time to take effect. It may also be useful for preventing reintubation when respiratory failure occurs after extubation.[103] However, patient cooperation is essential for successful use of this modality. Unfortunately, NIV tolerance cannot be safely predicted before extubation; therefore deliberate removal of the airway with the intent to switch to NIV carries a high risk for reintubation. (See Chapter 19 for additional information on NIV.)

FACTORS IN WEANING FAILURE

Recommendation 5: Spontaneous Breathing Trial Failure

As previously mentioned, if a patient fails an SBT, the causes of the failure must be determined and corrected before proceeding with liberation from mechanical ventilation. When the reversible causes of failure have been corrected, and if the patient still meets the criteria for discontinuation of ventilation, an SBT should be performed every 24 hours.[59] It is important to avoid pushing patients to the point of exhaustion during the weaning process because this ultimately can delay liberation from the ventilator. A failed SBT often reflects persistent mechanical abnormalities of the respiratory system, which may not reverse quickly.[77] Other causes or complications may be involved, such as compromised cardiovascular function (e.g., myocardial ischemia), impaired fluid status, acid-base disturbances, inadequate pain control, inappropriate sedation, the need for bronchodilator therapy, nutritional status, and psychological factors.

It is important that clinicians wait 24 hours before attempting another SBT in patients for whom it fails (Key Point 20.6). Frequent SBTs over a single day are not helpful and can lead to serious consequences. Even twice-daily SBTs offer no advantage over testing once a day.[10]

***Key Point* 20.6** Clinicians should wait 24 hours before attempting subsequent spontaneous breathing trials (SBTs) in patients for whom SBT fails.

NONRESPIRATORY FACTORS THAT MAY COMPLICATE WEANING

The respiratory problems that can lead to unsuccessful weaning attempts are similar to those that often lead to respiratory failure

BOX 20.12 Summary of the American Association for Respiratory Care Clinical Practice Guideline: Removal of the Endotracheal Tube—2007 Revision and Update

Indications
- When airway control provided by the endotracheal (ET) tube is no longer necessary (the patient should be able to maintain a patent airway and generate adequate spontaneous ventilation to maintain normal gas exchange).
- When an acute obstruction of the ET tube cannot be cleared rapidly. Reintubation or other appropriate techniques must be used to maintain effective gas exchange.
- When further medical care of the patient is explicitly declared futile (tube removal is allowed).

Contraindications
- No absolute contraindications to removal of the ET tube have been reported.

Hazards/Complications
- Possible hazards and complications include hypoxemia and hypercapnia from airway obstruction, resulting from edema of the trachea, vocal cords, or larynx, laryngospasm, bronchospasm, aspiration, respiratory muscle weakness, hypoventilation, excessive work of breathing, development of atelectasis, and postextubation pulmonary edema.

Limitations of Methodology
- Predicting an extubation outcome is sometimes difficult. It is of significant clinical importance because both extubation delay and unsuccessful extubation are associated with poor patient outcomes. The literature on extubation readiness is limited by few validated objective measures to accurately predict the extubation outcome for an individual patient.

Assessment of Extubation Readiness
- Patients should be able to maintain spontaneous ventilation adequately and should not require high levels of positive pressure or oxygenation to maintain adequate arterial blood gas oxygenation (P_aO_2/F_IO_2 >150—200 on an F_IO_2 of ≤0.4—0.5 and low levels of PEEP ≤5—8 cm H_2O; pH ≥7.25).
- Successful completion of 30- to 120-minute SBT performed with a low level of CPAP (e.g., 5 cm H_2O) or a low level of pressure support (5—7 cm H_2O) demonstrating adequate respiratory pattern and gas exchange.
- Other examples of measurements that can be used to assess extubation readiness include spontaneous respiratory rate, RSBI, vital capacity (VC), peak expiratory flow (PEF), transdiaphragmatic pressure gradient (Pdi), maximum inspiratory pressure (MIP), work of breathing (WOB), airway occlusion pressure ($P_{0.1}$), maximum voluntary ventilation (MVV), and sustained maximal inspiratory pressures (SMIP).
- Adequate respiratory muscle strength.
- Patients with artificial airways in place to facilitate treatment of respiratory failure should be considered for extubation when they have met weaning criteria.

Assessment of Outcome
- Patient assessment and a physical examination should follow removal of the ET tube to ensure adequate spontaneous ventilation and adequate oxygenation through the natural airway and to ensure that reintubation is not necessary.
- Some patients may require postextubation support or intervention to maintain adequate gas exchange independent of controlled mechanical ventilation. These adjunctive measures may include noninvasive positive pressure ventilation, CPAP, aerosolized racemic epinephrine, heliox, and possibly diagnostic bronchoscopy.

Monitoring
- Appropriately trained personnel.
- Frequent evaluation of vital signs, assessment of neurological status, patency of airway, auscultatory findings, WOB, and hemodynamic status.

Modified from AARC Clinical Practice Guidelines: Removal of the endotracheal tube, 2007 revision and update, *Respir Care* 52:81—93, 2007.

BOX 20.13 Criteria for Instituting Noninvasive Ventilation After Failure to Wean From Invasive Mechanical Ventilation in Extubated Patients

- Resolution of problems leading to respiratory failure
- Ability to tolerate a spontaneous breathing trial for 10 to 15 minutes
- Strong cough reflex
- Hemodynamic stability
- Minimal airway secretions
- Low F_IO_2 requirements
- Functioning gastrointestinal tract
- Optimum nutritional status

(see Fig. 20.1). Nonrespiratory factors also may contribute to failure of the SBT and are often neglected (Table 20.2).[97] The following sections review the common nonrespiratory factors that can delay or even prevent successful weaning of a patient from mechanical ventilation.

Cardiac Factors

Patients with abnormal cardiac function may develop acute congestive heart failure when abruptly disconnected from mechanical ventilation. The rapid drop in intrathoracic pressures causes two basic problems: (1) sudden increases in negative intrapleural pressure with spontaneous breaths may increase the left ventricular transmural pressure and afterload and (2) temporary redistribution of blood volume from the systemic venous system to the central veins, which can result in increased right, and subsequently left, ventricular filling. The increased venous return may alter the function and shape of the right and left ventricles, impair left ventricular function, and reduce the stroke volume.[97] With a preexisting heart condition, these acute changes can result in cardiac decompensation, thus contributing to problems in weaning (Case Study 20.3).

TABLE 20.2 Nonrespiratory Factors in Weaning Patients From Mechanical Ventilation

Category	Factor	Mechanism	Clinical Presentation
Cardiac status	Acute left ventricular failure	Increased preload because of increased venous return and decreased pulmonary capillary compression as intrathoracic pressure is reduced	Weaning fails, often after patient does well initially for 30–60 min; may develop acute respiratory and/or metabolic acidosis, hypoxemia, hypotension, chest pain, and cardiac dysrhythmias
Acid-base status	Acute alkalosis in patient with underlying CO_2 retention	Loss of preexisting metabolic compensation for hypercapnia; inability to sustain required $\dot{V}_E$ and WOB	Patient with COPD or other cause of chronic respiratory acidosis before acute insult fails weaning after several days of ventilation to a P_aCO_2 lower than the patient's pH-compensated level
	Respiratory alkalosis	Depression of ventilatory drive by hypocapnia and alkalemia	P_aCO_2 rises and pH falls during weaning attempt; patient is said to fail weaning if some arbitrary change in these values (e.g., 10 mm Hg increase in P_aCO_2) is used as a criterion for failure
	Metabolic acidosis	Increase in ventilatory demand to compensate for respiratory alkalosis	Patient may be unable to sustain required increase in $\dot{V}_E$ and WOB to maintain a lower P_aCO_2 to compensate for a lower HCO_3^-
Metabolic status	Hypophosphatemia and hypomagnesemia	Ventilatory muscle weakness	Patient weaning fails because of rapid shallow breathing, respiratory distress, and acute respiratory acidosis; maximal inspiratory pressure is decreased
	Hypothyroidism	Decreased ventilatory drive with possible ventilatory muscle weakness	Rare cause of weaning failure that occurs because of acute respiratory acidosis with or without respiratory distress
Drugs	Narcotics, sedatives, tranquilizers, and hypnotics	Depression of ventilatory drive	Patient fails weaning because of acute respiratory acidosis in the absence of tachypnea and respiratory distress
	Neuromuscular blocking agents	Ventilatory muscle weakness; delayed clearance in patient with renal insufficiency	Patient weaning fails because of rapid shallow breathing, respiratory distress, and acute respiratory acidosis; maximal inspiratory pressure is reduced
		Ventilatory muscle weakness caused by acute myopathy, especially in patients who have received high-dose systemic corticosteroids	Same as above; may have elevated muscle enzymes; can last for weeks or months
	Aminoglycosides	Neuromuscular blockade	Rare cause of weaning failure that occurs because of rapid shallow breathing, respiratory distress, and acute respiratory acidosis; maximal inspiratory force is reduced
Nutrition	Overfeeding	Increased CO_2 production, especially with excessive carbohydrate calories	Patient fails weaning because of excessive ventilatory demand (high $\dot{V}_E$ requirement to keep P_aCO_2 normal); unusual cause of weaning failure unless large caloric loads are administered
	Malnutrition	Effects of acute illness; preexisting nutritional deficiencies	May contribute to ventilatory muscle weakness, decreased ventilatory drive, impaired immunological function, fluid retention, depression; distinguishing this from other factors is difficult
Psychological status	Agitation; "psychological ventilator dependence"	Anxiety, fear, delirium, ICU psychosis, or influence of preexisting personality factors	Patient becomes agitated and panicky during attempt to reduce or discontinue ventilatory support; can be said to cause weaning failure when other factors are absent
	Lack of motivation	Depression, effects of drugs, organic brain dysfunction, or influence of preexisting personality factors	Patient refuses to participate in care (e.g., mobilization, bronchial hygiene, physiological measurements); flat affect and immobility in bed; considered when other factors are absent

COPD, Chronic obstructive pulmonary disease; *HCO_3-,* bicarbonate; *ICU,* intensive care unit; *P_aCO_2,* partial pressure of carbon dioxide; *pH,* hydrogen ion concentration; *$\dot{V}_E$,* minute ventilation; *WOB,* work of breathing.

From Pierson DJ: Non-respiratory aspects of weaning from mechanical ventilation, *Respir Care* 40:263–270, 1995.

Case Study 20.3

Failed Weaning Attempt

A 76-year-old man with a history of chronic obstructive pulmonary disease has been receiving ventilatory support for 4 days after an acute myocardial infarction. The ventilator settings are V_T 500 mL, IMV rate 8 breaths/min, F_IO_2 0.5, and PEEP/CPAP 5 cm H_2O. ABG results on these settings are pH 7.37, P_aCO_2 36 mm Hg, P_aO_2 78 mm Hg, and S_pO_2 93%.

The patient currently meets all criteria for weaning and is placed on a T-piece. Within 10 minutes he develops restlessness, tachycardia, rapid, shallow breathing, and diaphoresis. The S_pO_2 drops from 93% to 90%, and the pulmonary artery occlusion pressure rises from 12 to 17 mm Hg. The patient does not complain of chest pain and has no dysrhythmias.

What do you think is responsible for the failed weaning attempt?

Acid-Base Factors

A common reason that patients with chronic hypercapnia fail to wean is the presence of relative hyperventilation, respiratory alkalosis, and subsequent renal compensation, leading to a decrease in bicarbonate.[97] Table 20.3 presents an example of this situation. As the table shows, after 3 days of mechanical ventilation, the blood gas values appear normal. However, these results are not normal for this patient. The original state of compensated respiratory acidosis must be restored in 2 to 3 days by gradually reducing ventilatory support before weaning can succeed in this patient.

Even patients without preexisting chronic CO_2 retention can hyperventilate during controlled ventilation. When weaning is attempted, these patients remain apneic until CO_2 levels rise high enough to trigger the respiratory drive. Consequently, maintaining a respiratory alkalosis in this type of patient can severely delay the weaning process.

Patients with metabolic acidosis may also not do well during weaning unless the underlying cause of the acidosis is removed. The normal compensatory mechanism for a metabolic acidosis is a respiratory alkalosis (i.e., increased ventilation). Without the ventilator to help support this increased work, the patient is unable to maintain increased $\dot{V}_E$ and may not do well during weaning.

Metabolic Factors

Besides metabolic acidosis, three additional metabolic factors can affect ventilator weaning: hypophosphatemia, hypomagnesemia, and hypothyroidism. Hypophosphatemia, or phosphate deficiency, may contribute to muscle weakness and failure to wean. Values below normal (1.2 mmol/L) may impair respiratory muscle function.

Malnourished patients and those with chronic alcoholism often suffer from hypomagnesemia (low magnesium levels). Magnesium deficiency has also been associated with muscle weakness.

Patients with severe hypothyroidism may have impaired respiratory muscle function. This disorder also blunts the central response to hypercapnia and hypoxemia, which in turn may impair a patient's ability to wean.[97]

Effect of Pharmacological Agents

As discussed earlier in Chapter 15, the use of sedatives, opioids, tranquilizers, and hypnotic agents can all depress the central ventilatory drive. Use of these agents must be minimized for weaning to be successful. Neuromuscular blocking agents (NMBAs) (e.g., vecuronium bromide and atracurium besylate) cause paralysis and must clear the system before weaning can be initiated. Indeed, some patients demonstrate prolonged paralysis even after use of these agents is discontinued. The two primary reasons for prolonged paralysis after withdrawal of NMBAs are (1) a reduced ability to metabolize and excrete these drugs and (2) the development of an acute myopathy. In the former case, prolonged paralysis occurs as a result of interference with the normal renal or hepatic metabolism and elimination of the NMBAs. Prolonged paralysis occurs in severely ill patients with multiple organ failure secondary to critical illness, especially sepsis.[104] An acute myopathy can develop when high maintenance doses of corticosteroids and continuous nondepolarizing agents (e.g., vecuronium or pancuronium) are used. For example, this is seen in patients on ventilation who have a history of asthma.[105-107] Muscle biopsies from affected individuals show evidence of muscle destruction.[106] The limbs of affected individuals appear atrophied, and deep tendon reflexes are reduced or absent. Limb paralysis may last from several weeks to months.[107,108]

Nutritional Status and Exercise

Weakening of the respiratory muscles may occur in any patient who does not receive adequate nutrition or who was malnourished before admission. Underfeeding can lead to muscle wasting (including the diaphragm, heart, and other organ tissues), particularly in patients under the stress of an acute, severe illness. Other problems associated with malnutrition include a reduced central

TABLE 20.3 Blood Gas and pH Values Reflecting the Effect of Ventilator-Induced Respiratory Alkalosis on Weaning

Variable	Baseline	Respiratory Failure	On Ventilator	After 3 Days	Weaning
pH_a	7.38	7.24	7.56	7.4	7.24
P_aCO_2 (mm Hg)	58	76	40	40	58
HCO_3^- (mEq/L)	34	36	34	24	26

HCO_3^-, Bicarbonate; *P_aCO_2*, partial pressure of arterial carbon dioxide; *pHa*, hydrogen ion concentration.
From Pierson DJ: Non-respiratory aspects of weaning from mechanical ventilation, *Respir Care* 40:265, 1995.

response to hypoxemia and hypercapnia and an impaired immune response.

