SHORT COMMUNICATION

Must-know Facts about Ventilators for Nurses Working in Intensive Care Units

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Abstract

Amid the coronavirus disease-2019 (COVID-19) pandemic, frontline nurses, who tirelessly apply their expertise and knowledge to enhance patient outcomes in intensive care units (ICUs), must comprehensively understand ventilators. Given the variety of ventilators, each produced by different manufacturers and featuring distinct operational protocols, navigating their use can be challenging for nurses. This complexity often leads to confusion regarding the functionality and setup of these critical devices in a clinical setting. This article aims to clarify and provide a general overview of common ventilator setups and operating principles, specifically tailored for nurses. This article aims to explain or clarify ventilator technology, thereby empowering nurses with the knowledge and confidence needed to manage ventilatory support effectively for their patients.

Keywords: COVID-19, Intensive care units, Ventilator.

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Introduction

Ventilators play a pivotal role in critical care settings, providing precisely controlled artificial respiration to critically ill patients to enhance their oxygenation. Presently, positive-pressure ventilators are universally employed across all critical care environments, marking a significant evolution from the negative-pressure ventilators that predominated until the mid-20th century. Invasive positive pressure ventilation (IPPV) is administered through an invasive airway approach, such as endotracheal, nasotracheal, or tracheostomy tubes. Despite variations in settings and delivery mechanisms across different ventilator models and manufacturers, the core objectives and management strategies remain consistent. Acquiring a fundamental understanding of ventilator settings, modes, and management principles is essential for healthcare providers. This knowledge equips them to offer optimal care to critically ill patients requiring invasive mechanical ventilation, ensuring they can navigate the complexities of ventilatory support with confidence and expertise (Fig. 1).

Trial Run of a Ventilator

Conducting a trial run, also known as a trial test or pre-check, is an essential and universally mandated procedure for the operation of ventilators, without exception. A thorough trial run is imperative before connecting any ventilator to a patient. This process ensures the ventilator's optimal performance through a comprehensive self-check by the machine and a detailed assessment of all accessories integrated into the ventilator circuit. Should there be any discrepancies or malfunctions, the ventilator is designed to alert users and display relevant information on the user interface. While the specific protocols for conducting a trial run may vary slightly depending on the ventilator model and manufacturer, the importance of this step cannot be overstated. Proper setup and functioning of a ventilator are crucial in determining the outcomes for critically ill patients, making the trial run a vital component of patient care and ventilatory support management.

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Setting Up of COVID-19 Patient Circuit for Ventilation

The patient circuit of a ventilator serves as the conduit for delivering artificial respiration from the ventilator to the patient. This critical pathway begins at the ventilator's inspiratory port, where breathable air is generated and controlled, and concludes at the expiratory port, where exhaled gases are safely expelled. Essential accessories commonly utilised within the patient circuit are as follows:

- Inspiratory limb I and II.
- Expiratory limb.
- Bacterial filter-2.
- HME-1.
- Y-Connector-1.
- Catheter mount-1.
- Cuvette for Capnograph or EtCO2 (Optional).
- Test lung.
- Some ventilators come with external flow sensor connections that must be connected to the patient circuit.
- Water trap bag for condensed air (Inline or External).

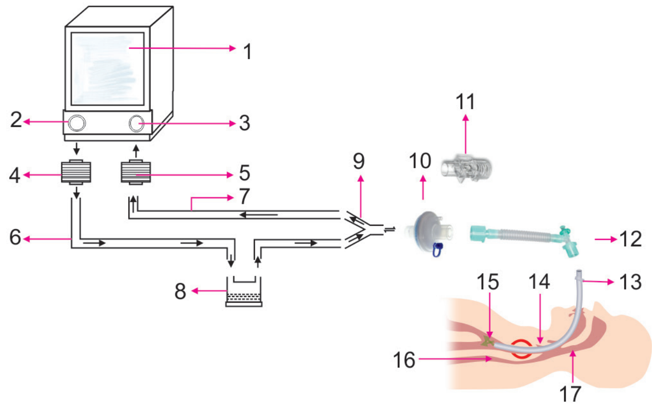

Fig. 1: Patient circuit of a ventilator

1. Ventilator unit; 2. Inspiratory port; 3. Expiratory port; 4 and 5. Bacterial filter; 6. Inspiratory limb; 7. Expiratory limb; 8. Humidifier (Not usually used for COVID-19 patient); 9. Patient wye (Y-Connector); 10. HME; 11. $EtCO_2$ cuvette/connector; 12. Catheter mount; 13. Endotracheal tube; 14. Larynx; 15. Trachea; 16. Oesophagus; 17. Pharynx

