Chapter 6

Obstructive Lung Diseases

Mechanical ventilation is often used in the setting of acute exacerbations of obstructive lung diseases like asthma and chronic obstructive pulmonary disease (COPD). These disorders are characterized by increased airway resistance secondary to bronchospasm and airway inflammation, collapse, and remodeling, often leading to inefficient exhalation and expiratory flow limitation. Patients with obstructive lung disease and inefficient exhalation require a longer expiratory time to achieve full exhalation.

Breath Stacking and Auto-PEEP

Mechanical ventilation in patients with inefficient exhalation can be challenging as patients may not achieve full exhalation prior to the triggering of another breath, a phenomenon known as **breath stacking**. In the setting of breath stacking, because full exhalation has not occurred, additional air remains within the alveoli at the end of expiration, a phenomenon known as **gas trapping**. Increased air within the alveoli at the end of expiration increases end-expiratory pressure, a phenomenon known as **auto-PEEP** (Fig. 6.1).

H. Poor, *Basics of Mechanical Ventilation*,
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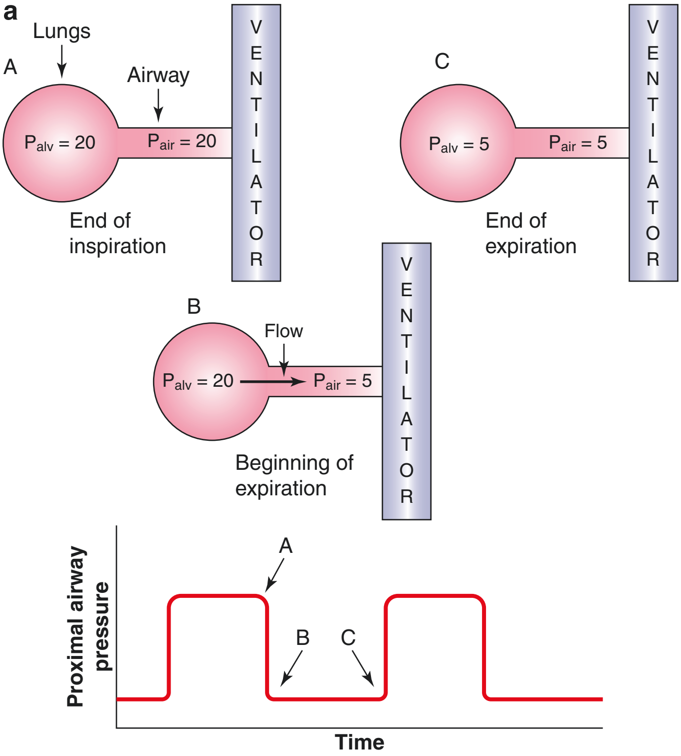
Key Concept #1

- **Breath stacking:** triggering another breath before complete exhalation
- **Gas trapping:** retention of extra air in alveoli at end of expiration because of incomplete exhalation
- **Auto-PEEP:** increase in alveolar end-expiratory pressure due to gas trapping

FIGURE 6.1 Effect of significantly increased airway resistance on exhalation. (**a**) Example of expiration in the setting of normal airway resistance. At the end of inspiration, alveolar pressure is 20 cm H_2O. At the beginning of expiration, proximal airway pressure is reduced to 5 cm H_2O (PEEP set on the ventilator). Because a pressure gradient exists between the alveolus and the proximal airway, air flows from the alveolus to the ventilator. In the setting of normal airway resistance, expiratory flow is fast enough for the alveolus to empty out a sufficient amount of air to reduce alveolar pressure to the level of proximal airway pressure. Note that if further time were allotted for expiration, no additional air would exit the alveolus, as no pressure gradient exists at the end of expiration between alveolar pressure and proximal airway pressure. (**b**) Example of expiration in the setting of significantly increased airway resistance. At the end of inspiration, alveolar pressure is 40 cm H_2O. At the beginning of expiration, proximal airway pressure is reduced to 5 cm H_2O (PEEP set on the ventilator). Because a pressure gradient exists between the alveolus and the proximal airway, air flows from the alveolus to the ventilator. In the setting of increased airway resistance, expiratory flow is slow—the alveolus is not able to empty out enough air to reduce alveolar pressure to the level of proximal airway pressure within the time allowed for expiration. The resultant increased alveolar pressure at the end of expiration is known as "auto-PEEP." Note that if further time were allotted for expiration, additional air would leave the alveolus because alveolar pressure at the end of expiration is still higher than proximal airway pressure.

