5 Basic Mechanical Ventilation

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A 30-year-old male patient came to the emergency department with history of fever, shortness of breath for 3 days, and alteration in sensorium since morning. He was in respiratory distress with respiratory rate of 34/min. He was drowsy (Glasgow coma score 8) and febrile (102 °F). His pulse was 110/min, blood pressure was 116/78 mmHg, and JVP was normal. He was immediately intubated and put on assisted ventilation.

Mechanical ventilation is indicated in patients with acute respiratory failure when they are unable to maintain adequate oxygenation and/or remove carbon dioxide. None of the ventilatory mode can cure the disease process. However, it supports ventilation till you address the reversible primary problem. Mechanical ventilation should not be started without thoughtful consideration as tracheal intubation and ventilation are associated with significant complications.

Step 1: Initial Resuscitation (Refer to Chap. 23, Vol. 2)

- Any patient coming to the emergency department should be examined quickly to assess oxygenation and hemodynamic status. Resuscitation should be started without delay.
- All patients with respiratory distress require immediate attention to airway.
- They should be put on supplemental oxygen via nasal cannula or face mask devices (set at flow rate > 4 L or a high-flow oxygen device (Flow rate 40–60 L/min) (HFNC) wherever indicated.

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Table 5.1 Indications and objectives of mechanical ventilation

To overcome the mechanical problem
Rest/unloading of the fatigued/overloaded inspiratory muscles
Prevention or treatment of the lung atelectasis
An adjunct to anesthetic or neuromuscular blockade
Treatment for flail chest
To regulate gas exchange
Reverse hypoxemia in patients with respiratory failure
Keep $PaCO_2$ lower than normal in patients with raised intracranial pressure
Normalize the $PaCO_2$ in patients with muscle fatigue or neuromuscular disease
To increase the lung volume
During end inspiration—Minimize V/Q mismatch and intrapulmonary shunting, improve hypoxemia, and treat atelectasis
During end expiration (positive end-expiratory pressure [PEEP]), keep alveoli open at the end of expiration and improve gas exchange in acute respiratory distress syndrome (ARDS) and other causes of alveolar collapse

- In patients with chronic obstructive pulmonary disease low flow (1–2 L) oxygen should be started to increase SpO_2 to 88–92%.
- If the patient requires ventilation, then one has to decide whether to use invasive or noninvasive mechanical ventilation and the mode of mechanical ventilation, and the initial ventilator settings.
- If patient needs invasive mechanical ventilation, he/she should be intubated and ventilated (Table 5.1).
- Circulation needs to be maintained by fluid infusion. If clinical evidence of cardiac impairment is present, fluids should be given cautiously.

Step 2: Choose the Settings of Mechanical Ventilation

Mechanical ventilation has the capacity to deliver different types of breaths. A breath is called mandatory if the breath is started, controlled and ended by ventilator. It is an assisted breath if the breath is started by patient but controlled and ended by ventilator. The breath is Spontaneous if the initiated, controlled and ended by patient.

Ventilator delivered mechanical breath has four phases-trigger, limit, cycling and expiratory phase. The types of breath delivered is determined by three variables—the trigger, limit, and cycling. Expiration is passive and is same in all types of breaths.

Triggering

The ventilator needs to know when to start a breath. This is known as triggering. A ventilator breath may be triggered (initiated) by the patient (when breathing spontaneously) or triggered by the ventilator (after a set time). A patient-triggered breath will always have small pressure deflection in pressure time scaler below the baseline denoting patient's inspiratory effort (negative airway pressure), which may be sometimes difficult to appreciate. A machine initiated breath will not have this initial negative deflection.

Ventilators use signals from various sites from within the ventilator circuit. The trigger signal can be sensed at the proximal endotracheal tube, in the inspiratory limb, and in the expiratory limb of the circuit. The trigger signal can be pressure, flow, time and neural signal.

Pressure triggering: This requires the patient to generate a small negative inspiratory pressure (generally negative 1–3 cm H_2O). This negative pressure is sensed by the ventilator, causing the ventilator to start inspiration and deliver the next breath.

Flow triggering: In this a minimum of flow around 10 L/m is always present in the ventilator circuit (Bias Flow). Flow triggering occurs when a flow transducer in the patient/ventilator systems senses a change in flow i.e. flow moves in to airway opening. Usually flow trigger is kept at 2 L/m. This is the preferable triggering mode in spontaneously breathing patient.