Note: Both the inspiratory port and the expiratory port should be secured with the bacterial filter and should be changed as per the infection control protocols

These accessories are integral to maintaining the functionality and effectiveness of ventilatory support, facilitating optimal oxygenation and ventilation in critically ill patients.

Notes on Humidifier and Heat Moisture Exchanger (HME)

A HME is usually used when the patient requires ventilator support for 24–48 hours (short term). If in case the ventilator support requirement is for more than 48 hours, it is better to use a humidifier (usual temperature setting is 37°C)[1] instead of HME to avoid complications associated with thick sputum and dry airways. However, a meta-analysis shows there is no significant difference in the primary outcome of mortality, airway obstruction and pneumonia when only HME or only humidifier is used.[2] When HME is connected, make sure that automatic tube compensation (ATC) or equivalent setting is on to balance the pressure variations.[3] Heat moisture exchanger is generally not recommended for patients with hypothermia and with viscous secretions.[1]

The inclusion of a humidifier in the ventilator circuit for COVID-19 patients is not routinely recommended due to the potential risk of aerosol generation, which can increase the spread of the virus. Despite the crucial need for anti-aerosol precautions in managing severe COVID-19 pneumonia, the challenge of managing viscous sputum produced by patients cannot be overlooked. At instances, where a patient's respiratory secretions become particularly thick and difficult to manage, the judicious use of a humidifier might prove beneficial. This approach requires careful consideration of both the risks associated with aerosol generation and the clinical need to maintain airway patency and facilitate sputum expectoration through adequate humidification, ensuring a balanced approach to patient care.[4]

Nebulisation of Patient under Ventilator

Always use the inline nebuliser module for nebulisation. Heat moisture exchanger may be removed during nebulisation as it may hamper the aerosol delivery. Make sure humid sensitive parts in the patient circuit are removed temporarily till the delivery of nebulisation to avoid short circuits in the sensors.

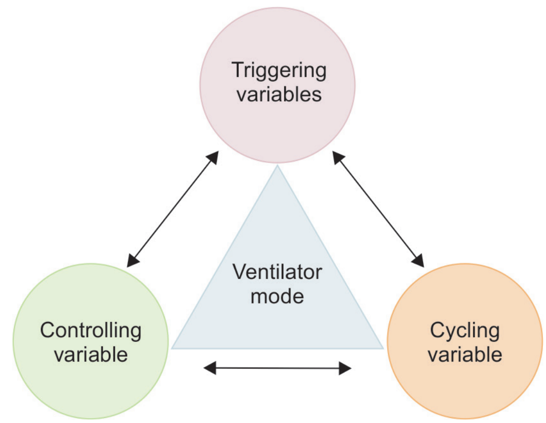

Fig. 2: Pictorial representation of variables defining the ventilator mode

Understanding the Ventilator Modes and Basic Concepts

Ventilator modes represent the methods by which artificial respiration is delivered to patients via a ventilator. Each mode can be defined by three critical variables: the triggering, cycling and controlling variables:

- The triggering variable is crucial for determining the initiation of a mechanically delivered breath. It can be set based on time, pressure, or flow, allowing for personalised adjustments to meet the patient's respiratory demand.
- The controlling variable specifies the primary aspect that the ventilator regulates during the inspiration phase. Options typically include pressure control or flow control (a.k.a. volume control). This variable ensures that each breath meets the preset criteria for delivering adequate ventilation.
- The cycling variable plays a crucial role in mechanical ventilation by determining the signal that instructs the ventilator to end the inspiratory phase. This variable can be set based on time, volume, or flow, each offering a distinct mechanism for concluding inspiration:
  - Time-based cycling terminates inspiration after a pre-determined duration, ensuring that each breath is delivered within a specific timeframe.
  - Volume-based cycling ends inspiration once a set tidal volume has been delivered to the patient, aligning ventilation with precise volume targets.
  - Flow-based cycling concludes the inspiratory phase when the flow rate decreases to a certain level, indicating that the desired lung expansion has been achieved.