P_{air} proximal airway pressure; P_{alv} alveolar pressure; *PEEP* positive end-expiratory pressure

Breath stacking and gas trapping increase end-expiratory alveolar pressure and volume; therefore, inspiration begins at already higher than normal lung volume and pressure. The administration of a set tidal volume (as occurs with volume-controlled ventilation) to lungs that have elevated end-expiratory volume and pressure results in elevated end-inspiratory lung volume and pressure. If breath stacking and gas trapping are severe enough, barotrauma may result from the increased pressure in the airways and the alveoli. Additionally, the increased intrathoracic pressure may compress cardiac structures, decreasing venous return to the heart and ultimately leading to hemodynamic compromise and even obstructive shock.



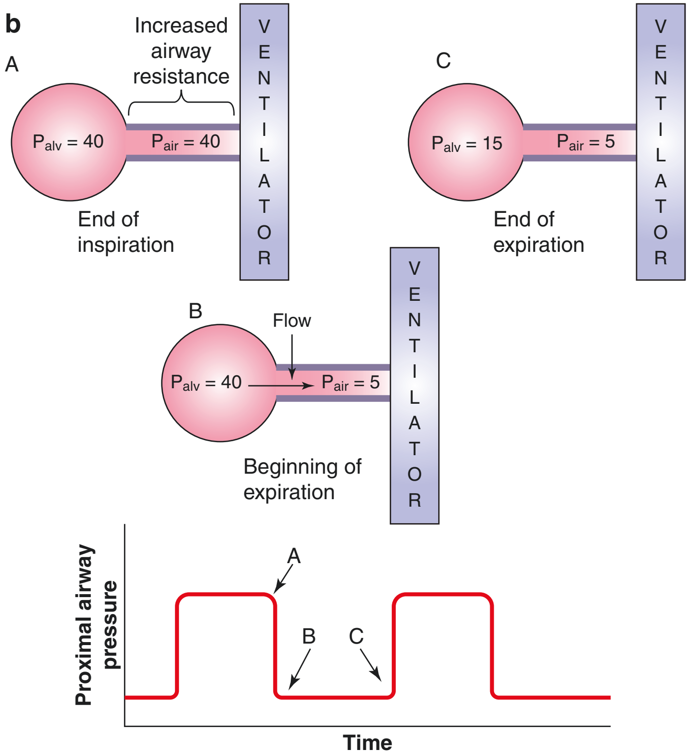


FIGURE 6.1 (continued)

As discussed in Chap. 4, elevated plateau pressure can suggest the presence of elevated end-inspiratory lung volume and hyperinflation in the setting of obstructive lung disease. In pressure-targeted modes (pressure-controlled ventilation and pressure support ventilation), where flow is administered to quickly achieve and maintain a set inspiratory pressure, the presence of elevated end-expiratory volume and pressure results in decreased tidal volume—less flow and volume will be needed to achieve the set inspiratory pressure, which can ultimately result in hypoventilation.

Key Concept #2
Elevated plateau pressure can signify hyperinflation in the setting of obstructive lung disease

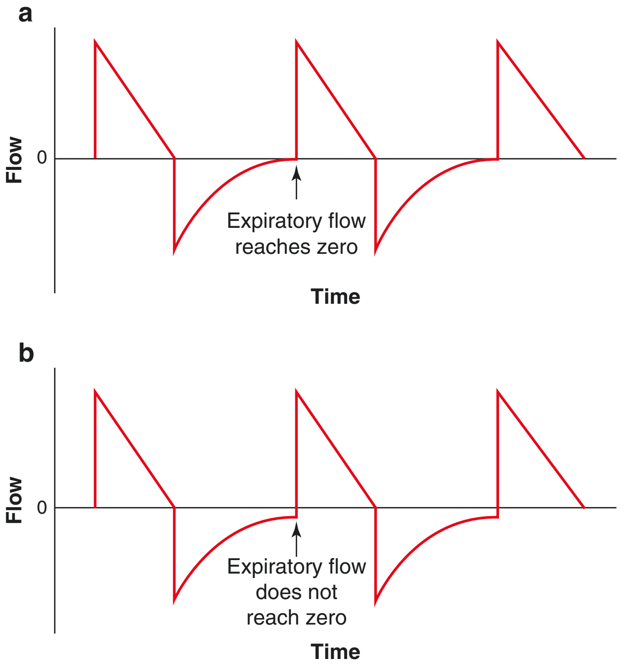


Fig. 6.2 Flow waveform patterns. (**a**) Normal expiratory flow pattern. Note that expiratory flow reaches zero prior to the initiation of the subsequent breath. (**b**) Expiratory flow pattern demonstrating breath stacking. Note that expiratory flow does not reach zero prior to the initiation of the subsequent breath. The presence of expiratory flow at the end of expiration implies that alveolar pressure is higher than proximal airway pressure at that time point.

