11 Ventilator Parameters

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I. Peak Inspiratory Pressure (PIP)
   A. Physiologic effects
      1. PIP (peak inspiratory pressure relative to atmospheric pressure) in part determines the pressure gradient between the onset and end of inspiration ($\Delta P = \text{PIP} - \text{PEEP}$), and thus affects the tidal volume and minute ventilation.
      2. During volume-targeted ventilation an increase in tidal volume corresponds to an increase in PIP during pressure ventilation. If tidal volume is not measured, initial PIP can be selected based on observation of the chest wall movement and magnitude of the breath sounds.
   B. Gas exchange effects
      1. An increase in PIP will increase tidal volume, and thus increase CO_2 elimination, and decrease $PaCO_2$.
      2. An increase in PIP will increase mean airway pressure, and thus improve oxygenation.
   C. Side effects
      1. An elevated PIP may increase the risk of ventilator-induced lung injury, from barotrauma/volutrauma, and thereby increase the risk of pulmonary air leaks and bronchopulmonary dysplasia.
      2. There is evidence that ventilator-induced lung injury is primarily caused by excessive tidal volume delivery (volutrauma) and lung overdistention rather than high peak pressures in the absence of excessive tidal volumes (barotrauma).
      3. It is important to adjust PIP based on lung compliance and ventilate with relatively small tidal volumes (e.g., 3–5 mL/kg). Adjustment of PIP is particularly important in the setting of rapidly changing lung compliance (e.g., post-surfactant treatment).

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II. Positive End Expiratory Pressure (PEEP)
   A. Physiologic effects
      1. PEEP in part determines lung volume during the expiratory phase, improves *V*/*Q* mismatch, and prevents alveolar collapse.
      2. PEEP contributes to the pressure gradient between the onset and end of inspiration ($\Delta P = \text{PIP} - \text{PEEP}$), and thus affects the tidal volume and minute ventilation.
      3. At least a minimum "physiologic" PEEP of 2–3 cm H_2O should be used in most intubated newborns to improve lung compliance and reduce the risk of atelectrauma from ventilation below the opening pressure of the terminal airways.
   B. Gas exchange effects
      1. An increase in PEEP increases expiratory lung volume (functional residual capacity) during the expiratory phase, and thus improves *V*/*Q* matching and oxygenation in patients whose disease state reduces expiratory lung volume.
      2. An increase in PEEP will increase mean airway pressure, and thus improve oxygenation in patients with respiratory distress syndrome (RDS).
      3. The lowest pulmonary vascular resistance as well as the best lung compliance is found when the lung is neither underinflated nor overinflated. Adequate PEEP improves lung compliance and may allow the use of lower peak pressures to achieve the same tidal volume. Adequate PEEP also maximizes oxygenation for a given mean airway pressure.
   C. Side effects
      1. An elevated PEEP may overdistend the lungs and lead to decreased lung compliance, decreased tidal volume for a given ΔP, and impaired CO_2 elimination.
      2. A very high PEEP may increase pulmonary vascular resistance and decrease cardiac output and oxygen transport.

III. Frequency (or rate)
   A. Physiologic effects
      1. The ventilator frequency (or rate) in part determines minute ventilation ($\text{MV} = f \times V_T$), and thus CO_2 elimination. Ventilation at high rates (≥60/min) frequently facilitates synchronization of the ventilator with spontaneous breaths.
      2. Spontaneous breathing rates are inversely related to gestational age and weight and the time constant of the respiratory system. Thus, infants with smaller and less compliant lungs (RDS) tend to breathe faster based on the principle of minimal work. When the spontaneous respiratory rate is low, excessive work has to be generated by the respiratory muscles to overcome lung and chest wall elastic forces to achieve larger tidal volumes. Therefore, more metabolically efficient alveolar ventilation can be achieved by the brain's respiratory center increasing the respiratory rate rather than increasing the tidal volume.
   B. Gas exchange effects. Very high frequencies as used in mid-frequency ventilation and high-frequency ventilation permit adequate minute ventilation while using lower peak inspiratory pressures and tidal volumes.
   C. Side effects. Use of very high ventilator frequencies may lead to insufficient inspiratory time and decreased tidal volume or insufficient expiratory time and gas trapping, which can negatively affect ventilation by decreasing lung compliance especially in infants with long time constants (established bronchopulmonary dysplasia, BPD). Gas trapping also decreases the pressure gradient between the airway opening and the lungs during pressure control ventilation, thus decreasing V_T.