Conversely, overfeeding, particularly with solutions using carbohydrates as the primary calorie source, can cause increases in O_2 consumption, CO_2 production, and minute ventilation. The increase in CO_2 production occurs during lipogenesis (i.e., the conversion of carbohydrates to lipids [fats]). Excessive carbohydrate feeding therefore may interfere with weaning from mechanical ventilation because of an increased CO_2 load that the patient must remove during ventilation. Monitoring the patient's metabolic rate and substrate utilization with indirect calorimetry can help minimize this type of problem with parenteral feeding (see Chapter 10).

Feedings must be carefully monitored. Nutritional solutions containing emulsified fats, proteins, carbohydrates, vitamins, and minerals must be provided in appropriate proportions for each patient. Mixed solutions containing emulsified fats do not appear to elevate the metabolic rate and can be used to meet nutritional and high-carbohydrate solutions.

Strengthening of respiratory muscles that are weak from lack of use is also important to avoid muscle atrophy and fatigue. Two generally accepted principles apply: First, the clinician must make sure the patient is adequately nourished without being overfed. Second, periods of exercise (spontaneous breathing) are required to strengthen the respiratory muscles, followed by undisturbed rest with sufficient ventilatory support during the night. Periodic mobilization of patients (e.g., the patient is assisted to walk and sit in a bedside chair) can also aid in mobilization of secretions and prevention of atelectasis).[60] Even following these principles, it is important to understand that muscle recovery is often unpredictable (see the following Clinical Scenario for an example).[64,109]

Clinical Scenario: Weaning

A child with C-1 quadriplegia received mechanical ventilation for 1 year. At that time, a phrenic nerve stimulator was inserted into the child's diaphragm. The phrenic nerve stimulator initially produced very low tidal volumes (V_Ts), which declined dramatically after a short period of diaphragm exertion. The stimulation was stopped, and 1 to 2 days of rest followed. It took at least 48 hours to recover the baseline V_T after the initial exercise of the unconditioned diaphragm. After 2 to 3 weeks, however, the fatigue factor disappeared, and effective V_T could be maintained during several hours of stimulation. This case study illustrates that the response to a well-controlled exercise program for strengthening and reconditioning the diaphragm was unpredictable. It could not be predicted that the initial fatigue problem would be corrected after 3 weeks. In this particular child, recovery was not linear but rather a continually varying process. Although the weaning process can often be unpredictable, respiratory failure that occurs early in weaning probably indicates that the patient needs more rest between spontaneous breathing trials.

Psychological Factors

Although the preceding discussion focused on physiological factors that can affect a patient's ability to be liberated from ventilatory support, it is important to recognize that psychological factors can also influence the success of a weaning trial. Indeed, the role of psychological factors on evidence-based weaning protocols remains quite ambiguous. Two intangible important psychological factors must be considered during weaning.[97] Patients who resist being mobilized and are reluctant to assume any responsibility for their recovery can hinder attempts of ventilator liberation. Weaning a patient from mechanical ventilation is typically more successful when the patient is optimistic about his or her illness, motivated to recover, and assists the health care team by being cooperative. Unmotivated patients therefore will probably take longer to wean than those patients who are optimistic about their recovery.

Psychological problems can manifest as fear, anxiety, delirium, ICU psychosis, depression, anger, denial, fear of shortness of breath, and fear of being left alone, among other symptoms. The use of sedatives and many other medications also tends to alter a patient's mental status (see Chapter 15). The attitudes of the nurse, physician, and therapist team and the patient's attitude toward the team can have a huge effect on the outcome of the weaning trial. Patients who are chemically dependent (e.g., tobacco, alcohol, pain medication) may also appear nervous and anxious after withdrawal from these chemical agents.

A number of disease-related issues can also contribute to psychological problems. Two important considerations are the severity and the duration of the illness. For example, older patients with debilitating diseases tend to be more depressed and anxious.[67] Another important issue is sleep deprivation, which is commonly associated with the ICU environment. Patients may report hallucinations and nightmares, express fear of dying or abandonment, and manifest heightened anxiety ascribed to their environment, medical treatment, lack of sleep, and the illness itself.

To allay some of these psychological fears, the clinician must focus on environmental and communication issues. In terms of environment, noise levels should be reduced and an adequate amount of time provided for undisturbed sleep. There are times when it is more important for the patient to receive a good night of sleep rather than obtaining routine vital signs during sleep hours, particularly because continuous monitoring is available. In terms of communication, eye contact, touching, and written or verbal communication efforts can be a valuable means for clinicians to connect with a patient. Health care workers often go into patient areas and perform a clinical procedure or check the equipment and never take the time to communicate with the patient. Establishing effective communication skills is critical for achieving successful clinical outcomes.

A delayed or failed weaning attempt can cause patients and staff to become depressed or anxious. Clinicians must have patience with the process and try to convey a feeling of calm and self-assurance to the patient.

Recommendation 6: Maintaining Ventilation in Patients With Spontaneous Breathing Trial Failure

Patients for whom an SBT fails should receive a stable, nonfatiguing, comfortable form of ventilatory support (see Box 20.4).[59] The clinical focus for the 24 hours after a failed SBT should be on maintaining adequate muscle unloading, optimizing comfort (and thus sedation needs), and preventing complications, rather than on aggressive ventilatory support reduction.[10] The patient may participate in part of the WOB as long as the load is not fatiguing.

As previously mentioned, repeated SBT on the same day is of no benefit. Repetitive and ritualistic attempts at gradual reductions in ventilator settings are not worth the time or effort.[110] To date there is no evidence that a gradual support reduction strategy is better than providing full, stable support between once-daily SBTs.[1] Some factors the respiratory therapist can adjust to improve patient comfort and minimize imposed ventilatory loads include the following:

- Carefully set the sensitivity level (i.e., ventilator-triggering system)
- Adjust flow patterns to match patient demand
- Make sure ventilator settings are appropriate to prevent air trapping (auto-PEEP)[1]
- If auto-PEEP is present, use applied PEEP to facilitate breath triggering and counteract the auto-PEEP

An interesting finding of the ACCP/SCCM/AARC task force was how poorly clinicians assess the potential for ventilator discontinuation, especially in patients considered ventilator dependent for longer than several days. This finding emphasizes the need for more focused assessment strategies for these types of patients. The following Clinical Scenario provides an example of a case of weaning failure.[59]

Clinical Scenario: Weaning Failure

A 47-year-old man is admitted to the ICU with a severe asthma exacerbation. He is intubated and mechanical ventilation is instituted. After 3 weeks of ventilatory support, the medical staff is unable to wean the patient. He has a difficult ventilation history, including the use of sedatives, analgesics, anxiolytics, and multiple bronchodilators. A tracheotomy is performed. About 36 hours later the patient dies, apparently from mucus plugging. A heat-moisture exchanger (HME) had been used with this patient, in whom increased secretions were compounded by a fluid overload. Although no autopsy was performed, excessive, thick secretions may have obstructed the airway and therefore contributed to the potential for the development of mucus plugging.

FINAL RECOMMENDATIONS

Recommendation 7: Anesthesia and Sedation Strategies and Protocols

Recommendation 7 states that anesthesia and sedation strategies and ventilator management should be aimed at early extubation in postoperative patients.[59] In these patients a depressed respiratory drive and pain are the main reasons for ventilator dependence. A lower anesthetic/sedation regimen may permit earlier extubation.[59] Ventilator modes that guarantee a certain breathing rate and $\dot{V}_E$ (CMV modes, IMV, and MMV) are important for patients with unreliable respiratory drives. The immediate postoperative patient may be ideally suited for simple automatic feedback modes that provide a backup form of support (e.g., MMV or VS).[47,52]

Recommendation 8: Weaning Protocols

Protocols for ventilator discontinuation, which are designed for nonphysician clinicians, should be developed and implemented by ICU staff. They must also be aimed at optimizing sedation.[59] Nonphysician protocols are often called therapist-driven protocols (TDPs) or nurse-driven protocols.

TDPs for weaning patients from ventilation have been found to be safe and to reduce hospital costs by shortening the time required for ventilatory support.[111,112] A variety of protocols exist; although they can take the form of outlines, tables, and algorithms, their content tends to be similar. Fig. 20.7 presents an example of a TDP.[113] It has been suggested that protocols heighten staff awareness of the process and generally promote weaning success.[112]

Protocols implemented by respiratory therapists and associated ICU team members are recognized as efficient, effective approaches to discontinuation of ventilatory support.[54,114-116] Nurses, respiratory therapists, and physicians involved in the patient's care must be informed of the patient's progress so that they can all work toward the goal of successfully weaning the patient from ventilatory support (Key Point 20.7).

Key Point 20.7 Weaning protocols have been shown to be efficient and effective approaches to discontinuation of ventilatory support.

A significant reduction in extubation failures and shorter weaning times are noted when TDPs and nurse-driven protocols are used.[11,114] Studies suggest that some physicians may be too conservative when considering whether a patient is ready for SBT or extubation or both.[111,117]

The choice of a specific protocol is best left to the individual institution. Protocols should not replace clinical judgment but rather complement it. Protocols should be updated regularly to reflect current medical evidence and clinical practice patterns as they evolve. Institutions must commit the resources necessary to develop and implement protocols. Reduced staff levels or inadequate staff training can jeopardize clinical outcomes (Key Point 20.8).

Key Point 20.8 "I believe that a skilled clinician at the bedside does more to facilitate ventilator weaning than any ventilator mode."[15]

Recommendation 9: Role of Tracheostomy in Weaning

A tracheostomy is considered when it becomes apparent that the patient will require prolonged ventilator assistance.[59] A tracheotomy is performed after the patient is stable on the ventilator and when the person appears likely to benefit from the procedure.[118] The procedure should be performed as soon as possible after the need for extended intubation has been verified, and it should be based on the patient's disease and his or her wishes. The procedure is usually performed within 7 days of the onset of respiratory failure, or sooner in neurologically impaired patients.[118,119] Patients who might benefit from a tracheostomy include the following:

- Those who require high levels of sedation to tolerate ETs
- Those with marginal respiratory mechanics and who may have tachypnea as a result
- Those in whom lower resistance (a potential benefit of TTs) may reduce the risk for muscle overload

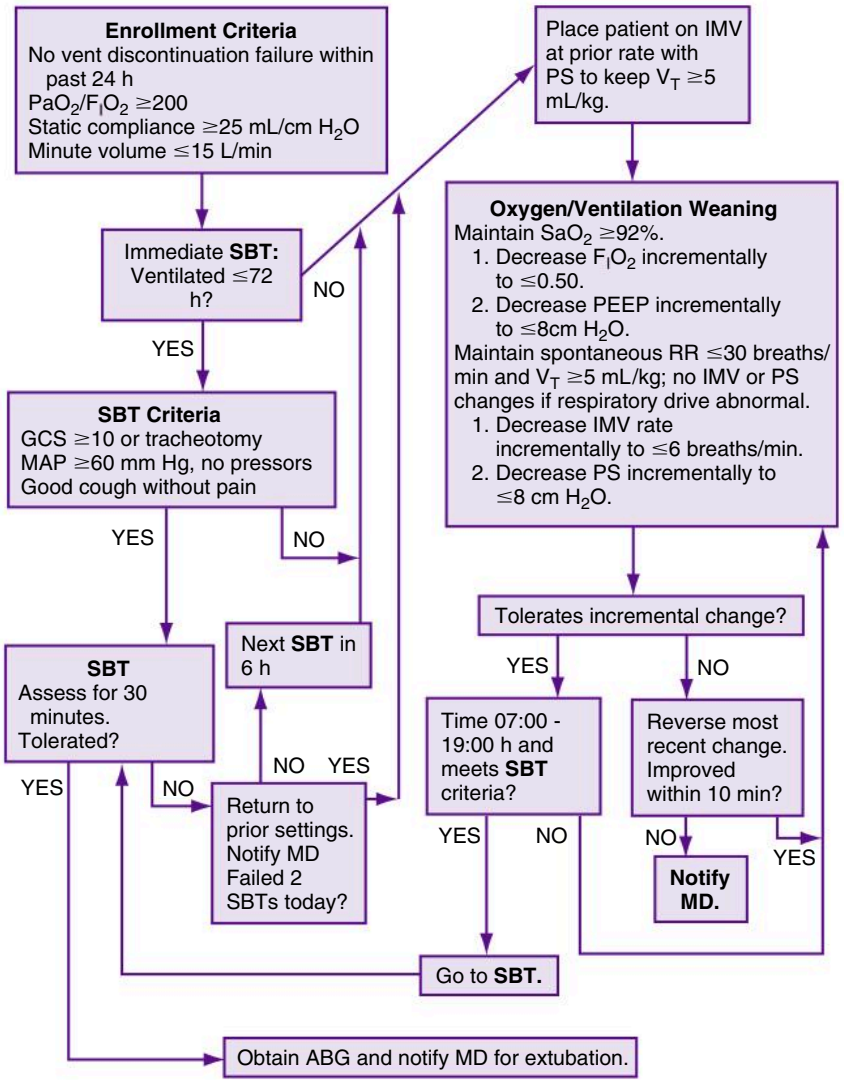

Fig. 20.7 Example of a weaning protocol or ventilator management protocol. *ABG*, Arterial blood gas; F_IO_2, fractional inspired O_2; *GCS*, Glasgow Coma Scale; *IMV*, intermittent mandatory ventilation; *MAP*, mean arterial pressure; P_aO_2/F_IO_2, ratio of partial pressure of O_2 in the arteries to the fractional inspired O_2; *PEEP*, positive end-expiratory pressure; *PS*, pressure support; *RR*, respiratory rate; S_aO_2, arterial O_2 saturation; *SBT*, spontaneous breathing trial; V_T, tidal volume. (Redrawn from Marelich GP, Murin S, Battistella F, et al.: Protocol weaning of mechanical ventilation in medical and surgical patients by respiratory care practitioners and nurses: effect on weaning time and incidence of ventilator-associated pneumonia, *Chest.* 118:459—467, 2000.)

- Those who may gain psychological benefit from the ability to eat, talk, and have greater mobility
- Those for whom increased mobility may aid physical therapy efforts[120-122]
- Ultimately the most important beneficial outcome of a tracheostomy is the potential to facilitate discontinuation of mechanical ventilatory support.

Despite a lack of data, the general clinical consensus is that patients receiving long-term mechanical ventilation have less facial discomfort when a nasotracheal or orotracheal tube is removed and replaced with a TT. Reduction in WOB and dead space and more effective secretion removal are possible benefits.[122] Interestingly, clinical data do not indicate that the rate of VAP is lower or that the duration of ventilation is shorter for patients with tracheostomies.

A tracheostomy site typically requires 7 to 10 days to mature. If the TT is inadvertently displaced in the first 24 to 72 hours, successful blind tube replacement is highly unlikely.[118]

Removal of a TT is not difficult and can proceed just like extubation. After the tube is removed, the stoma is covered with one or two gauze pads held in place with tape. A stoma is like an open wound, and barring complications, it heals in a few days in most patients. Patients are taught to support the stoma when they cough by applying pressure to the gauze bandage with the flat surface of the hand. The secretions brought to the mouth can be expectorated. A tracheostomy button is recommended if the stoma must remain open because of excessive secretions or for some other reason. This short, hollow tube is inserted into the stoma and is held in place by its inner flanges. It can be capped to occlude the opening if desired.[123]

Recommendation 10: Long-Term Care Facilities for Patients Requiring Prolonged Ventilation

Unless evidence of irreversible disease exists, a patient who requires prolonged ventilatory support should not be considered permanently ventilator dependent until 3 months have passed and all weaning attempts during that time have failed.[59] Those failing to wean may require placement in a long-term care facility.