Time triggering: A breath is time triggered when the patient does not initiate a breath and ventilator delivers a breath after a set time (depends on the set respiratory rate).This is the default setting in patient who do not have spontaneous breathing effort (e.g. on neuromuscular blocker).

Neural triggering: It is currently developed to minimise the delay interval between the generation of the signal to breathe in the brain (sensed by diaphragmatic muscle signals) and the actual delivery of flow from the ventilator.

Limit or Inspiratory Phase

This is the phase of the ventilator delivered breath that begins with the initiation of the breath, and ends when the ventilator stops inspiratory flow. Inspiratory valve is open and the expiratory valve is closed. During the inspiratory phase, air flow is determined by variables called limit variables which could be either pressure or flow. The limit variable does not terminate the inspiration; it allows inspiration to continue till the cycling criterion is reached.

Cycling: Changeover from Inspiration to Expiration

This is known as 'cycling.' Cycling defines how the ventilator recognizes that the inspiratory phase is over, and expiration starts with opening of the expiratory valve. Ventilators may cycle (changeover to expiration) when a certain tidal volume (set inspiratory tidal volume, volume cycled), inspiratory time (time cycled), flow rate (flow cycled). Pressure controlled ventilation is time cycled, volume controlled ventilation without pause is volume cycled and Pressure support mode is flow cycled.

In the expiratory phase, the inspiratory valve is closed and the expiratory valve is open.

- Once it has been decided that patient requires mechanical ventilation, the next step is to choose the appropriate mode of mechanical ventilation. Mode specifies the manner in which mechanical breath is delivered.

Table 5.2 Characteristics of commonly used modes of mechanical ventilation

Mode	Type of breath	Triggering mechanism	Cycling mechanism	Comments
CMV	Each breath delivers a preset mechanical tidal volume or pressure	Time	Inspiration is terminated by delivery of preset tidal volume or by time in pressure-controlled	Used in patients who have no respiratory effort
ACMV	Each breath, assist or control, delivers a preset mechanical tidal volume or pressure	Either patient-triggered (assist) or time-triggered (controlled)	Inspiration is terminated either by delivery of preset tidal volume (volume controlled) or by time in pressure-controlled	Alveolar hyperventilation may be a potential hazard
SIMV	Mechanical tidal breath at preset rate and the patient may breathe spontaneously between mandatory breaths	Mandatory breath may be time-triggered or patient-triggered	Mandatory breaths are volume- or time-cycled in; pressure-controlled patient controls spontaneous rate and volume	It provides an interval (synchronization window) just prior to triggering during which the ventilator is responsive to patient's effort and supports spontaneous breath
PSV	Pressure-support breaths are considered as spontaneous	Patient-triggered	The breaths are flow cycled by a set flow threshold, which is generated by the patient	This a commonly used mode for weaning

CMV controlled mandatory ventilation, *ACMV* assist-control mechanical ventilation, *IMV* intermittent mandatory ventilation, *SIMV* synchronized intermittent mandatory ventilation, *PSV* pressure-support ventilation

- The characteristics of commonly used modes of mechanical ventilation are summarized in Table 5.2. Assist-control mechanical ventilation (ACMV) is the most widely used method.
- Assist-control mode can be volume-controlled (more commonly used) or pressure-controlled. The differences between two are summarized in Table 5.3.
- The ventilatory support can be controlled mandatory ventilation (CMV) or assisted controlled mandatory ventilation (ACMV) depending on the use of patients' effort for triggering the ventilator.
- The patient's ventilation is totally controlled by the ventilator and the patient cannot trigger the ventilator during CMV, while ACMV delivers controlled breaths as well as assists patient-triggered breath.