IV. Inspiratory Time (T_I), Expiratory Time (T_E), and Inspiratory to Expiratory Ratio (*I*:*E* Ratio)
   A. Physiologic effects

1. The effects of the T_I and T_E are strongly influenced by the relationship of those times to the inspiratory and expiratory time constants.
2. A T_I as long as 3–5 time constants allows relatively complete inspiration.
3. T_I of 0.2–0.5 s is usually adequate for newborns with RDS.
4. Infants with a long time constant (e.g., BPD) may benefit from a longer T_I (up to approximately 0.6–0.8 s).

B. Gas exchange effects
1. Changes in T_I, T_E, and I:E ratio generally have modest effects on gas exchange.
2. A sufficient T_I is necessary for adequate tidal volume delivery and CO_2 elimination.
3. Use of relatively long T_I or high I:E ratio may improve oxygenation slightly.

C. Side effects
1. Use of a longer T_I (>0.5 s) generally does not improve ventilation or gas exchange and may lead to ventilator asynchrony and an increased risk of pulmonary air leak.
2. A very short T_I will lead to incomplete inspiration and decreased tidal volume.
3. A very short T_E or high I:E ratio can lead to incomplete expiration and increase gas trapping which can decrease lung compliance, decrease V_T, and impair cardiac output.

V. Inspired Oxygen Concentration (FiO_2)

A. Physiologic effects
1. Changes in FiO_2 alter alveolar oxygen pressure, and thus oxygenation.
2. Because both FiO_2 and mean airway pressure determine oxygenation, the most effective and less adverse approach should be used to optimize FiO_2.
3. When FiO_2 is above 0.6–0.7, increases in mean airway pressure are generally warranted.
4. When FiO_2 is below 0.3–0.4, decreases in mean airway pressure are generally preferred.

B. Gas exchange effects. FiO_2 directly determines alveolar PO_2 and thus PaO_2.

C. Side effects. A very high FiO_2 can damage the lung tissue, but the absolute level of FiO_2 that is toxic has not been determined.

VI. Flow
1. Inspiratory flow is directly set during volume control modes. The higher the flow for a given V_T, the shorter the T_I.
2. Inspiratory flow is indirectly set during pressure control modes and is a function of the set ΔP and the pressure rise time, for a given value of respiratory system time constant. Peak inspiratory flow decreases as respiratory system resistance increases or the pressure rise time increases.
3. Historically, infant ventilators were designed to deliver pressure limited breaths by diverting a pre-set constant flow through a pressure pop-off valve. This is referred to as the “time cycled, pressure limited” mode. At least one modern ventilator (AVEA, CareFusion) still offers this modality. In this scenario, changes in the pre-set constant circuit flow rate affect the airway pressure rise time during inspiration (i.e., the higher the set flow, the faster the pressure rise and the higher the peak inspiratory flow). This phenomenon has not been well studied in infants, but it probably affects arterial blood gases minimally as long as a sufficient flow is used.
4. Inadequate flow (i.e., long pressure rise time and low peak inspiratory flow) may contribute to air hunger, asynchrony, and increased work of breathing if effective opening pressure is not reached within an appropriate time.
5. Higher flow rates and steeper inspiratory pressure slopes (short pressure rise times) may be needed at high ventilator rates with short T_I to maintain adequate flow for complete inspiration.

6. Excessive flow may contribute to turbulence, inefficient gas exchange, and inadvertent PEEP.

VII. In summary, depending on the desired change in blood gases, the following ventilator parameter changes can be performed (Table 11.1).

VIII. Suggested Management Algorithm for RDS (Fig. 11.1) Table 11.2 lists abbreviations and symbols seen in the figure.

Table 11.1 Desired blood gas goal and corresponding ventilator parameter changes

Desired goal	PIP	PEEP	Frequency	*I*:*E* ratio	Flow
Decrease $PaCO_2$	↑	↓	↑	–	±↑
Increase $PaCO_2$	↓	↑	↓	–	±↑
Decrease PaO_2	↓	↓	–	↓	±↑
Increase PaO_2	↑	↑	–	↑	±↑