Recommendation 11: Clinician Familiarity With Long-Term Care Facilities

Critical care practitioners must be familiar with facilities in their communities or units in their hospitals that specialize in the management of patients who require prolonged mechanical ventilation.[59] Patients for whom weaning attempts in the ICU fail are transferred to long-term ventilatory care facilities when they are medically stable. These facilities should have demonstrated competence, safety, and success in accomplishing ventilator discontinuation. Often these facilities have fewer staff members and less costly monitoring equipment, which make them less expensive than ICUs.[59]

Recommendation 12: Weaning in Long-Term Ventilation Units

Patients who are medically stable and able to leave the ICU but who have not been successfully weaned in that environment have several options.[124] Box 20.14 lists alternative sites where these patients can be weaned. The following are the goals for weaning in long-term care facilities[124]:

- To reduce the amount of ventilatory support
- To reduce the invasiveness of support
- To increase independence from mechanical devices
- To preserve and/or improve current function
- To maintain medical stability

Weaning procedures in long-term care units are typically individually designed rather than designed according to a fixed protocol, as in the ICU. In addition, using a variety of techniques may be required because a method that works for one person might not work for another. For example, some patients may not need an artificial airway to maintain airway patency and may only require NIV during the night.[125]

Weaning is slow paced when a patient requires long-term ventilation. Daily SBTs are not performed because patients are unlikely to be weaned successfully in 24 hours. The medical staff in long-term facilities generally includes registered nurses and registered respiratory therapists who are experienced in the assessment and management of these patients. Staff members understand the need for slow withdrawal of ventilator support and the importance of patience.

Patients with chronic conditions such as amyotrophic lateral sclerosis, muscular dystrophy, severe chronic lung disease, loss of the central drive to breathe, phrenic nerve damage or paralysis, cervical fracture leading to paralysis, and other types of neuromuscular or chronic disorders may require permanent mechanical ventilation. In these cases, long-term ventilation refers to a means of support for patients who are not acutely ill but who are presumed to have a permanent need for such support.[124] Ventilator dependence can be challenging, but it does not have to be completely confining, and many patients have meaningful lives outside the hospital or medical facility. Chapter 21 discusses long-term ventilation for ventilator-dependent individuals.

BOX 20.14 Alternative Sites for Long-Term Ventilatory Support

- Regional weaning centers
- Noninvasive respiratory care units
- Long-term acute care facilities
- Extended care facilities
- Long-term ventilation units in acute care hospitals
- Home

From Pierson DJ: Long-term mechanical ventilation and weaning, *Respir Care* 40:289–295, 1995.

AMERICAN THORACIC SOCIETY/AMERICAN COLLEGE OF CHEST PHYSICIANS CLINICAL PRACTICE GUIDELINE: LIBERATION FROM MECHANICAL VENTILATION

A collaborative effort by representatives of the ATS and the American College of Chest Physicians (ACCP) produced a document outlining updated guidelines for the liberation from mechanical ventilation in critically ill adult patients.[60,126,127] The recommendations included in this recent guideline focus on six areas:

(1) The use of inspiratory pressure augmentation during spontaneous breathing trials;
(2) The use of a liberation protocol for acutely hospitalized adults who have been mechanically ventilated for > 24 hours;
(3) The use of NIV after extubation for high-risk patients who have been receiving mechanical ventilation for greater than 24 hours;
(4) Utilization of protocolized rehabilitation strategies to increase early mobilization of acutely hospitalized adults who have been receiving mechanical ventilation for >24 hours;
(5) Use of sedation liberation protocols that attempt to minimize sedation of patients who have been receiving mechanical ventilation for >24 hours;
(6) Performance of an endotracheal cuff leak test in mechanically ventilated adults who meet extubation criteria and are at a high risk for the development of postextubation. This guideline also provides a recommendation for the management of adult patients who fail a cuff leak test but otherwise demonstrate that they are ready for extubation (i.e., administration of systemic corticosteroids before an extubation attempt). (See Box 20.15.)

ETHICAL DILEMMA: WITHHOLDING AND WITHDRAWING VENTILATORY SUPPORT

The ethical and economic issues related to life support are becoming more important every day as the cost of medical care increases, the availability of payment declines, and the population ages.[128] Withholding and withdrawal of life support are important ethical issues related to death and dying.

BOX 20.15 Summary of ATS/ACCP Clinical Practice Guideline: Liberation From Mechanical Ventilation in Critically Ill Adults

- For acutely hospitalized patients ventilated more than 24 hours, the panel suggest an initial daily spontaneous breathing trial (SBT) conducted with inspiratory pressure augmentation (5-8 cm H_2O) rather than without (T-piece or continuous positive airway pressure). (Conditional recommendation, Moderate-quality evidence).
- Acutely hospitalized adults who have been mechanically ventilated for more than 24 hours be managed with a ventilator liberation protocol, rather than no protocol, (Conditional recommendation, Low certainty in the evidence).
- For patients at high risk for extubation failure who have been receiving mechanical ventilation for more than 24 hours and who have passed a spontaneous breathing trial, recommend extubation to preventative NIV (Strong recommendation, Moderate certainty in the evidence).
- For acutely hospitalized adults who have been mechanically ventilated for >24 hours, use protocolized rehabilitation directed toward early mobilization (Conditional recommendation, Low certainty in the evidence).
- For acutely hospitalized patients who have been mechanically ventilated >24 hours it is suggested that be managed with protocols that attempt to minimize sedation (Conditional recommendation, Low certainty in the evidence).
- Performance of a cuff leak test in mechanically ventilated adults who meet extubation criteria and are deemed high risk for postextubation stridor (Conditional recommendation, Very low certainty in the evidence).
- For adults who have failed a cuff leak test but are otherwise ready for extubation, it is suggested administrating systemic steroid for at least 4 hours before extubation (Conditional recommendation, Moderate certainty in the evidence).

Modified from Schmidt GA, Girard TD, Kress JP, et al: Official executive summary of an American Thoracic Society/American College of Chest Physicians clinical practice guideline: Liberation from mechanical ventilation in critically ill adults, *Am J Respir Crit Care Med* 195(1)115–119, 2017; Fan E, Zakhary B, Amaral A, et al.: Clinical practice guideline: summary for clinicians. Liberation from mechanical ventilation in critically ill adults, an ATS/ACCP Clinical Practice Guideline, *Ann Am Thorac Soc* 14:441–443, 2017.

SUMMARY

- Weaning from mechanical ventilator support generally can be easily accomplished for most patients. For those who require more time, several methods are available, including the traditional techniques of IMV, PSV, and T-piece weaning and the more advanced closed-loop modes such as ATC, MMV, and ASV.
- The recommendations established by the ACCP/SCCM/AARC task force have provided a solid foundation on which clinicians can better approach ventilator discontinuation.
- Verification that the problems leading to mechanical ventilation have been resolved is the first step in successfully liberating a patient from ventilatory support.
- Evaluation of appropriate criteria and the use of therapist-driven protocols or nurse-directed protocols can facilitate the process.
- Long-term care facilities provide a less demanding and less costly approach for patients who require longer ventilatory support and a slower weaning process.
- A recent ATS/ACCP clinical practice guideline provides additional evidence-based recommendations to optimize liberation from mechanical ventilation for critically ill adult patients.

REVIEW QUESTIONS *(See Appendix A for answers.)*

1. Which of the following would suggest that a patient is ready to be weaned from a ventilator?
   A. VC of 8 mL/kg IBW
   B. P_{Imax} of −15 cm H_2O
   C. V_D/V_T of 0.75
   D. f/V_T of 90 breaths/min/L
2. All of the following are closed-loop weaning modes except:
   A. VS
   B. ASV
   C. MMV
   D. T-piece trials
3. A respiratory therapist would consider ending an SBT under which of the following circumstances?
   A. The respiratory rate increases from 20 to 25 breaths/min
   B. The V_T decreases from 350 mL to 200 mL
   C. The systolic blood pressure decreases from 150 to 135 mm Hg
   D. The heart rate increases from 90 to 100 beats/min
4. You are called to the ICU to extubate a patient who has successfully completed a 120-minute SBT. Which of the following would indicate the potential for airway edema after extubation?
   A. P_{Imax}
   B. VC
   C. Cuff leak test
   D. S_pO_2
5. A patient develops stridor and shortness of breath after extubation. Which of the following is the first appropriate treatment for this problem?
   A. Reintubation
   B. Aerosolized racemic epinephrine
   C. Helium-oxygen by nonrebreathing mask
   D. Noninvasive mask ventilation
6. Which has been shown to be the unquestionably superior weaning technique?
   A. IMV
   B. PSV

C. T-piece trials
D. None of the above

7. State the ATS/ACCP Clinical Practice Guideline for performance of a cuff leak test in mechanically ventilated adults who meet extubation criteria.

8. A patient with amyotrophic lateral sclerosis has a tracheostomy tube in place. He has been unable to perform an SBT successfully and has been on mechanical ventilation for 4 months. An appropriate recommendation for this patient might be which of the following?
1. Transfer to a long-term care facility
2. Evaluation for use of NIV
3. Termination of ventilation
4. Waiting until the primary cause of respiratory failure has been resolved
   A. 1 and 2 only
   B. 2 and 3 only
   C. 1, 2, and 3 only
   D. 1, 2, and 4

9. Once a patient has been successfully weaned from ventilatory support, assessment of the airway for extubation would include all of the following except:
A. Ability to mobilize secretions
B. Presence of a strong cough
C. Presence of a peritubular leak on cuff deflation (successful cuff leak test)
D. Normal breath sounds

10. Which of the following are considered an advantage of using a nasal mask to deliver NIV?
1. Easy to fit and secure to the patient's face
2. Maintains the patient's ability to speak and eat
3. Mouth leaks
4. Less feeling of claustrophobia
   A. 1 and 2 only
   B. 2 and 3 only
   C. 3 and 4
   D. 1, 2, and 4

11. A physician wants to evaluate a male patient for discontinuation of ventilatory support. The patient is 70 kg and is receiving VC-IMV. He has no spontaneous respiratory efforts. Important parameters are: $V_T = 500$ mL; $f = 6$ breaths/min; $F_IO_2 = 0.4$; pH = 7.3; $P_aCO_2 = 58$ mm Hg; $P_aO_2 = 75$ mm Hg. The most appropriate ventilator change at this time is:
A. Implement PEEP
B. Increase V_T
C. Increase f
D. Begin an SBT

12. Which of the following are reported advantages of MMV?
1. The machine responds automatically to changes in $\dot{V}_E$.
2. Abrupt changes in CO_2 from a drop in spontaneous ventilation can be avoided.
3. Alveolar ventilation is monitored.
4. A much lower F_IO_2 can be used.
   A. 1 and 2
   B. 2 and 3
   C. 1, 2, and 3
   D. 2, 3, and 4

13. If the patient fails an SBT, the clinician should:
A. Determine the causes of the failure and correct them when possible
B. Place the patient on full support and repeat the SBT in 8 hours
C. Obtain an arterial blood gas analysis
D. Switch to an artificial intelligence system for weaning

14. Assessment of WOB is not commonly performed before weaning because:
A. It is not a reliable indicator of weaning success.
B. It can be difficult to perform and requires expensive equipment.
C. It can be easily determined by monitoring the respiratory rate.
D. It is more appropriately viewed as an indication for ventilation than as a criterion for weaning.

15. When weaning is unsuccessful for a patient who successfully performs an SBT, which of the following factors should be assessed?
1. Cardiac factors
2. Nutritional status and respiratory muscle strength
3. Acid-base status
4. Psychological factors
   A. 1 and 3
   B. 2 and 4
   C. 2, 3, and 4
   D. 1, 2, 3, and 4

16. Sedatives can alter a patient's respiratory rate and V_T, thus affecting the assessment for ventilator discontinuation.
A. True
B. False

17. All of the following are true for nonphysician protocols except:
A. They are more efficient than physician-directed weaning.
B. They are more costly than conventional weaning techniques.
C. They shorten weaning time.
D. They significantly reduce extubation failures.

18. A tracheotomy is indicated for which of the following types of patients receiving mechanical ventilation?
A. Those requiring low levels of sedation to tolerate ETs
B. Those with strong respiratory mechanics who rarely exhibit tachypnea
C. Those who may gain psychological benefit from the ability to eat, talk, and have greater mobility
D. Those with good mobility and easy tolerance of physical therapy efforts

19. Patients who fail weaning attempts in the ICU for 3 months are:
A. Transferred to long-term ventilatory care facilities when they are medically stable
B. Given a tracheostomy
C. Transferred to an ICU stepdown unit for physical therapy
D. Recommended for termination of ventilatory support

20. Automatic tube compensation can best be described as:
A. Variable PS with variable inspiratory flow compensation
B. Low-level PS with fixed flow-cycling criteria
C. MMV
D. Adaptive support using PS