Evaluation of the expiratory flow curve on the ventilator can aid in the identification of breath stacking (Fig. 6.2). Under normal conditions, the expiratory portion of the flow curve should return to zero before the end of expiration, indicating that expiratory flow has ceased. If a breath is triggered and administered before expiratory flow has reached zero, breath stacking is present.

Breath stacking can also be identified by listening to lung sounds. In order for wheezing to occur, flow must be present. Expiratory wheezing up until the very last moment prior to the subsequent breath being triggered indicates that expiratory flow has not reached zero at end-expiration and that breath stacking is present.

Key Concept #3

Identifying breath stacking:

- Expiratory flow does not reach zero at end of expiration
- Wheezing persists right up to initiation of subsequent breath

The magnitude of auto-PEEP can also be assessed by employing an **expiratory pause maneuver** on the ventilator (Fig. 6.3). With this maneuver, the expiratory valve is closed at the end of expiration, not allowing any additional air to leave the respiratory system. If, at the end of expiration, alveolar pressure is still higher than proximal airway pressure (PEEP applied at the ventilator), air will continue to flow from the alveoli to the ventilator, raising proximal airway pressure. The amount that proximal airway pressure rises above PEEP applied at the ventilator is referred to as auto-PEEP or **intrinsic PEEP**. Of note, PEEP applied at the ventilator is often referred to as **applied PEEP** or **extrinsic PEEP**. Total PEEP is equal to the sum of intrinsic PEEP and extrinsic PEEP. It is important that the expiratory pause maneuver be performed on a patient who is not making respiratory efforts—patient inspiratory and expiratory efforts will change the measured pressure and will not properly reflect the presence or degree of auto-PEEP.

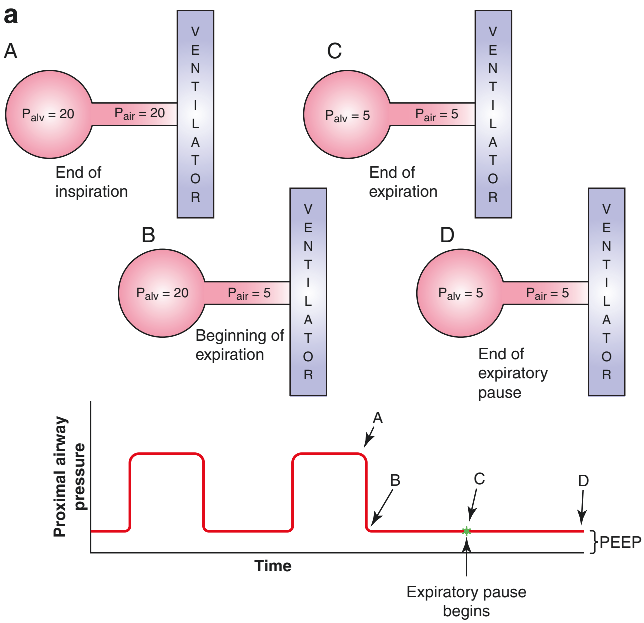


FIGURE 6.3 Expiratory pause maneuver demonstrating auto-PEEP. (**a**) Example of expiratory pause maneuver in the setting of normal airway resistance. At the end of expiration, the expiratory valve closes, not allowing any air to leave the respiratory system. Because alveolar pressure equals proximal airway pressure at the end of expiration, there is no additional flow from the alveolus to the ventilator; therefore, proximal airway pressure remains unchanged at the end of the expiratory pause maneuver, and there is no intrinsic PEEP. Total PEEP is thus equal to extrinsic PEEP. (**b**) Example of expiratory pause maneuver in the setting of significantly increased airway resistance. At the end of expiration, the expiratory valve closes, not allowing any air to leave the respiratory system. Because alveolar pressure is still higher than proximal airway pressure at the end of expiration, there is additional flow from the alveolus to the ventilator, which continues to increase proximal airway pressure. The additional increase in proximal airway pressure at the end of expiration is known as "intrinsic PEEP" or "auto-PEEP." In this case, intrinsic PEEP is 7 cm H_2O, extrinsic PEEP is 5 cm H_2O, and total PEEP is 12 cm H_2O. P_{air} proximal airway pressure; P_{alv} alveolar pressure; *PEEP* positive end-expiratory pressure; $PEEP_e$ extrinsic positive end-expiratory pressure; $PEEP_i$ intrinsic positive end-expiratory pressure