These options provide clinicians the flexibility to customise ventilation according to the patient's respiratory mechanics and clinical needs, optimising patient comfort and the effectiveness of ventilatory support (Fig. 2).

High-frequency Oscillatory Ventilation (HFOV)

High-frequency oscillatory ventilation represents a specialised technique within the spectrum of high-frequency ventilation (HFV) approaches, commonly deployed as a rescue strategy for patients with severe acute respiratory distress syndrome (ARDS)

Table 1: Types of ventilator modes

Ventilator mode	*Overview*	*Clinical implications*
Controlled mechanical ventilation (CMV)	CMV mandates all breaths without patient-initiated efforts, categorised based on targeting volume (VCV) or pressure (PCV).	Essential for patients lacking respiratory drive, necessitating sedation and neuromuscular blocking agents. Carries the risk of weakening respiratory muscles due to inactivity.
Assist-control ventilation (A/C)	Allows for both machine-initiated and patient-triggered breaths, all regulated by the ventilator. It can be set to volume (AC-VC) or pressure (AC-PC) targets.	Facilitates diaphragmatic engagement upon patient initiation. However, there's a risk of respiratory alkalosis if the patient experiences rapid breathing.
Synchronised intermittent mandatory ventilation (SIMV)	Delivers mandatory breaths at a preset rate and either a set volume (SIMV-VC) or pressure (SIMV-PC), synchronised with patient's breathing efforts within a specific timing window. Patients can breathe spontaneously between these mandatory breaths.	Diminishes the necessity for sedation and encourages natural diaphragmatic movement.
Pressure support ventilation (PSV) or spontaneous mode	All breaths are initiated and terminated by the patient. The ventilator augments the patient's breathing effort with pressure support during inhalation.	Lowers sedation requirements, supports the process of weaning from the ventilator, allows for personalised adjustment of pressure support to achieve desired tidal volume and helps maintain respiratory muscle activity, reducing work of breathing (WOB).
Pressure-regulated volume control (PRVC)[5]	Sets a mandatory rate and target tidal volume, with the ventilator adjusting to deliver these using the minimum necessary pressure.	Offers a dual-control approach that ensures volume delivery while minimising pressure, providing a balance between efficiency and safety.
Airway pressure release ventilation (APRV)	Alternates between two predefined pressure levels for specific durations, often with an inverse ratio of a prolonged inspiratory time to a shortened expiratory time, allowing spontaneous breathing at any phase.	Minimises sedation needs and encourages natural respiratory muscle function. Particularly beneficial for alveolar recruitment and used as a rescue strategy in ALI (Acute Lung Injury) or ARDS with extreme inverse ratios.
Continuous positive airway pressure (CPAP)	Supports the patient's spontaneous breaths by applying a constant positive pressure throughout the respiratory cycle.	Suitable for patients with the capability to maintain adequate tidal volumes independently, requiring an intact respiratory drive.

when traditional ventilation methods are ineffective. Characterised by the delivery of very small tidal volumes, often smaller than the anatomical dead space, HFOV operates at exceptionally high respiratory rates, typically between 300 and 900 breaths per minute. This method employs a reciprocating diaphragm mechanism to achieve these high rates, facilitating gas exchange through a process of continuous lung recruitment and minimising the risk of ventilator-induced lung injury. High-frequency oscillatory ventilation is compatible with standard endotracheal tubes, making it a versatile option in critical care settings for patients requiring advanced respiratory support[6] (Table 1).

Protective Lung Ventilation

Protective lung ventilation embodies the contemporary standard in mechanical ventilation strategies, extending its benefits to patients with and without ARDS. This approach prioritises the minimisation of ventilator-induced lung injury through several key features as follows.