References

1. MacIntyre NR: Evidence-based ventilatory weaning and discontinuation, *Respir Care* 49:830–836, 2004.
2. MacIntyre NR: Respiratory mechanics in the patient who is weaning from the ventilator, *Respir Care* 50:275–286, 2005.
3. Kacmarek RM: Discontinuing ventilatory support. In Kacmarek RM, Stoller JK, Heuer AJ, editors: *Egan's fundamentals of respiratory care*, ed 12, St. Louis, MO, 2021, Elsevier, pp 1186–1211.
4. MacIntyre NR, Leatherman NE: Ventilatory muscle loads and the frequency–tidal volume pattern during inspiratory pressure–assisted (pressure-supported) ventilation, *Am Rev Respir Dis* 141:327–331, 1990.
5. Esteban A, Alia I, Ibanez J, et al.: Modes of mechanical ventilation and weaning: a national survey of Spanish hospitals. The Spanish Lung Failure Collaborative Group, *Chest* 106:1188–1193, 1994.
6. Pierson DJ: Weaning from mechanical ventilation: why all the confusion? *Respir Care* 40:228–232, 1995.
7. Sharar SR: Weaning and extubation are not the same thing, *Respir Care* 40:239–243, 1995.
8. Epstein SK: Etiology of extubation failure and the predictive value of the rapid shallow breathing index, *Am J Respir Crit Care Med* 152:545–549, 1995.
9. Esteban A, Alia I, Gordo F, et al.: Extubation outcome after spontaneous breathing trials with T-tube or pressure support ventilation. The Spanish Lung Failure Collaborative Group, *Am J Respir Crit Care Med* 156:459–465, 1997.
10. Esteban A, Frutos F, Tobin MJ, et al.: A comparison of four methods of weaning patients from mechanical ventilation. Spanish Lung Failure Collaborative Group, *N Engl J Med* 332:345–350, 1995.
11. Meade MO, Guyatt GH, Cook DJ: Weaning from mechanical ventilation: the evidence from clinical research, *Respir Care* 46:1408–1415, 2001.
12. Brochard L, Kauss A, Benito S, et al.: Comparison of three methods of gradual withdrawing from ventilatory support during weaning from mechanical ventilation, *Am J Respir Crit Care Med* 150:896–903, 1994.
13. Esteban A, Anzueto A, Alia I, et al.: How is mechanical ventilation employed in the intensive care unit? An international utilization review, *Am J Respir Crit Care Med* 161:1450–1458, 2000.
14. Kirby R, Robinson E, Shultz J, et al.: Continuous-flow ventilation as an alternative to assisted or controlled ventilation in infants, *Anesth Analg* 51:871–875, 1972.
15. Hess DR: Mechanical ventilation strategies: what's new and what's worth keeping? *Respir Care* 47:1007–1017, 2002.
16. Marini JJ: Weaning techniques and protocols, *Respir Care* 40:233–238, 1995.
17. MacIntyre NR: Respiratory function during pressure support ventilation, *Chest* 89:677–683, 1986.
18. Leith DE, Bradley M: Ventilatory muscle strength and endurance training, *J Appl Physiol* 41:508–518, 1976.
19. Heuer AJ: Medical gas therapy. In Kacmarek RM, Stoller JK, Heuer AJ, editors: *Egan's fundamentals of respiratory care*, ed 10, St. Louis, MO, 2013, Mosby, pp 887–944.
20. Chatburn RL, Mireles-Cabodevila E: Closed-loop control of mechanical ventilation: description and classification of targeting schemes, *Respir Care* 56:85–102, 2011.
21. Shapiro M, Wilson RK, Casar G, et al.: Work of breathing through different sized endotracheal tubes, *Crit Care Med* 14:1028–1031, 1986.
22. Wright PE, Marini JJ, Bernard GR: In vitro versus in vivo comparison of endotracheal tube airflow resistance, *Am Rev Respir Dis* 140:10–16, 1989.
23. Brochard L, Rua F, Lorino H, et al.: Inspiratory pressure support compensates for the additional work of breathing caused by the endotracheal tube, *Anesthesiology* 75:739–745, 1991.
24. Kuhlen R, Rossaint R: The role of spontaneous breathing during mechanical ventilation, *Respir Care* 47:296–303, 2002.
25. Oczenski W, Kepka A, Krenn H, et al.: Automatic tube compensation in patients after cardiac surgery: effects on oxygen consumption and breathing pattern, *Crit Care Med* 30:1467–1471, 2002.
26. Mols G, Rohr E, Benzing A, et al.: Breathing pattern associated with respiratory comfort during automatic tube compensation and pressure support ventilation in normal subjects, *Acta Anaesthesiol Scand* 44:223–230, 2002.
27. Fabry B, Haberthur C, Zappe D, et al.: Breathing pattern and additional work of breathing in spontaneously breathing patients with different ventilatory demands during inspiratory pressure support and automatic tube compensation, *Intensive Care Med* 23:545–552, 1997.
28. Kacmarek RM: Ventilatory adjuncts, *Respir Care* 47:319–330, 2002.
29. Guttman J, Eberhert L, Fabry B, et al.: Continuous calculation of intratracheal pressure in tracheally intubated patients, *Anesthesiology* 79:503–513, 1993.
30. Fabry B, Guttman J, Eberhard L, et al.: Automatic compensation of endotracheal tube resistance in spontaneously breathing patients, *Technol Health Care* 1:281–291, 1994.
31. Branson R: Understanding and implementing advances in ventilator capabilities, *Curr Opin Crit Care* 10:23–32, 2004.
32. Elsasser S, Guttmann J, Stocker R, et al.: Accuracy of automatic tube compensation in new-generation mechanical ventilators, *Crit Care Med* 31:2619–2626, 2003.
33. Fujino Y, Uchiyama A, Mashimo T, et al.: Spontaneously breathing lung model comparison of work of breathing between automatic tube compensation and pressure support, *Respir Care* 48:38–45, 2003.
34. Branson RD, Johannigman JA: What is the evidence base for the newer ventilation modes? *Respir Care* 49:742–760, 2004, 2004.
35. Haberthur C, Elsasser S, Eberhard L, et al.: Total versus tube-related additional work of breathing in ventilator-dependent patients, *Acta Anaesthesiol Scand* 44:749–757, 2000.
36. Guttmann J, Bernhard H, Mols G, et al.: Respiratory comfort of automatic tube compensation and inspiratory pressure support in conscious humans, *Intensive Care Med* 23:1119–1124, 1997.
37. Guttmann J, Haberthur C, Mols G, et al.: Automatic tube compensation (ATC), *Minerva Anestesiol* 68:369–377, 2002.
38. Straus C, Louis B, Isabey D, et al.: Contribution of the endotracheal tube and the upper airway to breathing workload, *Am J Respir Crit Care Med* 157:23–30, 1998.
39. Haberthur C, Mols G, Elsasser S, et al.: Extubation after breathing trials with automatic tube compensation, T-tube, or pressure support ventilation, *Acta Anaesthesiol Scand* 46:973–979, 2002.
40. Guttman J, Haberthur C, Mols G: Automatic tube compensation, *Respir Care Clin N Am* 7:475–501, 2001.
41. Hess DR, Branson RD: Ventilators and weaning modes. Part II, *Respir Care Clin N Am* 6:407–435, 2000.
42. Branson RD, Johannigman JA, Campbell RS, et al.: Closed-loop mechanical ventilation, *Respir Care* 47:427–451, 2002.
43. Roth H, Luecke T, Lansche G, et al.: Effects of patient-triggered automatic switching between mandatory and supported ventilation in postoperative weaning period, *Intensive Care Med* 27:47–51, 2001.
44. Holt SJ, Sanders RC, Thurman TL, et al.: An evaluation of automode, a computer-controller ventilator mode, with the Siemens Servo 300A ventilator using a porcine model, *Respir Care* 46:26–36, 2001.
45. Hewlett AM, Platt AS, Terry VG: Mandatory minute volume: a new concept in weaning from mechanical ventilation, *Anaesthesia* 32:163–169, 1977.
46. Quan SF, Parides GC, Knoper SR: Mandatory minute ventilation (MMV): an overview, *Respir Care* 35:898–905, 1990.
47. Davis S, Potgieter PD, Linton DM: Mandatory minute volume weaning in patients with pulmonary pathology, *Anaesth Intensive Care* 17:170–174, 1989.
48. Cairo JM: *Mosby's respiratory care equipment*, ed 11, St. Louis, MO, 2022, Mosby.
49. Campbell RS, Branson RD, Johannigman JA: Adaptive support ventilation, *Respir Care Clin N Am* 7:425–440, 2001.
50. Otis AB, Fenn WO, Rahn H: Mechanics of breathing in man, *J Appl Physiol* 2:592–607, 1950.
51. Weiler N, Eberle B, Heinrichs W: Adaptive lung ventilation (ALV) during anesthesia for pulmonary surgery: automatic response to transitions to and from one-lung ventilation, *J Clin Monit Comput* 14:245–252, 1998.
52. Linton DM, Potgieter PD, Davis S, et al.: Automatic weaning from mechanical ventilation using an adaptive lung ventilation controller, *Chest* 106:1843–1850, 1994.
53. Petter AH, Chiolero RL, Cassina T, et al.: Automatic "respiratory/weaning" with adaptive support ventilation: the effect on duration of

endotracheal intubation and patient management, *Anesth Analg* 97:1743–1750, 2003.
54. Strickland JH, Hasson JH: A computer-controlled ventilator weaning system: a clinical trial, *Chest* 103:1220–1226, 1993.
55. Rose L, Presneill JL, Cade JF: Update in computer-driven weaning from mechanical ventilation, *Anaesth Intensive Care* 35:213–221, 2007.
56. Lellouche F, Mancebo J, Jolliet P, et al.: A multicenter randomized trial of computer-driven protocolized weaning from mechanical ventilation, *Am J Respir Crit Care Med* 174(8):894–900, 2006.
57. Rose L, Presneill JL, Johnston L, et al.: A randomized, controlled trial of conventional versus automated weaning from mechanical ventilation using SmartCare/PS, *Intensive Care Med* 34:1788–1795, 2008.
58. Cook DJ, Meade MO, Guyatt GH, et al.: *Weaning from mechanical ventilation*. For the McMaster evidence based practice center, Rockville, Md, 2000, Agency for Healthcare Research and Quality. Contract No. 290-97-0017, Task order no. 2.
59. MacIntyre NR, Cook DJ, Ely EW, et al.: ACCP/AARC/SCCM Task force. Evidence-Based guidelines for weaning and discontinuing ventilatory support: a collective task force facilitated by the American College of chest physicians; the American association for respiratory care; and the American College of critical care medicine, *Chest* 120(Suppl 6):375S–395S, 2001; also in: Respir Care 2002;47(1): 69–90.
60. Girard TD, Alhazzani W, Kress JP, et al.: An official American Thoracic Society/American College of Chest Physicians Clinical Practice Guideline: liberation from mechanical ventilation in critically ill adults, 195(1):120–133, 2017.
61. MacIntyre NR: The ventilator discontinuation process: an expanding evidence, *Respir Care* 58(6):1074–1086, 2013.
62. Cook D, Meade M, Perry AG: Qualitative studies on the patient's experience of weaning from mechanical ventilation, *Chest* 120(Suppl 6):469S–473S, 2001.
63. Meade M, Guyatt G, Cook D, et al.: Predicting success in weaning from mechanical ventilation, *Chest* 120(Suppl 6):400S–424S, 2001.
64. Epstein SK: Weaning from mechanical ventilation, *Respir Care* 47:454–466, 2002.
65. Ely EW, Baker AM, Dunagan DP, et al.: Effect on the duration of mechanical ventilation of identifying patients capable of breathing spontaneously, *N Engl J Med* 335:1864–1869, 1996.
66. Tobin MJ: Predicting ventilator independence, *Semin Respir Med* 199314:275–280, 1993.
67. MacIntyre NR: Psychological factors in weaning from mechanical ventilatory support, *Respir Care* 40:277–281, 1995.
68. Khamiees M, Amoateng-Adjepong Y, Manthous CA: Propofol infusion is associated with a higher rapid shallow breathing index in patients preparing to wean from mechanical ventilation, *Respir Care* 47:150–153, 2002.
69. Yang KL, Tobin MJ: A prospective study of indexes predicting the outcome of trials of weaning from mechanical ventilation, *N Engl J Med* 324:1445–1450, 1991.
70. Lee KH, Hui KP, Chan TB, et al.: Rapid shallow breathing (frequency-tidal volume ratio) did not predict extubation outcome, *Chest* 105:540–543, 1994.
71. Yang KL: Inspiratory pressure/maximal inspiratory pressure ratio: a predictive index of weaning outcome, *Intensive Care Med* 19:204–208, 1993.
72. El-Khatib MF, Baumeister B, Smith PG, et al.: Inspiratory pressure/maximal inspiratory pressure: does it predict successful extubation in critically ill infants and children? *Intensive Care Med* 22:264–268, 1996.
73. Capdevila XJ, Perrigault PF, Perey PJ, et al.: Occlusion pressure and its ratio to maximum inspiratory pressure are useful predictors for successful extubation following T-piece weaning trial, *Chest* 108:482–489, 1995.
74. Sassoon CSH, Te TT, Mahutte CK, et al.: Airway occlusion pressure: an important indicator for successful weaning in patients with chronic obstructive pulmonary disease, *Am Rev Respir Dis* 135:107–113, 1987.
75. Scott GC, Burki NK: The relationship of resting ventilation to mouth occlusion pressure: an index of resting respiratory function, *Chest* 98:900–906, 1990.
76. Sasson CSH, Mahutte CK: Airway occlusion pressure and breathing pattern as predictors of weaning outcome, *Am Rev Respir Dis* 148:860–866, 1993.
77. Jubran A, Tobin MJ: Pathophysiologic basis of acute respiratory distress in patients who fail a trial of weaning from mechanical ventilation, *Am J Respir Crit Care Med* 155:906–915, 1997.
78. Stoller JK: Establishing clinical unweanability, *Respir Care* 36:186–198, 1991.
79. Mitsuoka M, Kinninger KH, Johnson FW, et al.: Utility of measurements of oxygen cost of breathing in predicting success or failure in trials of reduced mechanical ventilatory support, *Respir Care* 46:902–910, 2001.
80. Esteban A, Alia I, Tobin MJ, et al.: Effect of spontaneous breathing trial duration on outcome of attempts to discontinue mechanical ventilation. Spanish Lung Failure Collaborative Group, *Am J Respir Crit Care Med* 159:512–518, 1999.
81. Esteban A, Alia I, Gordo F, et al.: Extubation outcome after spontaneous breathing trials with T-tube or pressure support ventilation. Spanish Lung Failure Collaborative Group, *Am J Respir Crit Care Med* 156:459–465, 1997. (Erratum in *Am J Respir Crit Care Med* 156:2028, 1997).
82. Cohen JD, Shapiro M, Grozovski E, et al.: Automatic tube compensation-assisted respiratory rate to tidal volume ratio improves the prediction of weaning outcome, *Chest* 122:980–984, 2002.
83. Matic I, Majeric-Kogler V: Comparison of pressure support and T-tube weaning from mechanical ventilation: randomized prospective study, *Croat Med J* 45:162–166, 2004.
84. Vallverdu I, Calaf N, Subirana M, et al.: Clinical characteristics, respiratory functional parameters, and outcome of two-hour T-piece trial in patients weaning from mechanical ventilation, *Am J Respir Crit Care Med* 158:1855–1862, 1998.
85. Salam A, Smina M, Gada P, et al.: The effect of arterial blood gas values on extubation decisions, *Respir Care* 48:1033–1037, 2003.
86. Coplin WM, Pierson DJ, Cooley KD, et al.: Implications of extubation delay in brain-injured patients meeting standard weaning criteria, *Am J Respir Crit Care Med* 161:1530–1536, 2000.
87. Marik PE: The cuff-leak test as a predictor of postextubation stridor: a prospective study, *Respir Care* 41:509–511, 1996.
88. Meade MO, Guyatt GH, Cook DJ, et al.: Trials of corticosteroids to prevent postextubation airway complications, *Chest* 120(Suppl 6):464S–468S, 2001.
89. Fisher MM, Raper RF: The "cuff-leak" test for extubation, *Anaesthesia* 47:10–12, 1992.
90. Engoren M: Evaluation of the cuff-leak test in a cardiac surgery population, *Chest* 116:1029–1031, 1999.
91. Epstein SK: Extubation, *Respir Care* 47:483–492, 2002.
92. Epstein SK, Ciubotaru RL, Wong JB: Effect of failed extubation on the outcome of mechanical ventilation, *Chest* 112:186–192, 1997.
93. Meade MO, Guyatt G, Butler R, et al.: Trials comparing early versus late extubation following cardiovascular surgery, *Chest* 120(Suppl 6):445S–453S, 2001.
94. Rady MY, Ryan T: Perioperative predictors of extubation failure and the effect on clinical outcome after cardiac surgery, *Crit Care Med* 27:340–347, 1999.
95. Solh E, Bhat A, Gunen H, et al.: Extubation failure in the elderly, *Respir Med* 98:661–668, 2004.
96. AARC Clinical Practice Guideline: Removal of the endotracheal tube, *Respir Care* 52:81–93, 2007.
97. ACCP AARC, A.C.C.C.M. Taskforce: evidence-based guidelines for weaning and discontinuing ventilatory support, *Respir Care* 47:69–90, 2002.
98. Girault C, Daudenthun I, Chevron V, et al.: Noninvasive ventilation as a systematic extubation and weaning technique in acute-on-chronic respiratory failure: a prospective, randomized controlled study, *Am J Respir Crit Care Med* 160:86–92, 1999.
99. Nava L, Ambrosino N, Rubini F, et al.: Survival and prediction of successful ventilator weaning in COPD patients requiring mechanical ventilation for more than 21 days, *Eur Respir J* 7:1645–1652, 1994.
100. Hill NS, Lin D, Levy M, et al.: Noninvasive positive pressure ventilation (NPPV) to facilitate extubation after acute respiratory failure: a feasibility study [abstract], *Am J Respir Crit Care Med* 161:A263, 2000.
101. Ferrer M, Esquinas A, Arancibia F, et al.: Noninvasive ventilation during persistent weaning failure: a randomized controlled trial, *Am J Respir Crit Care Med* 168:70–76, 2003.
102. Navalesi P: Weaning and noninvasive ventilation: the odd couple [editorial], *Am J Respir Crit Care Med* 168:5–6, 2003.