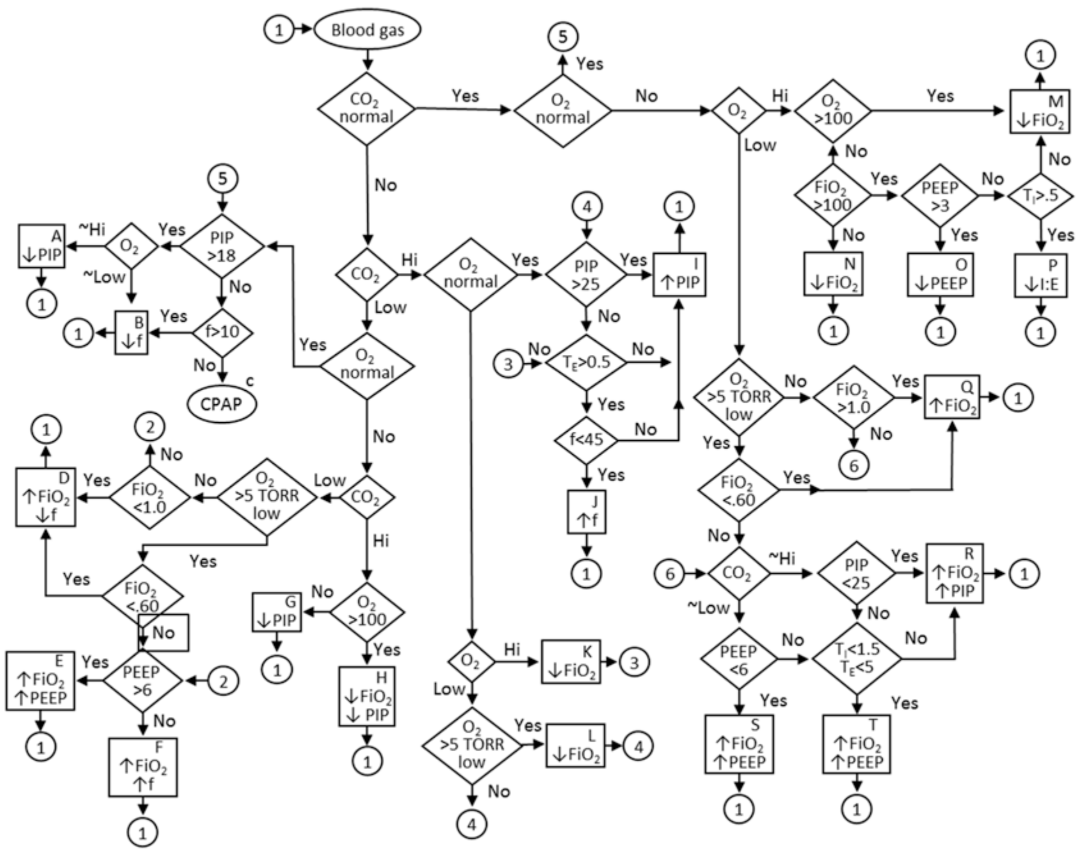

Fig. 11.1 Flowchart illustrating simplified version of ventilator algorithm. Symbols: I, calls for decisions; O, type and direction of ventilator setting changes. Abbreviations: *CO_2* arterial carbon dioxide tension (mmHg), *O_2* arterial oxygen tension (mmHg), *FiO_2* fraction of inspired oxygen, *PIP* peak inspiratory pressure (cm H_2O), *PEEP* positive end-expiratory pressure (cm H_2O), *CPAP* continuous positive airway pressure (cm H_2O), *I:E* ratio of inspiratory to expiratory time, *f* ventilator frequency (breaths per minute), T_I inspiratory time (s), T_E expiratory time (s), *HI* variable in decision symbol is above normal range, *LOW* variable in decision symbol is below normal range, *~HI* variable in decision symbol is at high side of normal, *~LOW* variable in decision symbol is at low side of normal

Table 11.2 Abbreviations and symbols used in the flowchart in figure

CO_2	Arterial carbon dioxide tension (mmHg)
O_2	Arterial oxygen tension (mmHg)
F_iO_2	Fraction of inspired oxygen
PIP	Peak inspiratory pressure (cm H_2O)
Paw	Mean airway pressure (cm H_2O)
PEEP	Positive end-expiratory pressure (cm H_2O)
CPAP	Continuous positive airway pressure without mechanical ventilation (cm H_2O)
I:*E*	Ratio of inspiratory to expiratory time
f	Ventilator frequency (breaths/min). Unless otherwise specified, a change in frequency should be accompanied by a change in *I*:*E* to maintain the same T_I, so that tidal volume remains constant
T_I	Inspiratory time (s)
T_E	Expiratory time (s)
HI	The variable in the decision symbol is above normal range
LOW	The variable in the decision symbol is below normal range
≈HI	The variable in the decision symbol is at the high end of normal
≈LOW	The variable in the decision symbol is at the low end of normal
↑	Increase
↓	Decrease
>	Greater than
<	Less than
Torr	Unit of pressure; 1 Torr–1 mmHg

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Suggested Reading

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