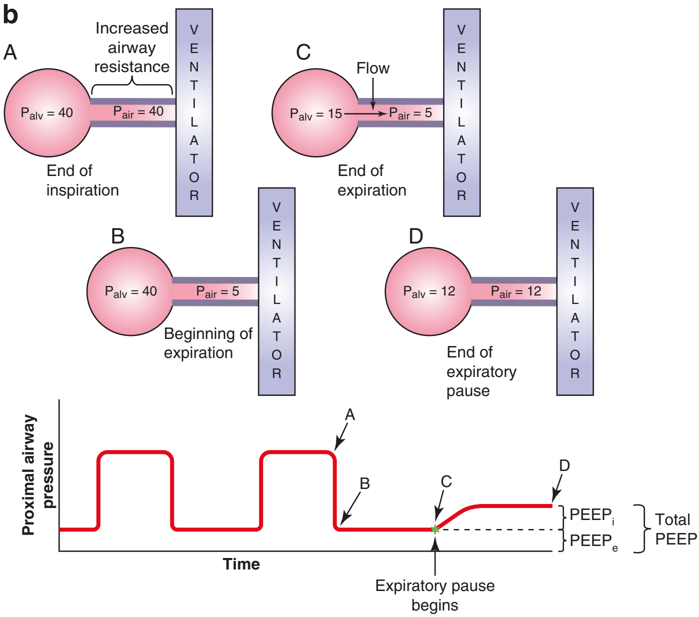


FIGURE 6.3 (continued)

Key Concept #4
Magnitude of auto-PEEP can be assessed with the **expiratory pause maneuver**

Ventilator Management Strategies

The central principle in managing patients on the ventilator with obstructive lung disease and expiratory flow limitation is to increase the time allowed for exhalation and to decrease tidal volume so that less air needs to be exhaled. By increasing the expiratory time, there is a greater chance that expiratory flow will reach zero prior to the subsequent breath,

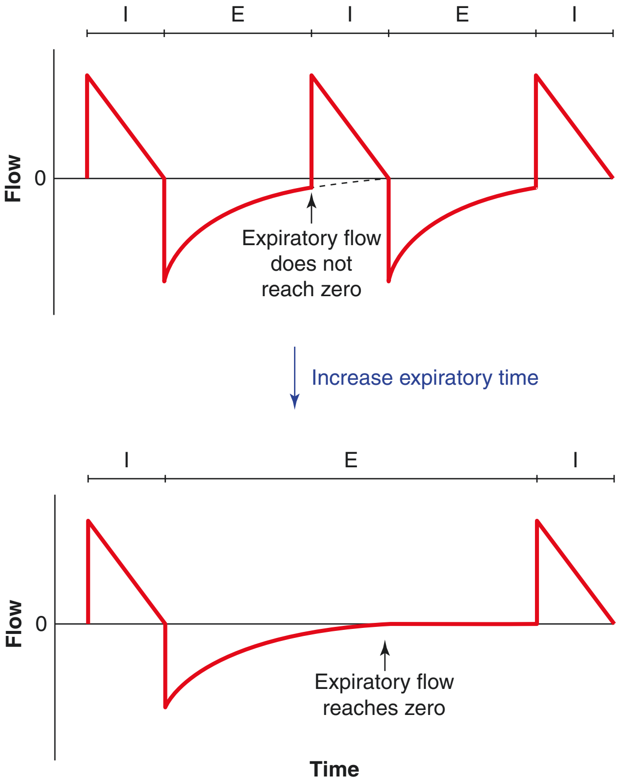


FIGURE 6.4 Flow waveforms demonstrating that gas trapping can be diminished by increasing time for expiration. Note that expiratory flow does not reach zero prior to the subsequent breath in the top diagram but in the lower diagram, with increased time for expiration, expiratory flow does reach zero.

decreasing the degree of gas trapping, auto-PEEP, and hyperinflation (Fig. 6.4).

From the perspective of the ventilator, expiration is defined as the time during the respiratory cycle that is not inspiration. Specifically, it is the time between when one breath cycles off and the next breath is triggered. The relative time a patient spends in inspiration versus expiration is known as the **inspiration:expiration ratio (I:E ratio)**. Patients with obstructive lung disease and expiratory flow limitation undergoing mechanical ventilation benefit from low I:E ratios in order to maximize expiratory time. A patient can be in only one of two phases of the respiratory cycle: inspiratory or expiratory. By decreasing the overall time spent in inspiration, expiratory time increases and the I:E ratio decreases. Time spent in inspiration can be decreased by either decreasing the inspiratory time per breath (i.e., reducing the time it takes to deliver each breath) or by reducing the number of inspirations per unit time (i.e., reducing the respiratory rate) (Fig. 6.5).