103. Sassoon CSH: Noninvasive positive-pressure ventilation in acute respiratory failure: review of reported experience with special attention to use during weaning, *Respir Care* 40:282–288, 1995.
104. Mathewson HS: Prolonged neuromuscular blockade [editorial], *Respir Care* 38:522–523, 1993.
105. Douglass JA, Tuxen DV, Horne M, et al.: Myopathy in severe asthma, *Am Rev Respir Dis* 146:517–519, 1992.
106. Griffin D, Fairman N, Coursin D, et al.: Acute myopathy during treatment of status asthmaticus with corticosteroids and steroidal muscle relaxants, *Chest* 102:510–514, 1992.
107. Segredo V, Caldwell JE, Matthay MA, et al.: Persistent paralysis in critically ill patients after long-term administration of vecuronium, *N Engl J Med* 327:524–528, 1992.
108. Hansen-Glaschen J, Cowen J, Raps EC: Neuromuscular blockade in the intensive care unit: more than we bargained for [editorial], *Am Rev Respir Dis* 147:234–236, 1993.
109. Stoller JK: Physiological rationale for resting the ventilatory muscles, *Respir Care* 36:290–296, 1991.
110. MacIntyre NR: Bringing scientific evidence to the ventilator weaning and discontinuation process: evidence-based practice guidelines [editorial], *Respir Care* 47:29–30, 2002.
111. Wood G, MacLeod B, Moffatt S: Weaning from mechanical ventilation: physician-directed vs a respiratory therapist-directed protocol, *Respir Care* 40:219–224, 1995.
112. Domini L, Wallace P, Pilbeam SP: *Weaning protocol in ICU can save money. AARC adult acute care section Bulletin Winter*, 1996.
113. Marelich GP, Murin S, Battistella F, et al.: Protocol weaning of mechanical ventilation in medical and surgical patients by respiratory care practitioners and nurses: effect on weaning time and incidence of ventilator-associated pneumonia, *Chest* 118:459–467, 2000.
114. Ely EW, Meade MO, Haponik EF, et al.: Mechanical ventilator weaning protocols driven by nonphysician health-care professionals: evidence-based clinical practice guidelines, *Chest* 120(Suppl 6): 454S–463S, 2001.
115. Ely EW, Bennett PA, Bowton DL, et al.: Large scale implementation of respiratory therapist-driven protocol for ventilator weaning, *Am J Respir Crit Care Med* 159:439–446, 1999.
116. Kollef MH, Shapiro SD, Silver P, et al.: A randomized, controlled trial of protocol-directed versus physician-directed weaning from mechanical ventilation, *Crit Care Med* 25:567–574, 1997.
117. Stoller JK, Mascha EJ, Kester L, et al.: Randomized controlled trial of physician-directed versus respiratory therapy consult service–directed respiratory care to adult non-ICU inpatients, *Am J Respir Crit Care Med* 158:1068–1075, 1998.
118. Littlewood K, Durbin CG: Evidenced-based airway management, *Respir Care* 46:1392–1405, 2001.
119. Harrop JS, Sharan AD, Scheid EH, et al.: Tracheostomy placement in patients with complete cervical spinal cord injuries: American Spinal Injury Association Grade A, *J Neurosurg* 100:20–23, 2004.
120. Heffner JE: The role of tracheotomy in weaning, *Chest* 120(Suppl 6):477S–481S, 2001.
121. Maziak DE, Meade MO, Todd TR: The timing of tracheotomy: a systematic review, *Chest* 114:605–609, 1998.
122. Jaeger JM, Littlewood KA, Durbin CG: The role of tracheostomy in weaning from mechanical ventilation, *Respir Care* 47:469–480, 2002.
123. Bortner PL, May RA: Artificial airways and tubes. In Eubanks DH, Bone RC, editors: *Principles and applications of cardiorespiratory care equipment*, St. Louis, MO, 1994, Mosby, pp 117–145.
124. Pierson DJ: Long-term mechanical ventilation and weaning, *Respir Care* 40:289–295, 1995.
125. Curtis JR: The long-term outcomes of mechanical ventilation: what are they and should they be used? *Respir Care* 47:496–505, 2002.
126. Schmidt GA, Girard TD, Kress JP, et al.: Official executive summary of an American Thoracic Society/American College of Chest Physicians clinical practice guideline: liberation from mechanical ventilation in critically ill adults, *Am J Respir Crit Care Med* 195(1):115–119, 2017.
127. Fan E, Zakhary B, Amaral A, et al.: Clinical practice guideline: summary for clinicians. Liberation from mechanical ventilation in critically ill adults, an ATS/ACCP clinical practice guideline, *Ann Am Thorac Soc* 14:441–443, 2017.
128. Wilson ME, Azoulay E: The ethics of withholding and withdrawing ventilatory support. In Tobin JJ, editor: *Principles and practice of mechanical ventilation*, ed 3, New York, NY, 2013, McGraw-Hill.

CHAPTER 21

Long-Term Ventilation

OUTLINE

KEY TERMS

- Chest cuirass
- Decannulation
- Erosive esophagitis
- Gastrostomy or jejunostomy tubes
- Ileus
- Pneumobelt
- Respite care
- Rocking bed

LEARNING OBJECTIVES

On completion of this chapter, the reader will be able to do the following:

1. State the goals of mechanical ventilation in a home environment.
2. List the criteria for selection of patients suitable for successful homecare ventilation.
3. Name the factors used to estimate the cost of home mechanical ventilation.
4. Describe facilities used for the care of patients requiring extended ventilator management in terms of type of care provided and cost.
5. Identify the factors used when considering selection of a ventilator for home use.
6. Compare the criteria for discharging a child versus discharging an adult who is ventilator dependent.
7. Explain the use of the following noninvasive ventilation techniques: pneumobelt, chest cuirass, full-body chamber (tank ventilator), and body suit (jacket ventilator).
8. List follow-up assessment techniques used with patients on home ventilation.
9. Describe some of the difficulties families experience when caring for a patient in the home.
10. Identify pieces of equipment that are essential to accomplishing intermittent positive pressure ventilation in the home.
11. Name the specific equipment needed for patients in the home who cannot be without ventilator support.
12. Name the appropriate modes used with first-generation portable/homecare ventilators.
13. On the basis of a patient's assessment and ventilator parameters, name the operational features required for that patient's home ventilator and any additional equipment that will be needed.
14. Discuss the instructions given to the patient and caregivers when preparing a patient for discharge home.
15. List the items that should appear in a monthly report of patients on home mechanical ventilation.

16. Describe patients who would benefit from continuous positive airway pressure by nasal mask or pillows.
17. Recommend solutions to potential complications and side effects of nasal mask continuous positive airway pressure.
18. Recognize from a clinical example a potential complication of negative pressure ventilation.
19. Name three methods of improving secretion clearance besides suctioning.
20. List the advantages of using mechanical insufflation-exsufflation in conjunction with positive pressure ventilation.
21. List five psychological problems that can occur in ventilator-assisted individuals.
22. Explain the procedure for accomplishing speech in ventilator-assisted individuals.
23. Compare the functions of the Portex and Pittsburg speaking tracheostomy tubes.
24. Name one essential step required by the respiratory therapist when setting up a speaking valve for a ventilator-assisted individual.
25. List six circumstances in which speaking devices may be contraindicated.

Most patients receiving mechanical ventilation require ventilatory support for fewer than 7 days. Approximately 5% of those patients requiring more than 7 days cannot be successfully weaned from ventilatory support and require long-term mechanical ventilation (LTMV). For these patients, weaning is slow paced and may not always result in ventilator discontinuation.[1]

Patients requiring LTMV can be divided into two groups: those recovering from an acute illness and unable to maintain adequate ventilation for prolonged periods, and those with chronic progressive cardiopulmonary disorders. Patients who have an acute, severe illness may not recover sufficiently to be weaned from ventilation while in an acute care facility and are generally transferred to special units on mechanical ventilation within the hospital, long-term care facilities, or their homes. Chronic progressive disorders that require LTMV include ventilatory muscle disorders, alveolar hypoventilation, obstructive lung diseases, restrictive lung diseases, and cardiac diseases (e.g., congenital cardiac diseases).[2]

Mortality rates for patients receiving LTMV are high (2-year mortality rate of 57%; 5-year mortality rate range of 66%–97%).[3-5] Patients who are successfully liberated from the ventilator and decannulated have a greater chance of survival.[4]

The number of ventilator-assisted individuals (VAIs) being discharged to homes or alternative care sites has significantly increased during the past 3 decades[6] (Key Point 21.1). Approximately 11,419 VAIs were in the United States in 2002, with care requiring an annual cost of almost $3.2 billion. Most of the costs for the treatment of VAIs are absorbed by acute care hospitals, where reimbursement is typically inadequate. As a consequence of rising costs and falling reimbursements, specialized respiratory care units in acute, intermediate, and chronic care facilities were developed. However, the growth of these specialty units has slowed, again because of limited funding and reimbursement.[4,7]

The following five major factors have added to this upsurge in numbers of VAIs:

1. Continued advances in pulmonary medicine and technology have contributed to increased survival rates of critically ill adults and children. Many of these patients can be saved, stabilized, and sent home or to alternative sites for continued ventilator support.[8]
2. An increased emphasis has been placed on earlier discharge of patients from acute care hospitals to reduce the cost of medical care. These patients can be transferred to less costly facilities for continued care.
3. Noninvasive positive pressure ventilation (NIV) such as bilevel mask ventilation is an effective alternative to invasive ventilation, as both an initial mode of treatment and a long-term alternative to managing ventilator-dependent patients.
4. Simpler and more versatile equipment is available for home use.
5. An increase in medical equipment agencies and the availability of homecare services that provide ventilator care outside the hospital. These latter services allow the patient to benefit from the psychological advantages of being in the family setting or a nonacute care environment.

Key Point 21.1 Long-term ventilator-assisted patients are defined by the American College of Chest Physicians (ACCP) as individuals requiring mechanical ventilation for at least 6 hours per day for 21 days or more.[6]

An excellent example of a VAI who not only survived but lived a quality life is Christopher Reeve, an actor and active sportsman who sustained a high cervical fracture as a result of a horseback riding accident that left him a quadriplegic. With his determination and the support of his wife, family, and caregivers, he was able to have a productive life while being maintained on LTMV for 10 years. During this time, he directed films, became a public speaker, raised awareness of spinal cord injury, and became a strong advocate for stem cell research.[9]

The number of elder Americans is increasing, along with an increase in the number of people with chronic illnesses. Given these trends and the demand for controlling health care costs, it is anticipated that the number of VAIs discharged to home or alternative care sites will continue to increase. LTMV has been shown to be a safe and effective alternative to acute care institutionalization. The home is generally the least expensive environment and the one that provides the greatest level of patient independence and family support. For this reason, a large part of this chapter is devoted to a discussion of home mechanical ventilation.

GOALS OF LONG-TERM MECHANICAL VENTILATION

The overall goal of LTMV at home or other alternative care sites is to improve the patient's quality of life by providing the following environmental attributes[2,10]:

1. Enhancing the individual's living potential
2. Improving physical and physiological level of function
3. Reducing morbidity
4. Lessening hospitalizations
5. Extending life
6. Providing cost-effective care

Because patients require different levels of care, it is desirable for every patient to progress to his or her point of maximum activity and take an active role in his or her own care. If this is accomplished, his or her psychosocial well-being will also improve.

SITES FOR VENTILATOR-DEPENDENT PATIENTS

The terminology used to describe facilities for VAIs is not standardized. Sites can be grouped into three general categories: acute care, intermediate care, and long-term care.[1]

Acute Care Sites

Acute care sites include the following:

- Intensive care units (ICU), which provide invasive monitoring, extensive care, and a higher ratio of practitioners to patients. These units are more expensive and provide the least amount of patient independence and quality of life.
- Specialized respiratory care units, which have fewer resources and are generally designed for more stable VAIs. These are often designated units within a hospital and may be called *pulmonary specialty wards,*[11] *respiratory special care units,* and *chronic assisted ventilator care units.*[12]
- General medical-surgical care units, which are typically located on general patient floors of the hospital. Nursing and allied health staff working on these general medical-surgical units often require additional preparation and training to manage these VAIs.
- Long-term acute care hospitals, which are specifically designed to care for patients who require extensive monitoring and care, such as daily physician visits, continuous monitoring, intravenous therapy, wound care, and isolation. These patients may still be acutely ill but no longer require the intensive care provided in a critical care unit in the hospital.[12] Long-term ventilator hospitals fall into this category.

VAIs in specialized units located within a hospital typically have the following characteristics:

- Longer hospital stays
- Lower hospital mortality rates
- Higher weaning rates
- Higher likelihood of being discharged to their homes
- Longer life expectancy after discharge
- Greater independence in daily activities

Success revolved around the strong leaderships of pulmonologists, who are dedicated to the care of these individuals.[13]

Intermediate Care Sites

Intermediate care sites usually include subacute care units, long-term care hospitals, and rehabilitation hospitals. Intermediate care sites are not as expensive as acute care sites and provide somewhat more patient independence and quality of life.

Subacute care units may be located in acute care hospitals. They often admit patients who require physiological monitoring, intravenous therapy, or postoperative care.

Long-term care hospitals are designed to provide care for long-term invasive ventilator-dependent patients (i.e., length of stay usually exceeds 25 days). These patients may still require high levels of positive end-expiratory pressure (PEEP) or fraction of inspired oxygen (F_IO_2). Once they are liberated from the ventilator or switched to a noninvasive method of support, these patients can then be transferred to a congregate living center or home.

Admission to a rehabilitation hospital is based on the patient's specific rehabilitation goals. Current standards include the requirement for nursing rehabilitation care and at least two additional rehabilitation needs, such as physical therapy, occupational therapy, or speech therapy. After a 10-day trial period, patients must be able to participate for 3 hours of therapy per day.