Table 5.3 Comparison between volume-controlled and pressure-controlled breaths

Variable	Type of breath	
	Volume-controlled	Pressure-controlled
Tidal volume	Set by the operator; remains constant	Variable with changes in patients' effort and respiratory system impedance
Peak inspiratory pressure	Variable with changes in patients' effort and respiratory system impedance	Set by the operator; remains constant
Inspiratory time	Set by the operator or as a function of respiratory rate and flow settings	Set by the operator; remains constant
Inspiratory flow	Set by the operator or as a function of respiratory rate and tidal volume	Variable with changes in patients' effort and respiratory system impedance
Inspiratory flow waveforms	Set by the operator; remains constant; can use constant, sine, or decelerating flow waveforms	Flow waves are always decelerating

- ACMV is the most commonly used mode of mechanical ventilation and can be used to deliver either volume-preset or pressure-preset ventilation.
- In volume-preset ACMV, a preset tidal volume (VT) is delivered, irrespective of inspiratory pressure.
- In pressure-preset ACMV, a fixed inspiratory pressure (Pinsp) is applied to the respiratory system. The VT is determined by lung and chest wall compliance and airway resistance and the set time.
- A drawback of pressure controlled ventilation is that serious hypoventilation may occur if the airway resistance increases or respiratory system compliance decreases at a given preset pressure and time.
- A drawback with volume controlled ventilation is that the flow rate is fixed, and cannot vary with the patient's demands from time to time. This can cause patient-ventilator dyssynchrony. On the other hand, in pressure controlled ventilation, the flow is unlimited, resulting in better flow matching.
- Presence of a leak results in loss of ventilation during VCV. With PCV, some leak compensation is possible, where the flow increases to reach the set pressure.
- Although both volume-set and pressure-set ACMVs can achieve the same levels of ventilation, volume-preset ACMV is more frequently used.

Step 3: Set the Ventilator Setting

The various initial ventilatory settings for a patient with the normal lung are given in Table 5.4.

These settings can be later modified based on the progress of the patient's clinical condition.

Hypotension is very common complication after initiation of ventilation. This may be due to various causes like raised intrathoracic pressure including auto-PEEP, relief of respiratory distress, effects of sedatives,, and preexistent hypovolemia or

Table 5.4 Initial ventilatory setting

Mode—assist/control (volume or pressure)	
Tidal volume	6–8 mL/Kg ideal body weight (see formula in Appendix B)
Inspiratory time Inspiratory flow	0.7–1.2 s Four times minute ventilation (approx)
Rate	12–20 breaths/min
PEEP	4–5 cm H_2O
FiO_2	1.0
Plateau pressure	<30 cm H_2O
Once the patient is stabilized	
FiO_2	To maintain PaO_2 more than 60 mmHg or SpO_2 more than 93–94% in normal lung and 88–92% in hypercapnic respiratory failure
PEEP	Set according to FiO_2 requirements (predetermined according to the degree of hypoxemia)
Plateau pressure Driving pressure (plateau-PEEP)	Recheck in an attempt to keep plateau pressure below 30 cm H_2O Keep below 13 cm H_2O

other cardiac compromise. This should be kept in mind and should be prevented or treated initially with fluids. FiO_2 may be initially set at 1.0 as one may not be aware of the oxygen requirement of patient and later decrease to minimum in order to maintain target oxygenation.

- During mechanical ventilation the oxygenation is determined by the FiO_2, PEEP and mean airway pressure and $PaCO_2$ is determined by minute ventilation.

Step 4: Set Alarms

The following alarms need to be set:

- Peak pressure—high/low—10–15 cm above or below the peak inspiratory pressure
- Minute ventilation—high/low—50% above or below the set volume
- Low exhaled tidal volume—50% of the delivered tidal volume
- High respiratory rate
- Set apnea ventilation parameters

Step 5: Connect the Ventilator to the Patient

- Connect the patient to the ventilator.