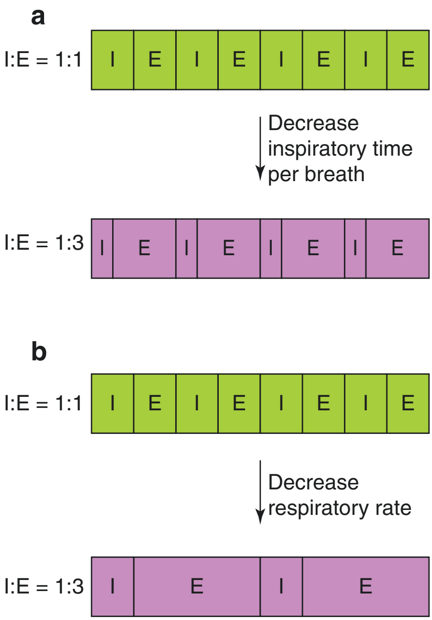


FIGURE 6.5 Different ways to decrease the I:E ratio and increase expiratory time. (**a**) Total inspiratory time and I:E ratio decreased by reducing inspiratory time per breath. (**b**) Total inspiratory time and I:E ratio decreased by reducing respiratory rate. E expiration; I inspiration

While low respiratory rate and tidal volume are optimal for managing patients with expiratory flow limitation, utilizing this strategy will often result in hypoventilation and hypercapnia. This permissive hypercapnia is allowed because of the benefits of preventing breath stacking, auto-PEEP, and hyperinflation. Permissive hypercapnia is also utilized in the management of ARDS with low tidal volume ventilation (Chap. 5).

Assist-Control

For modes of ventilation that use an assist-control trigger (volume-controlled ventilation or pressure-controlled ventilation), decreasing the set respiratory rate will reduce total inspiratory time and therefore increase expiratory time. For example, if a patient's respiratory rate is 20 breaths per minute with an inspiratory time of 1 second per breath, the patient is spending a total of 20 seconds per minute in the inspiratory phase. Therefore, the patient is spending 40 seconds per minute in the expiratory phase, which equates to 2 seconds per expiratory cycle. Decreasing the respiratory rate to 10 breaths per minute would result in the patient spending a total of 10 seconds per minute in the inspiratory phase and thus a total of 50 seconds per minute in the expiratory phase, which equates to 5 seconds per expiratory cycle. The respiratory rate can be reduced using the ventilator only if the breaths are ventilator-triggered breaths. Reducing the respiratory rate for a patient who has exclusively patient-triggered breaths will not affect the respiratory rate. In these scenarios, sedation, and even paralysis, may be necessary to reduce the respiratory rate.

Volume-Controlled Ventilation

As previously discussed, in volume-controlled ventilation, the target is flow, and the cycle is volume. Increasing flow reduces the time required to deliver the set tidal volume, which reduces inspiratory time for each breath. Decreasing inspiratory time for each breath will then increase expiratory time. Note that, based on the equation from Chap. 4, increasing flow will also increase proximal airway pressure:

$$P_{\text{air}} = Q \times R + \frac{V}{C}$$

C = compliance
Q = flow
P_{air} = proximal airway pressure
R = airway resistance
V = volume

However, most of this pressure is dissipated in the endotracheal tube and central airways, which can withstand this increased pressure. Alveolar pressure will not be affected if tidal volume remains the same.

Decreasing tidal volume will also increase expiratory time. By decreasing volume, less time is needed for inspiration at a given flow, resulting in an increase in expiratory time. Additionally, with decreased tidal volume, less time is needed to fully expire the total administered tidal volume.

Key Concept #5
Ventilator strategies to increase expiratory time in VCV:

- Decrease respiratory rate
- Decrease tidal volume
- Increase flow rate

Pressure-Controlled Ventilation

In pressure-controlled ventilation, the target is proximal airway pressure, and the cycle is time. Inspiratory time can be directly reduced, leading to an increase in expiratory time. Tidal volume can be reduced by decreasing proximal airway pressure. With decreased tidal volume, less time is needed to fully expire the total administered tidal volume.

Pressure Support Ventilation

In pressure support ventilation, the target is proximal airway pressure, and the cycle is flow. Similar to pressure-controlled ventilation, proximal airway pressure can be reduced, which decreases tidal volume. Inspiratory time can be decreased by increasing the flow cycle threshold, which is the percentage of peak flow to which inspiratory flow must diminish in order for inspiration to be terminated. By increasing this threshold, flow does not have to reach as low a level, and inspiration will be terminated sooner, resulting in decreased inspiratory time. This decreased inspiratory time will also result in decreased tidal volume.

Suggested Readings

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