Long-Term Care Sites

Long-term care sites include skilled nursing facilities, congregate living centers, and single-family homes. These sites do not have the resources to treat acutely ill patients. Long-term care sites are *not* the ideal site for weaning a patient from ventilation. However, they are the least expensive and provide a better quality of life and more independence for the patient.

Skilled nursing facilities include nursing homes, extended care facilities, and convalescent centers. A greater number of VAIs are being admitted in these locations.

Congregate living centers are commonly large private residences, apartments, foster homes, or homes with as many as 6 to 10 patients. These sites are more common in Europe than in the United States.[10]

Homes are typically the preferred environment for caring for ventilator-dependent patients. The quality of life for patients living at home is enhanced, and the home is less costly than most other sites, perhaps with the exception of skilled nursing facilities. The family usually provides most of the support, both financial and medical.

Increasing pressure from managed care and utilization review is resulting in more rapid discharge from ICUs and acute care facilities. Intermediate- and long-term care sites provide newer and less costly approaches to patient care.[14-21] Treatment objectives are generally met at specific facilities. For example, weaning may occur in acute or intermediate care facilities, but it is usually inappropriate in the home.[10]

PATIENT SELECTION

Patient selection is the key to success for any long-term care ventilation program. Although many factors must be considered in this selection, they can be broadly grouped into three areas:

1. Disease process and clinical stability
2. Psychological evaluation of patient and family
3. Financial considerations

Disease Process and Clinical Stability

Previous studies have shown that some patients with disorders requiring LTMV may be more successfully managed than others.[22-25] The following three categories can be used to describe ventilator-dependent patients.[1,10]

1. Patients recovering from acute illnesses and acute respiratory failure who do not respond to repeated attempts at liberation from the ventilator. These patients may need mechanical ventilation for an extended period and will require several weeks to months for recovery but are likely to recover. Some of these patients may sustain several hours of unsupported spontaneous breathing but generally will fatigue when challenged with longer periods of ventilator disconnection.
2. Patients with chronic disorders who only require mechanical ventilation for a part of the day, such as at night, but can support spontaneous ventilation on their own for several hours each day.

3. Patients requiring continuous ventilatory support to survive, that is, patients diagnosed as having complete loss of ventilatory function with absent or severely impaired spontaneous breathing efforts. These patients are unable to sustain spontaneous ventilation and depend on life support from the ventilator. Their disorder is inexorably progressive. (Box 21.1 lists the disorders grouped in each category.)

Patients with neuromuscular conditions, skeletal disorders, central hypoventilation syndromes, and stable chronic lung diseases are more likely to have long-term success than patients with disorders causing failure of gas exchange. Disease processes affecting other organ systems besides the pulmonary system are associated with a higher risk for complications. Patients affected with these types of conditions are not suitable for long-term ventilation in most extended care facilities and require a long-term acute care facility. Box 21.2 lists medical conditions appropriate for long-term ventilation.[6,10,25]

Individuals who are considered candidates for LTMV in the home or in extended care facilities must be clinically and physiologically stable to the degree that they are free from any medical complications for at least 2 weeks before discharge. Proof of medical stability must include stable cardiovascular and renal function; no evidence of uncontrolled hemorrhage or coma or, if comatose, prognosis for improvement; acceptable arterial blood gas (ABG) values; freedom from acute respiratory infections and fever; stabile F_IO_2 requirements; and ventilator settings that do *not* result in high inspiratory pressures or high levels of PEEP (Case Study 21.1).

Other considerations include the ability to clear secretions (either spontaneously or by suctioning), the ability to tolerate and meet criteria for a face mask or nasal mask for NIV, or the presence of a tracheostomy tube (TT) for invasive positive pressure ventilation (IPPV). Additionally, major diagnostic tests or therapeutic interventions should not be anticipated for at least 1 month after discharge. Box 21.3 lists selection criteria for children.[26]

BOX 21.1 Patient Groups Requiring Long-Term Mechanical Ventilation

1. Patients recovering from acute illnesses and acute respiratory failure who do not respond to repeated attempts at liberation from the ventilator. This group might include patients who have had a major insult to the respiratory system caused by a severe medical illness, such as acute respiratory distress syndrome or severe pneumonia; patients who had a catastrophic postoperative event; and patients in whom an acute illness develops superimposed on a chronic disorder (e.g., malnutrition, advanced age, heart disease, systemic infection, COPD).
2. Patients with chronic disorders who require mechanical ventilation for only a portion of the day, such as at night, but can support spontaneous ventilation on their own for several hours each day, such as severe COPD, kyphoscoliosis, and severe or progressing neuromuscular disorders, such as amyotrophic lateral sclerosis.
3. Patients requiring continuous ventilatory support to survive, that is, patients diagnosed as having complete loss of ventilatory function with absent or severely impaired spontaneous breathing efforts. Examples include intracranial hemorrhage, cerebrovascular accidents, central alveolar hypoventilation syndrome, and diaphragmatic paralysis. This group also includes patients with severe respiratory muscle failure such as those with a high spinal cord injury, end-stage pulmonary interstitial fibrosis, and end-stage neuromuscular disorders.

BOX 21.2 Medical Conditions Appropriate for Long-Term Mechanical Ventilation

Central Nervous System Disorders
- Arnold-Chiari malformation
- Central nervous system trauma
- Cerebrovascular disorders
- Congenital and acquired central control of breathing disorders
- Myelomeningocele
- Spinal cord traumatic injuries

Neuromuscular Disorders
- Amyotrophic lateral sclerosis
- Congenital childhood hypotonia
- Guillain-Barré syndrome
- Infant botulism
- Muscular dystrophy
- Myasthenia gravis
- Phrenic nerve paralysis
- Polio and postpolio sequelae
- Spinal muscular atrophy
- Myotonic dystrophy

Skeletal Disorders
- Kyphoscoliosis
- Thoracic wall deformities
- Thoracoplasty

Cardiovascular Disorders
- Acquired heart diseases
- Congenital heart diseases

Respiratory Disorders
Upper Airway
- Pierre Robin syndrome
- Tracheomalacia
- Vocal cord paralysis

Lower Respiratory Tract
- Bronchopulmonary dysplasia
- Chronic obstructive pulmonary disease
- Complications of acute lung injury
- Cystic fibrosis
- Complications of infectious pneumonias
- Pulmonary fibrotic diseases

From Make BJ, Hill NS, Goldberg AI: Mechanical ventilation beyond the intensive care unit: report of a consensus conference of the American College of Chest Physicians, *Chest* 113:289S-344S, 1998.

Psychosocial Factors

The psychological stability and coping skills of the patient and family are critical to the success of long-term ventilation. The

Case Study 21.1

Patient Case—Difficulty Weaning

A 48-year-old male patient with stable amyotrophic lateral sclerosis (requiring nocturnal ventilation only) develops chest pain and is taken to the emergency department by his family. An electrocardiogram reveals an anterior myocardial infarction. The patient is intubated with a 7.5-Fr endotracheal tube and placed on appropriate ventilatory support.

The patient is stabilized, and, after 2 days on ventilation, a spontaneous breathing trial (SBT) is attempted. The patient fails the SBT. He also fails SBTs evaluated over the next week. A tracheostomy is placed.

After 4 weeks in an acute care setting, the patient is medically stable but requires continuous ventilation. Why has it become so difficult to wean this patient? Would you recommend transferring this patient to another facility?

BOX 21.3

Selection Criteria for Children to Be Ventilated at Home Infants and children being considered for home mechanical ventilation may have additional criteria besides clinical stability and financial resources that must be fulfilled. These criteria include the following:

- Positive trends in weight gain and growth curve
- Stamina for periods of play while ventilated
- Family determined to be suitable candidates, as shown by their awareness of potential stresses of long-term homecare and commitment to implementing the program
- Adequate family support from home nurses, homemaker aids, and family and friends

From American Thoracic Society Board of Directors: Official statement, *Am Rev Respir Dis* 141:258–259, 1990.

family must be made aware of the patient's prognosis and advantages and disadvantages of LTMV.

In cases in which the patient will be going home, a detailed psychological evaluation may be necessary to determine the ability of the patient and family to cope with stress.[10,22] If the requirements for patient care exceed the family's capabilities, professional assistance is essential. The availability of other support systems such as home health agencies, **respite care**, and psychological consultants are often critical to the success or failure of homecare candidates. The need for support and counseling is assessed before discharge and reassessed periodically while the patient remains on mechanical ventilatory support.[27,28]

Financial Considerations

Regardless of the location in which it is provided, mechanical ventilation is an expensive treatment modality. Note that mechanical ventilation in an ICU and acute care unit is the most expensive option of the facilities previously mentioned, whereas homecare ventilation is the least expensive.[14-17] It is important to recognize that despite the significant savings accrued when a patient receives ventilatory care in the home, the overall cost can strain family budgets, even for those who are insured.

A variety of factors can influence the total cost associated with delivering LTMV. These factors include the following patient characteristics[11,20]:

- Diagnosis
- Age
- Level of acuity
- Need for rehabilitation services (e.g., occupational therapy, physical therapy)
- Type of ventilator selected
- Need for monitoring
- Supplemental oxygen (O_2)
- Medications

For example, patients with chronic obstructive pulmonary disease (COPD) may require a higher level of care than patients with neuromuscular disorders because of the need for additional care such as suctioning, bronchopulmonary drainage, bronchodilator therapy, and anxiolytic and antibiotic administration. Children younger than 10 years may require higher costs because of special needs compared with adults.

For homecare patients, ventilator equipment can be bought at a reasonable price; however, in many cases, families may choose to rent the ventilator because regular service, maintenance, and 24-hour emergency services are available as part of the rental contract. Unfortunately, the costs of accessory medical supplies, including items such as suction catheters, skin lotions, and absorbent underpads, may be difficult to estimate and can significantly increase the total cost of care.

The major factor affecting the cost of homecare is the need for professional or skilled caregivers. This cost depends on the availability of family members and how much they are willing and able to do. Cost also depends on patient independence and self-care abilities and the number of hours and level of care required from others.[21]

It is important to recognize that inadequate third-party coverage for supplies and equipment, which is almost always passed on to the patient and family, must be factored into the costs of providing LTMV in the home. An estimate of the actual cost to the patient must be determined as accurately as possible and presented to the patient and family before discharging the patient from the care facility to the home.

PREPARATION FOR DISCHARGE TO THE HOME

Respiratory therapists who are assigned to prepare a ventilator-assisted patient for transfer to another facility or home must ensure that the receiving site can accommodate the patient's and family's needs. Although similarities in discharge planning exist between an acute care and an intermediate care facility, the transfer from either of these facilities to the patient's home requires particular attention.[28,29]

When the VAI is being transferred home, preparation is extremely important. Preparation of the home begins almost simultaneously with home and patient assessment and includes the process of equipment selection. The coordinated efforts of the multidisciplinary health care team, a comprehensive discharge prescription, and an educational program for the patient and caregivers are developed to ensure a safe transition from hospital to home or alternative care site (Key Point 21.2).

***Key Point* 21.2** A discharge plan should contain the basic components of assessment, education, training, and a plan of care.[10]

The discharge process may be complex and time consuming depending on the patient's medical condition, needs, and goals. Consequently, it is initiated as early as possible before transfer to make it as smooth as possible. This often requires a minimum of a 7- to 14-day period before the patient is discharged because this much time may be needed to obtain insurance verification and authorization and equipment procurement. In other words, the plan may begin almost as soon as the patient is admitted to the acute care facility or as soon as he or she is identified as a VAI. The discharge planning process ensures patient safety and optimal outcome in the new environment.

The goal of the discharge planning team is to identify all patient care issues that need to be addressed before discharge and develop a plan of care to facilitate transfer.[10,29,30] The health care team generally consists of the patient and family, the patient's primary physician, a pulmonary physician, a nurse, a respiratory therapist, and a social worker/hospital discharge planner. Depending on the patient's level of care, other specialists, such as a physical therapist, a psychologist, an occupational therapist, a speech-language pathologist, and a clinical dietitian, may also be included. The durable medical equipment (DME) supplier will also be a crucial member of this team, and equipment should be selected as soon as possible. A coordinator should be designated if a hospital-based discharge planner is not available.[31]

Team members must communicate regularly to discuss the patient's progress and address any issues that may hinder the discharge process. A thorough review of the patient's hospital record is also important to determine the patient's history and established medical condition. Ventilator settings are discussed to ensure that the DME supplier can provide a ventilator that can accommodate the desired settings. An assessment of the financial status of the patient is imperative to ensure that additional assistance can be pursued for gaps that exist between third-party reimbursement and actual cost.

Geographical and Home Assessment

The geographical area where the patient will reside should be considered. This is necessary to ensure that a home health agency or DME provider is located near the patient's home and is available if technical assistance is required. Also, a hospital emergency department should be within a reasonable driving distance.

As part of the discharge plan, the medical supplier or practitioner assesses the patient's home environment to see whether any modifications must be made before the patient goes home. In general, this assessment includes a home visit to view the size of the patient care area and determine whether it is adequate for the prescribed equipment. Areas should be available for storage and cleaning and disposal of supplies. Judging the accessibility into and out of the home and between rooms is important and should not be overlooked. The home should also be assessed for safety (e.g., fire extinguishers, smoke detectors and alarms). The family needs to have telephone service. The number of people in the home may be a factor in the size of the space, and, of course, the primary caregivers must be identified.

The electrical system must provide adequate amperage for the ventilation, suction equipment, O_2 concentrator if needed, and other necessary electrical devices. An important step is counting the number and type of electrical outlets and determining the amperage requirements of the equipment (Box 21.4). This may be accomplished by the family, or it may require an electrician.[32] When modifications in the home are recommended, they will not be covered by health insurance, which means that they will be out-of-pocket costs for the family. Therefore only absolutely necessary modifications should be made.[33]

BOX 21.4 Mapping Electrical Circuits in the Home

1. Place a number by each of the circuit breakers or fuses in the main electrical panel.
2. On a piece of paper for each room in the home, draw a square representing the room and mark each receptacle or light in the room.
3. Make sure each receptacle has a small appliance or light plugged into it. Turn on all the lights and small appliances plugged into an electrical outlet.
4. Turn off the first circuit and note the appliances affected (they will be off). Mark the circuit number by the receptacles and lights in that room on the drawing for that room.
5. Turn that circuit back on and turn off the next circuit in the numbering sequence.
6. Continue until all appliances or lights in all rooms have been assigned to a circuit.

From May D: *Rehabilitation and continuity of care in pulmonary disease*, St. Louis, MO, 1990, Mosby.

Family Education

A written educational program is provided to caregivers and includes measurable performance objectives. At least three caregivers should be selected, with one being trained at a high enough level to be able to train and instruct other caregivers. Each discharge team member is responsible for educating the caregivers in specific areas of the management of the ventilator-dependent patient. The educational component includes providing detailed instructions on the operation of the ventilator, cardiopulmonary resuscitation, the use of manual resuscitators, aseptic suctioning techniques, tracheostomy care, tracheostomy collars and humidification systems, methods of disinfecting equipment, bronchial hygiene therapies such as chest physiotherapy, aerosolized medication administration, bowel and bladder care, and bathing. The family is also taught to recognize early signs and symptoms of a respiratory infection (assessment) and what action must be taken if such a situation arises. Part of this process requires that the caregivers stay in the acute care facility for 24 to 48 hours before discharge, providing total care to the patient under the supervision of the medical staff. Additionally, a written protocol with directions for respiratory treatments and other aspects of care is included.