- Permissive Hypercapnia: Allowing higher levels of carbon dioxide (CO_2) in the blood as a trade-off for reduced mechanical ventilation pressures, acknowledging that strict normalisation of CO_2 levels may not be necessary for all patients and can, in some cases, be detrimental.
- Lower Plateau Pressures: Keeping the pressure applied to the lungs during the ventilatory cycle at a minimal level to prevent overdistension of the lung tissues.
- Low Tidal Volume Ventilation: Administering a reduced volume of air per breath, typically ranging from 4 to 8 mL/kg of ideal body weight (as opposed to actual body weight), to prevent alveolar overdistension and subsequent lung injury.[7]

For COVID-19 patients experiencing ARDS, adherence to lung-protective ventilation protocols is notably high, with their pulmonary response to the disease mirroring that of ARDS from other causes. This alignment underscores the effectiveness and applicability of protective lung ventilation strategies in managing the respiratory complications associated with COVID-19, reinforcing its status as a critical component of care for these critically ill patients.[8]

Typical Initial Ventilator Settings

Ventilator settings are critical to patient care and must be monitored and documented as per agency policy and following any adjustments by the attending physician, tailored to the patient's evolving condition. These assessments are performed by the doctor as frequently as every 1–4 hours. In some jurisdictions, the continuous monitoring of ventilated patients is a shared responsibility between registered nurses and respiratory therapists, with findings communicated to the attending doctor for potential adjustments to ventilator settings, aiming to optimise patient outcomes. It is imperative for the nurse overseeing the patient's care to be well-informed about the ventilator's alarm settings, ensuring prompt response to any changes in the patient's respiratory status (Table 2).

Interpreting Causes of Ventilator Alarms and the Possible Interventions to Be Considered

Causes of High-pressure Alarm (Usual Settings 10–15 cm H_2O above Peak Inspiratory Pressure):[9]

- **Increased Airway Secretions**
  - **Intervention**: Perform suctioning as necessary. Using humidified oxygen can help liquefy secretions for easier removal.

Table 2: The initial ventilator settings the nurse needs to be familiar

Ventilator parameter	*Definition*	*Standard settings/Adjustment criteria*
Respiratory rate (f)	The frequency at which the ventilator administers breaths each minute.	Typically adjusted between 6 and 20 breaths per minute to meet the patient's ventilatory demand.
Tidal volume (VT)	The amount of air delivered to the patient with each breath by the ventilator.	Ranges from 6 to 10 mL/kg of the patient's body weight, tailored to prevent lung injury while ensuring adequate ventilation.
Oxygen concentration (FIO_2)	The percentage of oxygen supplied to the patient through the ventilator.	Set to ensure PaO_2 remains above 60 mm Hg or SpO_2 stays over 90%, optimising oxygen delivery while minimising toxicity.
Positive end-expiratory Pressure (PEEP)	A positive pressure maintained during the expiratory phase to enhance lung's functional residual capacity.	Commonly set around 5 cm H_2O, adjusted based on patient response to improve oxygenation and prevent alveolar collapse.
Pressure support	Additional positive pressure provided during inspiration to support the patient's own breaths.	Typically ranges from 6 to 18 cm H2O, depending on the patient's effort and need for assistance during spontaneous breathing.
I:E Ratio (Inspiratory to expiratory ratio)	The proportion between the duration of inhalation and exhalation.	Usually set between 1:2 and 1:1.5, with adjustments for IRV when clinically indicated.
Inspiratory flow rate and time	The rate at which tidal volume is delivered and the duration of the inspiratory phase.	Flow rates set between 40 and 80 L/min with an inspiratory time ranging from 0.8 to 1.2 seconds, optimised for patient comfort.
Sensitivity	The threshold effort a patient needs to exert to trigger the ventilator to deliver a breath.	Pressure triggers set 0.5–1.5 cm H_2O below baseline, and flow triggers adjusted to 1–3 L/min below baseline flow.
High-pressure limit	The maximum pressure the ventilator is allowed to reach during breath delivery to prevent barotrauma.	Set 10–20 cm H_2O above the peak inspiratory pressure, ensuring a safety margin while accommodating patient-specific needs.