Step 6: Monitoring and Adjustments During Mechanical Ventilation

- Patients should be closely monitored. Plateau pressure should be measured at least every 4 h and after any changes in tidal volume and PEEP in Volume controlled mode
- Tidal volume (delivered) should be checked periodically in Pressure controlled and Pressure support mode of ventilation.
- The ventilatory setting should be adjusted as described in mechanical ventilation in ARDS and obstructive airway diseases in Chaps. 5 and 6, Vol. 1.
- A few patients are difficult to synchronise with the ventilator and continue to demonstrate a high work of breathing. Auto-PEEP (Dynamic hyperinflation) may be responsible for this in patients with obstructive airway disease, and addition of extrinsic PEEP to nearly counterbalance the auto-PEEP improves the patient's comfort dramatically. The external PEEP should be set approximately 80% of auto-PEEP.
- If there is ineffective triggering apart from assessment of Auto PEEP, look for insensitive trigger setting (increase trigger setting), high minute ventilation causing short expiratory time (corrected by decreasing tidal volume, respiratory rate or increasing flow rate), or over assistance in pressure support (decrease pressure support).
- Double triggering is another commonly encountered asynchrony and is caused by patient taking breaths prematurely before the next breath is initiated, and will lead to breath stacking. This can be minimised by decreasing the trigger sensitivity or by increasing inspiratory time. Another approach is to increase minute ventilation though this worsens auto-PEEP and bicarbonate loss.
- If the problem still persists, then a careful search should be made for processes that might drive the patient to a respiratory rate higher than is desirable (e.g., acidosis, pleural effusion, incorrect ventilator settings (e.g., low flow or low set tidal volume and pain).
- If the patient continues to make significant inspiratory efforts after these, then judicious sedation is advised.
- If there is frequent high-pressure alarm, then look for bronchospasm, pneumothorax, atelectasis, blockade of endotracheal tube with secretions, right main bronchus intubation, etc.
- Once the patient improves and the respiratory muscles are adequately rested, the patient should assume some of the work of breathing and be evaluated for weaning from the mechanical ventilation. The patients fulfilling the weaning criteria are extubated.

Step 7: Monitor and Manage Complications

Ventilation is never without complications. They should be diagnosed and managed (Table 5.5).

Table 5.5 Complications of intubation and mechanical ventilation

Equipment
Malfunction or disconnection
Incorrect settings
Pulmonary
Airway intubation (e.g., damage to teeth, vocal cords, and trachea)
Ventilator-associated pneumonia
Ventilator-associated lung injury (e.g., diffuse lung injury due to regional overdistension or tidal recruitment of alveoli)
Overt barotraumas (e.g., pneumothorax)
O_2 toxicity
Patient–ventilator asynchrony
Circulation
↓ Right ventricular preload → ↓ cardiac output
↑ Right ventricular afterload (if the lung is overdistended)
↓ Splanchnic blood flow with high levels of PEEP or mean Paw
↑ Intracranial pressure with high levels of PEEP or mean Paw
Fluid retention due to ↓ cardiac output → ↓ renal blood flow
Other
Gut distension (air swallowing, hypomotility)
Mucosal ulceration and bleeding
Peripheral and respiratory muscle weakness
Sleep disturbance, agitation, and fear (which may be prolonged after recovery)
Neuropsychiatric complications

Table 5.6 Criteria for assessing readiness of patients for weaning

Some evidence of reversal of the underlying cause of respiratory failure
Adequate oxygenation (e.g., $PaO_2/FiO_2 > 200$, requiring PEEP < 5–8 cm H_2O, $FiO_2 < 0.4$–0.5, and pH > 7.25)
Hemodynamic stability, no active myocardial ischemia, no clinically significant hypotension or use of vasopressors (low dose vasopressor is acceptable)
The capability to initiate an inspiratory effort

Step 8: Weaning from the Ventilator (Chap. 9, Vol. 1)

- Patients who have recovered considerably from the underlying diseases should be assessed daily for readiness of weaning (Table 5.6), and those satisfying criteria should be given a spontaneous breathing trial (SBT).
- Patients may be given SBT after they fulfill the weaning assessment criteria and monitored for 5 min for signs of SBT failure (Table 5.7). Those who successfully tolerate this the SBT trial should be prolonged for 30–120 min and if successful, can be extubated. If SBT trial fails patient should be reconnected to the ventilator.

Table 5.7 Criteria for defining failure of SBT—various parameters monitored during SBT

$SpO_2 \leq 90\%$ and/or $PaO_2 \leq 60$ mmHg
Spontaneous tidal volume ≤ 4 mL/kg ideal body weight
Respiratory rate ≥ 35/min
RSBI (rapid shallow breathing index): Respiratory rate/tidal volume in L: >105
pH ≤ 7.30 if measured
Respiratory distress
Two or more of the following:
Heart rate ≥ 120/min or ≥ 20% increase from the baseline
Marked use of accessory muscles
Abdominal paradox
Diaphoresis
Marked subjective dyspnea

Step 9: Monitoring During Postextubation Period

- Once the patient is extubated, he/she should be monitored for any appearance of respiratory distress/failure because some patients may develop weaning failure and may require reintubation.
- Elective use, post extubation of NIV in COPD and HFNC in others has been found to be helpful in patients for high risk of reintubation.

Suggested Reading

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