Not all caregivers will be able to tolerate performing some procedures, such as suctioning, bladder and bowel management, or bathing. Not surprisingly, working with a ventilator-dependent patient can be intimidating. Patience is essential in family training. In some cases, additional family members or outside caregivers are needed. An adequate number of caregivers should be identified and trained to allow the family time for sleep, work, and

relaxation. Outside caregivers may include the immediate family and extended family, friends, nonprofessional paid caregivers, volunteers, and paid licensed health professionals.

The respiratory therapist is charged with the responsibility to teach caregivers the skills necessary for airway maintenance (suctioning and tracheostomy care), ventilator settings, circuit maintenance, infection control, troubleshooting the equipment, and emergency measures. A basic checklist of these skills is given to the patient and family and used to guide the educational process. All family members involved in the patient's care need to demonstrate adequate hands-on performance of all aspects of patient care before the patient is discharged. Fig. 21.1 is an example of a caregiver assessment sheet. Once these tasks are learned and competencies are demonstrated, the patient is placed on the home ventilator several days before discharge, allowing family members to become comfortable with the process.

Additional Preparation

The primary physician typically arranges for medical care of the patient with a local physician and nursing service if the patient will reside in a location far from where the initial treatment was provided. The local hospital emergency department near the patient's residence should be designated for emergency care, with an emergency plan clearly outlined. The local power company must be notified in writing of the patient's condition. The patient's home will need a priority status for electrical power service in case of a power failure.

The family and patient must be prepared for emergency situations such as fires, hurricanes, tornados, flooding, and so forth. A contingency plan must be in place if power loss occurs from any of these disasters. A disaster may require evacuating the patient from the home to a special-needs shelter. Because of these possibilities, local fire departments, emergency medical teams, utility companies, police departments, and the local hospital emergency department should all be aware of the patient's urgent medical needs. Many communities have an office of emergency management that maintains a log of homecare patients along with their home addresses and contact information. This information can be critical in the case of a prolonged power outage or in the event that an emergency evacuation is required for the geographical area where the homecare patient resides.

FOLLOW-UP AND EVALUATION

Before the patient is discharged, equipment and supplies are set up in the patient's home or another care site and checked for proper placement and function. Members of the discharge planning team assist with the transfer from the acute care facility to the intermediate care facility or from the intermediate care facility to home or another alternative long-term care facility.

When a transfer to home is being coordinated, practitioners from the homecare company must be present. They can assist with the transfer to the ambulance and from the ambulance to the home. Homecare practitioners must be present when the patient arrives home to reassure the patient and family and alleviate any apprehensions.

Part of the assessment of the patient involves how the patient feels about his or her interaction with the ventilator once he or she arrives home. Simple but key questions to ask include the following[34]:

- Are you feeling anxious?
- Are you getting a deep enough breath?
- Does the breath last long enough?
- Is it too deep?
- Do you have enough time to get all your air out?
- Do you need more breaths? Do you need fewer breaths?

Initially patients may require frequent home visits or daily calls until they are stable and adjusted to a routine of care. Once this routine is established, only formal monthly visits are necessary to evaluate the patient and report on progress. Box 21.5 reviews follow-up and evaluation of infants and children. Evaluations during home visits may include patient assessment parameters such as bedside pulmonary function studies, vital signs, and pulse oximetry. Assessment in the home does not generally include ABG studies.

Assessment may include observation of the home environment and assessment of the equipment and any other problems the patient or family members may have. In some cases, other health care providers may need retraining. For example, a homecare nurse may be disposing of the TT after each weekly visit, not realizing this was not appropriate. Another example involves a family member calling the homecare respiratory therapist because of a frequent high-pressure alarm. In this latter example, the family needs retraining about how to identify when suctioning is needed.

A written report is completed after the monthly visit, and copies are sent to the patient's physician, homecare agency, and other members of the health care team. This report might include the following:

- Identification of company, servicing location, date, and time
- Patient name, address, phone, e-mail
- Patient diagnosis
- Physician and phone number
- Prescribed equipment and procedures
- Assessment (vital signs, breath sounds, sputum evaluation, O_2 saturation [S_pO_2], ventilator parameter and alarm settings, functioning of ancillary equipment)
- Caregiver and patient (if possible) comprehension of equipment and procedures
- Compliance with plan of care
- Recommendations of DME company representative

The task of caring for ventilator-dependent patients often creates frustration and anxiety for family members who are the primary caregivers. If problems are identified during home visits, the patient's physician should be notified. It may be necessary to provide psychological counseling to family members or suggest an alternative means of care (e.g., respite care) to allow family members time to rest.

Adequate Nutrition

Another aspect that must not be ignored is the nutritional status of the patient. Food intake is critical in avoiding problems associated with poor nutrition, such as increased risk for infection (e.g., pneumonia) and weakened muscles, including the diaphragm.[35] Caregivers should have a general idea of the patient's food and fluid intake and output. Constipation and bowel impaction need to be avoided. Some patients are at risk for aspiration when taking food by mouth, in which case a preferred feeding route might be through a **gastrostomy tube** or a **jejunostomy tube**.

Family Issues

Despite all efforts to discharge patients successfully to home, some factors may be difficult to manage. Significant delays in discharge

QUALITY CARE HEALTH AGENCY
CAREGIVER CHECK-OFF SHEET

I, (caregiver name) _____ , have received adequate instruction and demonstration from a homecare instructor and have successfully returned the demonstration of the following procedures:

RESPIRATORY CARE SKILL	Inst Date	Demo. (initial)	Return Demo.	Not Applic.
Airway Suctioning Procedure				
- Manually hyperinflate/hyperoxygenate with resuscitation bag prior to suctioning.				
- Airway suctioning (ET or TT), selecting suction pressure, duration, etc.				
- Aseptic technique and assessment of patient during procedure.				
- Postsuctioning manual hyperinflation/hyperoxygenation				
- Follow-up assessment of patient				
- Equipment cleaning and maintenance				
Ventilator Management				
- Prescribed settings and confirmation of settings				
- Alarm settings, conditions, and responses				
- Circuit changes and equipment cleaning				
- Safety precautions				
- Emergency response (e.g., electrical power loss, emergency weather conditions [hurricane evacuation, etc.])				
- Troubleshooting situations (e.g., frequent high-pressure alarms, ventilator failure [manual ventilation], airway occluded, etc.)				
- Patient assessment: for respiratory infections, for pneumothorax, for early signs of respiratory distress, etc.				
Additional Management Procedures				
- Aerosolized medication administration				
- Chest physiotherapy				
- Patient ambulation				
- Others				

Caregiver signature: _____

I feel comfortable that the above named caregiver can provide the skills listed for (patient name _____).

Homecare Instructor: (name/signature) _____

Date: _____

Fig. 21.1 An assessment sheet used for evaluating caregiver skill performance.

BOX 21.5 Follow-up and Evaluation for Infants and Children Ventilated in the Home

Ventilator requirements of infants and children change because of their growth and development. Periodic (once every 2–3 months) in-hospital evaluations may be necessary for the first 2 years of life and twice yearly thereafter until age 4 or 5 years.

from the hospital may occur if organizing the discharge plan or providing adequate funding is not possible.[4,33] Often one or more family members will lose employment time when a patient is discharged to home. This can worsen the family's financial position. Planned funding may have been based on the family's budget before discharge.

In addition, the respite for family caregivers may not be adequate. Getting extended family members and friends to help will not be successful unless these individuals are adequately trained in the care of the VAI. When caregivers from outside the family are in the home 24 hours a day, this erodes family privacy and can be stressful.[36] When external caregivers take vacation or sick days, the family caregivers often have to step in to provide additional coverage.

Careful, well-planned, timely preparation is absolutely essential to success in discharging a VAI from an acute care facility to home or a skilled nursing facility. Patient and home assessment, caregiver education and training, and demonstration of care by caregivers are all important elements. Box 21.6 lists the primary components of a discharge plan for sending the patient home on long-term ventilation.[33]

BOX 21.6 Primary Components of a Discharge Plan for Sending the Patient Home on Long-Term Ventilation

Preparation of the Patient for Discharge

- Stabilization of the patient's medical condition
- Evaluation and development of realistic goals
- Rehabilitation planning to set the stage for training
- Physical rehabilitation training plan to increase the patient's strength and endurance

Discharge Plan Implementation

- Appointment of a discharge planning team and a team leader
- Assignment of team member responsibilities
- Communication among team members
- Education of the caregivers and the patient
- Review of the patient's chart and ventilator orders
- Geographical survey of patient's home location
- Assessment of the home environment
- Review of the electrical system in the home
- Provision of a written education program and instructions
- Demonstration by caregiver(s)
- Primary physician and nursing service arrangements
- Planning for emergencies

EQUIPMENT SELECTION FOR HOME VENTILATION

When patients are transferred to their home, equipment setup, instructions, and planning are especially important. Families must have immediate access to all required equipment and supplies. Box 21.7 provides a preliminary checklist of equipment for care of the mechanically ventilated patient in the home.[10,21]

It should be apparent that the most important equipment to be selected is the ventilator. Selection depends on the goals for the particular patient. Ventilation can be provided by IPPV to patients with a TT. IPPV is indicated for patients who have persistent symptomatic hypoventilation. It is also indicated for patients who do not meet selection criteria for NIV or who are unable to tolerate NIV or negative pressure ventilation (NPV).

This section reviews ventilator selection for IPPV and NPV and the use of noninvasive devices, such as the rocking bed and the pneumobelt, continuous positive airway pressure (CPAP) devices, and noninvasive devices for secretion clearance. The use of NIV is discussed in Chapter 19.

Tracheostomy Tubes

The use of TTs is essential for invasive LTMV. Generally, a tracheotomy is performed as soon as possible after the need for extended intubation is verified and it appears the patient is likely to benefit from the procedure. This usually occurs when a patient is stabilized on the ventilator in an acute care hospital within about 7 days of the onset of respiratory failure or sooner in patients who are neurologically impaired.[37-39] Chapter 20 reviews the role of tracheostomy in ventilator discontinuation. The use of speaking tubes and devices for patients with long-term tracheostomies is explained later in this chapter.

Ventilator Selection

Many types and models of ventilators are available for home use. Some of these are quite sophisticated, offering an array of modes, alarm systems, and other complex ventilatory characteristics. Although these machines may occasionally be necessary for medical stability outside the hospital, simple technology should be the goal of ventilator selection when it is possible.[34,40]

The most important factors in choosing a ventilator are the following:

- *Reliability.* The ventilator must be mechanically dependable and trouble free for extended periods without breaking down or requiring costly maintenance.
- *Safety.* The ventilator must be safe to operate in O_2-enriched environments and have an adequate alarm system to warn of low ventilating pressure, high ventilating pressure, patient disconnection, and mechanical failure.
- *Versatility.* The ventilator should be portable or able to be adjusted for travel outside the home, necessitating the use of reliable internal and external battery sources and alarms.
- *User-friendly.* Ventilator controls should be easy to understand and manipulate. The circuit should be simple and easy to change.
- *Easy patient cycling.* The ventilator should be easy to cycle in the volume-controlled continuous mandatory ventilation (VC-CMV) mode for patients able to make spontaneous efforts.

For all home ventilator patients, backup ventilatory support must be available in case of electrical failure or malfunction.

BOX 21.7 Respiratory Care Plan Equipment Checklist for Ventilator-Dependent Patients at the Home Site

Mechanical Ventilator and Related Equipment

- Primary ventilator with operating instructions
- Prescription for ventilator parameter and alarm settings, specific time on and off ventilator, critical values
- Circuits (disposable or nondisposable with instructions for cleaning and assembly)
- Connectors, PEEP valves (as needed with instructions)
- Humidifier, heater, bracket, and heat-moisture exchanger (and instructions for use and cleaning)
- Temperature probes (if heater is used)
- Power supply, including external 12-volt battery and connecting cable
- Backup ventilator (for patients who cannot be without ventilator support)
- Manual resuscitation bag
- Tracheostomy attachments
- Replacement ventilator circuit filters
- Patient monitor and alarms (if not incorporated in ventilator), including instructions
- Communication aids (e.g., call button, bell, intercom, infant audiovisual monitor)
- Test lung for ventilator
- Noninvasive patient interfaces with head gear and chin-strap (as indicated)

Airway Management Equipment

- Suction machine (portable, with instructions)
- Suction container
- Appropriately sized catheters
- Connecting tube(s)
- Latex gloves
- Instructions for tracheostomy tubes (TT), including name, type, and size of artificial airway with instructions for care
- Replacement TTs (appropriately sized with one size smaller and instructions)
- Disposable inner TT cannulas (as indicated)
- Tracheostomy care kits (with instructions)
- Speaking valve for tracheostomy (as indicated with instructions)
- Appropriate cleaning solution, sterile saline, or water solution
- Water-soluble lubricant
- Syringes
- Antibiotic ointment
- Oxygen administration equipment
  - O_2 concentrator
  - E-cylinder backup
  - O_2 tubing
  - Tracheostomy collar or T-tube adaptor
  - Large-bore tubing
  - Nasal cannula

Disinfectant Solution

- Vinegar/water 1:3
- Quaternary ammonium compound

Miscellaneous

- Compressor for aerosolized medications
- Spacers for metered-dose inhaler medications
- Wheelchair
- Hospital bed
- Bedside commode

A self-inflating manual resuscitator should be readily available, and caregivers should be instructed on proper use of these devices. If a patient can maintain spontaneous ventilation for 4 or more consecutive hours, a manual resuscitator may be all that is necessary as a backup.[32,41] For patients who are totally dependent on ventilatory support or those who live far from medical support, a second mechanical ventilator is necessary as a backup. Those patients who require supplemental O_2 should also have a concentrator and an E-cylinder as a backup.

Examples of Homecare and Transport Ventilators

A positive pressure ventilator is the most commonly used device for providing ventilatory support for homecare patients. Unlike the large and sophisticated positive pressure ventilators used in the ICU, homecare ventilators have an array of advantages; notably, they are compact, lightweight, and portable. Most of these homecare units are designed to use three different power sources: normal AC current, internal DC battery, and external DC battery. Ventilators that use an external DC battery can be mounted relatively easily on a wheelchair or placed in a motor vehicle, enhancing a patient's capability of mobility and participation in other activities.

Many homecare positive pressure ventilators have been developed in the past three decades. The following sections do not completely describe all of the available features of each ventilator, but a brief review is provided. Additional information about these units and other homecare ventilators is described elsewhere.[41,42]

First-generation portable volume ventilators. Most of the first-generation portable ventilators are no longer manufactured; however, many are still used in this country and around the world. This is because of their simplicity and reliability. First-generation ventilators are lightweight (average, 30 lb) and can serve as both transport ventilators and ventilators for long-term care sites. In general, they are easy-to-use, piston-driven ventilators that can provide VC-CMV and VC-IMV modes. They also have high- and low-pressure, ventilator-malfunction, and power-loss alarms. Some offer additional alarms such as "setting error" (e.g., Aequitron LP6 Plus and LP10 [Covidien-Nellcor Puritan Bennett, Boulder, CO] and Lifecare PLV-100 and PLV-102 [Philips Respironics, Eindhoven, The Netherlands]).