- **Patient Coughing or Gagging**
  - **Intervention**: Suction if needed to clear secretions prompted by coughing or gagging. Hyper-oxygenate the patient with 100% oxygen before suction and maximum suction time should not exceed 10 seconds. If suction needs to be repeated, do not forget to hyper-oxygenate.
- **Wheezing or Bronchospasm**
  - **Intervention**: Notify the physician immediately. Follow prescribed treatments to alleviate bronchospasm and ease airway resistance.
- **Endotracheal Tube Displacement**
  - **Intervention**: Reposition the tube to the appropriate mark and confirm bilateral air entry through auscultation or $EtCO_2$ monitoring.
- **Ventilator Tube Obstruction due to Condensation**
  - **Intervention**: Drain condensate from the tubing into a separate container to prevent water aspiration and potential bacterial contamination.
- **Kinked or Compressed Tubing**
  - **Intervention**: Utilise a bite block or an oral airway if the patient is biting the ET tube, ensuring open airflow.
- **Patient Anxiety or Ventilator Discordance**
  - **Intervention**: Consult with a physician regarding sedation to help the patient adapt to the ventilator rhythm more comfortably.

Causes of Low-pressure Alarm (Usually set 5–10 cm H_2O below Peak Inspiratory Pressure).[10]

- **Disconnection or Leak in the Ventilator System**
  - **Intervention**: Check and secure all connections. Maintain ET or tracheostomy cuff pressure between 18 and 22 mm Hg to prevent aspiration or air leak.[11,12] High cuff pressure can cause tracheal bleeding, ischemia and pressure necrosis, while low cuff pressure can increase the risk of aspiration pneumonia. Routine deflation of the cuff is not recommended due to the increased risk of aspiration and hypoxia.[13]
- **Patient Stops Spontaneous Breathing**
  - **Intervention**: Initiate manual ventilation and seek immediate assistance.
- **Apnoea or Respiratory Arrest**
  - **Intervention**: Manually ventilate the patient and summon rapid response or emergency services. For precaution, always make sure the apnoea alarm and backup ventilation are in the 'on' position in ventilator settings.
- **High Tidal Volume or Minute Ventilation**
  - **Intervention**: Evaluate the patient's pain or anxiety levels. Adjust medications as ordered and clear any condensate in the tubing.
- **Low Tidal Volume or Minute Ventilation**
  - **Intervention**: Assess the patient's effort, ensuring ventilator settings align with clinical guidelines. Notify the physician for adjustments.
- **Ventilator Operational Issues**
  - **Intervention**: Verify power connections and ensure the internal battery is fully charged to maintain ventilator operation. In case of power failure, the battery backup in the ventilator may provide an average of 20–30 minutes of power supply. In case of operational issues which cannot be resolved immediately, manually ventilate the patient with an Ambu till another ventilator is ready to connect to the patient.

In situations where the cause of a ventilator alarm is unclear, the immediate response should be to manually ventilate the patient using a resuscitation bag, ensuring continuous ventilation until the issue is resolved. It is imperative that resuscitation equipment, equipped with a high-efficiency particulate air (HEPA) filter and a positive end-expiratory pressure (PEEP) valve for enhanced safety, is readily accessible at the bedside. Additionally, nurses must adhere to strict personal protective equipment (PPE) guidelines and infection control protocols to safeguard both their health and that of their patients. This approach not only ensures the patient's respiratory needs are met without interruption but also maintains the highest standards of infection prevention and control within the healthcare setting.

NOTE: This article serves as a foundational overview of managing critically ill patients receiving invasive positive pressure ventilation (IPPV). It is crucial to understand that any adjustments to ventilator settings must be entrusted to an experienced intensivist, ensuring that modifications are made with precision and expertise. Medication administration to these patients should strictly follow a physician's directive, emphasising the importance of medical oversight in treatment protocols. Given the significant risk of disease transmission within ICU settings, adherence to stringent personal protective equipment (PPE) protocols by healthcare personnel is imperative. This measure is vital for protecting both healthcare workers and patients from potential infection, underscoring the critical nature of comprehensive safety practices in the care of critically ill patients under IPPV.

Conclusion

In conclusion, when an intensive care nurse has a profound understanding of the fundamental concepts and operational mechanics of ventilators, they are well-equipped to adapt this knowledge across various types of ventilatory support systems. This comprehensive insight fosters confidence among nurses, enabling them to proficiently manage ventilated patients, particularly in the challenging context of COVID-19. Equipped with this expertise, nurses can swiftly identify patient care issues and implement timely nursing interventions, thereby significantly contributing to improved patient outcomes. The ability to navigate the complexities of ventilator settings and respond effectively to the dynamic needs of critically ill patients underscores the pivotal role of skilled nursing care in achieving successful healthcare delivery.

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