These units generally operate from a standard 115- to 120-volt AC electrical outlet. Although they possess an internal battery, these batteries have limited capabilities (15–60 minutes). The battery capacity varies depending on the ventilator settings and by the type of ventilator being used.[43] Most portable ventilators can be connected to a 12-volt DC, deep-cycle marine-type battery as an external power source. These batteries are heavy (30–40 lb) but can provide extended power for several hours depending on the

workload (respiratory rate *[f]* and tidal volume [V_T]) set on the ventilator.

To provide an intermittent mandatory ventilation (IMV) system for home use, practitioners used to add an external H-valve assembly to home ventilators. However, the additional equipment increased the cost and complexity of home ventilatory support. Consequently, manufacturers designed subsequent models to provide the IMV/synchronized IMV (SIMV) mode without the need for added circuitry. Example ventilators include the LP10 and LP20 ventilators. Although these ventilators simplify the IMV circuitry, demand or continuous-gas flow systems are not incorporated into their design. During spontaneous breathing, the patient must draw gas from an air intake valve in the piston chamber or through the exhalation valve of the ventilator circuit. As a result, the inspiratory work of breathing (WOB) can be significant.[10,44] Therefore IMV/SIMV is not recommended for long-term ventilation with these ventilators (Key Point 21.3).[10,43-45]

***Key Point* 21.3** "The SIMV mode found on *(older generation)* home care ventilators is not recommended without modification of the gas delivery system with a one-way valve in the inspiratory limb to allow inspiration from the atmosphere. A continuous high gas flow system may also be used but is not preferred in the long-term home setting."[10]

When the patient requires an F_IO_2 greater than 0.21, O_2 must be bled into the system. This can be done after the outflow valve from the ventilator by using a separate O_2 source (concentrator or cylinder O_2). It is important to recognize that adding flow to the inspiratory limb of the ventilator may make it more difficult for the ventilator to sense a patient's inspiratory effort. Ventilators with a sensitivity setting (patient triggering) may need the sensitivity reset. Another option is to use a reservoir bag or mixing chamber primed with O_2 that can be added to the ventilator's air intake. Sometimes this procedure can increase the F_IO_2 to more than 0.4, depending on the ventilator in use.

Some units have a system to provide up to 100% O_2-enriched gas to the patient. A reservoir or optional elbow attachment is connected to the machine's patient outlet to allow a flow of O_2 to be introduced into the patient circuit. These systems deliver up to 100% O_2-enriched gas, depending on the flow of the gas and changes in a patient's minute ventilation ($\dot{V}_E$). In general, a patient's F_IO_2 requirements should be less than 0.40. The need for an F_IO_2 greater than 0.40 indicates clinical instability that requires more respiratory care than is available at home.

On most portable ventilators, PEEP can be obtained by attaching an external threshold resistor to the patient circuit exhalation valve. These PEEP valves add to circuit complexity and may become dislodged from the exhalation valve or cause V_T loss.[33,46] They may also increase a patient's WOB, especially if the machine sensitivity is not properly adjusted.[33] PEEP should not be used for patients ventilated at home unless absolutely necessary. Its use also often indicates clinical instability, especially when adequate oxygenation must be maintained.[33]

First-generation ventilators have provided dependable service in a variety of environments for many years. Although these devices are considered reliable devices by some patients, a second generation of ventilators is available with a variety of improvements in IMV delivery, patient triggering, PEEP, and F_IO_2 administration.

BOX 21.8 Transport and Homecare Ventilators

First-Generation Portable Volume Ventilators
- LP-6 Plus, LP-10, LP-20 (Puritan Bennett Covidien Ltd) Lifecare PLV 100, and PLV 102 (Philips Respironics)
- TBird Legacy (CareFusion Corp.)

Current-Generation Portable Ventilators
- LTV 1200, LTV2 ventilators (Vyaire Medical, Mettawa, IL)
- Newport HT70 Plus (Medtronic Minimally Invasive Therapies, Minneapolis, MN)
- Philips Trilogy Evo (Philips North America Corporation, Andover, MA)
- Vyaire ReVel Ventilator (Vyaire Medical, Mettawa, IL)

Current-generation portable ventilators. Current portable positive pressure ventilators are primarily microprocessor controlled. These second-generation portable ventilators may be patient or time triggered; pressure or volume targeted; and pressure, volume, flow, or time cycled. Examples of current-generation units are listed in Box 21.8.

Current-generation homecare ventilators are much more advanced in their design and provide a greater number of advanced features (e.g., LTV 1200 ventilators [Vyaire Medical, Mettawa, IL]). The LTV series ventilators are electrically powered units that use an internal rotary compressor to generate gas flow. The LTV 1200 model ventilator is small enough to be portable (see Fig. 19.3). The LTV 1200 model offers enough features and alarms to allow it to be used in the acute care setting. LTV ventilators provide ventilation in the following modes: CMV, IMV, CPAP, apnea backup ventilation, and NIV. The IMV provided is more advanced than with first-generation ventilators, and the WOB associated with it is not as high. Other second-generation ventilators, such as the Newport HT70 Plus (Medtronic Minimally Invasive Therapies, Minneapolis, MN), can provide a variety of features (Fig. 21.2). Some features include A/CMV, IMV, spontaneous, NIV, pressure support, pressure control, and volume control ventilation. The Newport HT70 is lightweight and small and can be operated from a variety of AC or DC external power sources or from an internal dual battery system. It can be used for infant, pediatric, and adult populations.

Extensive alarm systems are incorporated into newer homecare ventilators. Some alarms are automatic, whereas other alarms are adjustable and require the operator to enter a desired alarm setting. Alarms can alert the operator in cases of low battery power, power loss, low pressure, high pressure, power switchover, apnea, O_2 fail, and microprocessor malfunction.[41,45]

Current-generation ventilators provide a variety of features that can be used for portable and home use. Respiratory therapists must familiarize themselves with all units used by their organization because functions and features can vary considerably from one unit to another.

It is important to recognize that versatility is important when selecting a long-term ventilator. However, quality, reliability, and safety are the most important factors that must be considered when selecting an appropriate homecare and transport ventilator.

Fig. 21.2 The Newport HT70 ventilator. (Courtesy Medtronics Minimally Invasive Therapies, Minneapolis, MN.)

COMPLICATIONS OF LONG-TERM POSITIVE PRESSURE VENTILATION

In addition to the potential failure or malfunction of the ventilator or artificial airway, complications of long-term positive pressure ventilation may also include the following:

- Pulmonary complications
- Complications to the cardiovascular system, the airway, and the gastrointestinal (GI) tract and neurological complications
- Problems associated with immobility
- Psychological dysfunction

The pulmonary, cardiovascular, and GI problems in long-term VAIs are similar, in many respects, to those seen in critically ill patients on ventilation (see Chapters 16 and 17 for additional information on complications of mechanical ventilation.) Fig. 21.3 compares airway problems in the acute care setting (acute complications) with the long-term care facility (chronic complications). Complications to the airway in VAIs are listed in Box 21.9.[3] Unlike nosocomial infections in the ICU setting, ventilator-associated pneumonia (VAP) in VAIs is often caused by enteric gram-negative bacteria such as *Enterobacter* spp., *Escherichia coli, Klebsiella* spp., and *Pseudomonas aeruginosa*.[3] These organisms are often resistant to a variety of antibiotics. In patients receiving home mechanical ventilation by NIV, *Staphylococcus aureus* has been cited as a common contaminant of the ventilator circuit and nasal mask. Colonization of this organism has also been found in patients' nostrils.[47]

GI disorders may occur in VAI from chronic illness, resulting in system breakdown. GI problems in VAIs may include the following:

- Damage to the GI mucosa from stress
- Swallowing dysfunction and aspiration
- Hypomotility of the GI tract causing constipation and **ileus**

In addition, placement of nasogastric tubes or the occurrence of reflux can cause **erosive esophagitis**, which may occur in up to 50% of VAIs.[48]

Approximately 45% of patients who transfer to long-term care facilities on mechanical ventilation have some type of neurological disorder, which is generally the primary cause of their ventilator

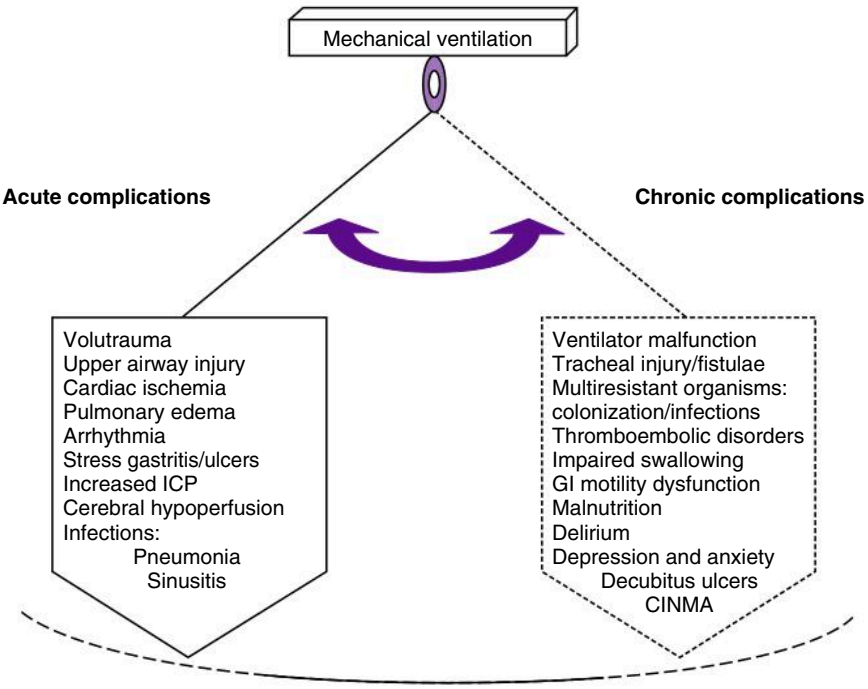

Fig. 21.3 Acute and chronic complications of mechanical ventilation. *CINMA,* Critical illness neuromuscular abnormality; *GI,* gastrointestinal; *ICP,* intracranial pressure. (From Chatila WM, Criner GJ: Complications of long-term mechanical ventilation, *Respir Care Clin N Am* 8:631, 2002.)

BOX 21.9 Complications to the Airway in Long-Term Ventilation

Nasopharyngeal Injury
- Sinusitis
- Otitis
- Injury to the nasal septum
- Ulceration to the nose, mouth, lips, and pharynx

Laryngeal Injury
- Damage to the laryngeal cartilages (e.g., arytenoid cartilage, cricoid cartilage)
- Glottic and subglottic stenosis
- Vocal cord injury or paralysis

Tracheal Injury
- Infection or bleeding of the stoma
- Granuloma formation
- Tracheal stenosis, malacia, or dilation
- Tracheoinnominate or tracheoesophageal fistula formation

From Chatila WM, Criner GJ: Complications of long-term mechanical ventilation, *Respir Care Clin N Am* 8:631, 2002.

dependence.[48] Neurological or neuromuscular dysfunctions can be caused by patients' chronic morbidities or follow an acute severe illness. Determining the major contributing neuropsychological problem is not always possible.[48]

To avoid some of the complications of long-term ventilation, early mobilization, as part of the rehabilitation process, can help reduce muscle and skeletal wasting and reduce the risk for decubitus ulcers.

Psychological problems in VAIs can be attributed to a host of causes, including the following[48]:
- Severity of illness
- Longevity of illness
- Multiple medications (sedatives, analgesics, psychotropics, steroids [see Chapter 15])
- Sleep disruption
- Delirium
- Anxiety
- Depression

As previously noted, critically ill patients who cannot be easily weaned from ventilatory support after recovery of the acute illness are more susceptible to complications of mechanical ventilation.[48] Efforts must be aimed at preventing these complications to have a better chance of discontinuing ventilation and improving the patient's quality of life.

ALTERNATIVES TO INVASIVE MECHANICAL VENTILATION AT HOME

In addition to NIV by nasal mask and invasive mechanical ventilation via a TT, alternative methods of ventilation for VAIs include NPV, noninvasive breathing support devices, nasal CPAP for treating obstructive sleep apnea (OSA), and glossopharyngeal breathing.

Noninvasive Positive Pressure Ventilation

For years NPV and IPPV were the only mechanical ventilation systems available for people with moderate to severe chronic respiratory failure. Since the early 1980s, a number of alternative methods of mechanical ventilation for use in the home and acute care facility have been introduced. The effectiveness of NIV delivered through a nasal mask, nasal pillows, a mouthpiece or mouth seal, or CPAP through a nasal mask have been examined in several studies of patients with neuromuscular disorders, chest wall defects, obstructive and restrictive intrinsic lung diseases, and OSA.[49-58] These studies found that NIV or CPAP can prevent episodes of severe hypoxemia and hypercapnia in selected groups of patients. In addition, daytime P_aO_2 and P_aCO_2 improved in the studies' subjects. Improvement in respiratory muscle strength and stabilization of lung volumes was also reported.[59] Patients reported subjective improvement in symptoms such as headaches and daytime somnolence and an increase in their ability to perform activities of daily living. Abundant evidence now supports the effectiveness of NIV and CPAP assistance in the homecare setting.

Chapter 19 provides an extensive discussion of NIV as an alternative method for support of ventilation in both the acute care and long-term care of patients.

Negative Pressure Ventilation

Negative pressure ventilation (NPV) is durable, easy to use, and dependable. It is used less often than invasive mechanical ventilation or NIV but is occasionally used for long-term ventilation. NPV can provide support to a patient without requiring an artificial airway; thus patients can speak, eat, and drink while avoiding the complications associated with artificial airways.

Use of NPV is preferable for patients with disorders such as neuromuscular disease, spinal cord injuries, chest wall disorders, or central hypoventilation syndromes.[60-64] Nighttime use in patients with COPD is another example of their application, although some of these patients find NPV difficult to tolerate.[60,61] Note that for the treatment of *acute* respiratory failure in patients with COPD, NIV is the mode of choice.[65]

If excessive airway secretions, decreased pulmonary compliance, or increased airway resistance are present, or if the patient is at risk for aspiration, NPV is not recommended (see Chapter 1 for additional details about the physiology of NPV). NPV is available in three basic designs: iron lung (tank ventilator), cuirass, and body suit or jacket ventilator.[66,67]

Tank Ventilators/Iron Lungs

Iron lung ventilators enclose the patient's whole body (except for the head) and seal around the neck. They are sometimes referred to as *body tanks*. The Emerson Respirator (or "iron lung") and the Philips Respironics Lifecare NEV-100 are two examples.

Tank ventilators work by transmitting negative pressure across the chest wall, into the pleural space, and finally to the alveolar level. The resulting increase in transpulmonary pressure causes air to enter the lungs. Exhalation is passive and depends on the elastic recoil of the lung and chest wall.[66,67]

Tank ventilators have several disadvantages: they are large (3 m long and 136 kg) and cumbersome and make bronchial drainage, intravenous therapy, and physical contact with the patient difficult. In some patients, negative pressure applied to the abdominal area and thorax results in a pooling of blood in the abdominal vasculature, which leads to a decrease in venous return to the heart and, subsequently, a reduction in cardiac output. If a patient is