

Intensive Care Nursery House Staff Manual

Respiratory Support

ABBREVIATIONS

FIO ₂	<i>Fractional concentration of O₂ in inspired gas</i>
PaO ₂	<i>Partial pressure of arterial oxygen</i>
PAO ₂	<i>Partial pressure of alveolar oxygen</i>
PaCO ₂	<i>Partial pressure of arterial carbon dioxide</i>
PACO ₂	<i>Partial pressure of alveolar carbon dioxide</i>
tcPCO ₂	<i>Transcutaneous PCO₂</i>
PBAR	<i>Barometric pressure</i>
PH ₂ O	<i>Partial pressure of water</i>
RQ	<i>Respiratory quotient (CO₂ production/oxygen consumption)</i>
SaO ₂	<i>Arterial blood hemoglobin oxygen saturation</i>
SpO ₂	<i>Arterial oxygen saturation measured by pulse oximetry</i>
PIP	<i>Peak inspiratory pressure</i>
PEEP	<i>Positive end-expiratory pressure</i>
CPAP	<i>Continuous positive airway pressure</i>
\bar{P}_{AW}	<i>Mean airway pressure</i>
FRC	<i>Functional residual capacity</i>
Ti	<i>Inspiratory time</i>
Te	<i>Expiratory time</i>
IMV	<i>Intermittent mandatory ventilation</i>
SIMV	<i>Synchronized intermittent mandatory ventilation</i>
HFV	<i>High frequency ventilation</i>

OXYGEN (Oxygen is a drug!):

- A. Most infants require only enough O₂ to maintain SpO₂ **between 87% to 92%**, usually achieved with PaO₂ of 40 to 60 mmHg, if pH is normal. Patients with pulmonary hypertension may require a much higher PaO₂.
- B. With tracheal suctioning, it may be necessary to raise the inspired O₂ temporarily. This should not be ordered routinely but only when the infant needs it. These orders are good for only 24h.

OXYGEN DELIVERY and MEASUREMENT:

- A. **Oxygen blenders** allow O₂ concentration to be adjusted between 21% and 100%.
- B. **Head Hoods** permit non-intubated infants to breathe high concentrations of humidified oxygen. Without a silencer they can be very noisy.
- C. **Nasal Cannulae** allow non-intubated infants to breathe high O₂ concentrations and to be less encumbered than with a head hood. O₂ flows of 0.25-0.5 L/min are usually sufficient to meet oxygen needs. O₂ concentrations >50% may be delivered via nasal cannulae, depending on the size of the patient. The actual alveolar O₂ depends both

on FIO_2 and flow rate and varies with respiratory rate, tidal volume and the amount of room air entrained with each breath.

D. FIO_2 is measured by **portable O_2 analyzers**, calibrated to display % inspired O_2 .

ALVEOLAR GAS EQUATION, used to calculate PAO_2 (the maximal arterial oxygen tension that theoretically can be achieved at any given FIO_2), is defined as:

$$PAO_2 = FIO_2 (PBAR - PH_2O) - PACO_2/RQ$$

This can be simplified by the following considerations:

- PH_2O at $37^\circ C = 47$ mmHg.
- $PBAR$ at sea level varies from 745 to 765 mmHg, and can be assumed for this calculation to be 747 mmHg.
- Assume that $PACO_2 = PaCO_2$.
- Assume that $RQ = 1$.

Then, the Alveolar Gas Equation can be simplified to:

$$PAO_2 = FIO_2 (700) - PaCO_2$$

Example: Using this simplified version, we can calculate that an infant, who is breathing 30% O_2 ($FIO_2 = 0.3$), has an arterial CO_2 of 40 mmHg and has perfect matching of ventilation and perfusion, would have an alveolar oxygen tension of:

$$PAO_2 = 0.3(700) - 40 = 170 \text{ mmHg}$$

IMPORTANT TECHNIQUES

MASK and BAG VENTILATION:

- A. The gas flow rate should be ~5-6 L/min.
- B. Place the infant's head in neutral position facing straight forward.
- C. Ensure that the mask fits closely to the face and covers the mouth and nose without compressing the eyes or nares. **Do not allow the mask to slide down from bridge of nose and occlude the nares.**
- D. Do not apply pressure with your fingers to the submental triangle, as you may push the tongue back and obstruct the airway. Keep your fingers on the mandible.
- E. Place the small finger of one hand at the angle of the jaw and pull forward.
- F. Apply sufficient pressure to the bag to move the chest gently with each inflation. Over-inflation of the lung, even for brief periods, can initiate lung damage that may persist for months to years.
- G. Allow sufficient time between each breath for complete exhalation.
- H. If the infant is making spontaneous breathing efforts, attempt to inflate the lungs as the infant inhales.
- I. Generate sufficient PEEP to maintain FRC (~5 cmH₂O) and increase PaO_2 without compromising intravascular pressures.
- J. Insert an orogastric tube and leave it open to atmospheric pressure to avoid gastric distention that may prevent descent of the diaphragm and interfere with ventilation.

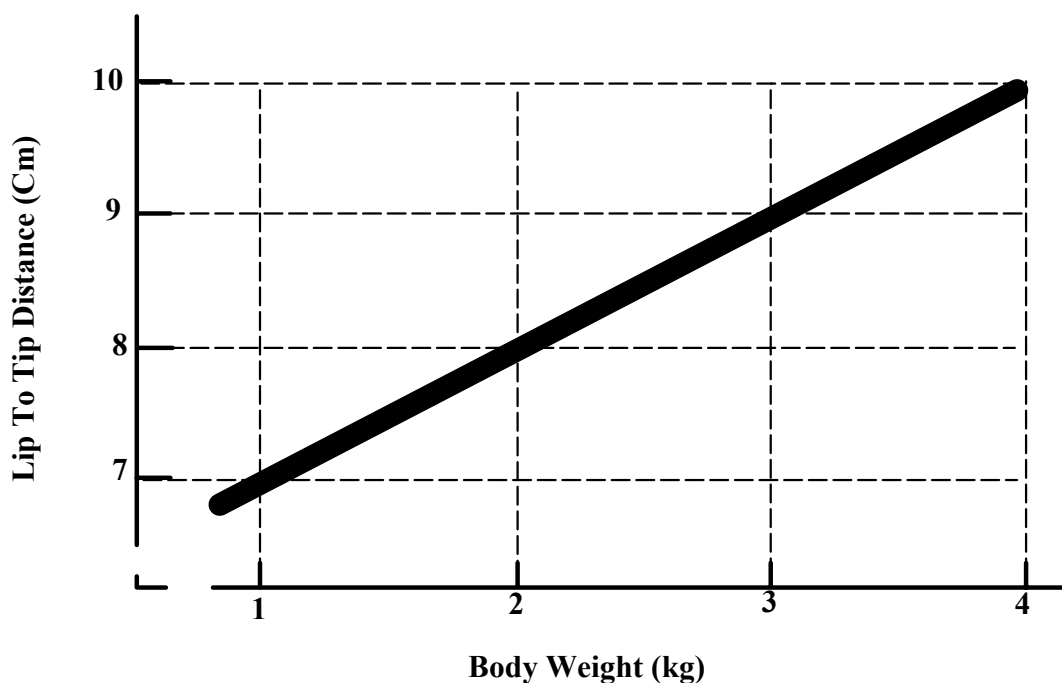
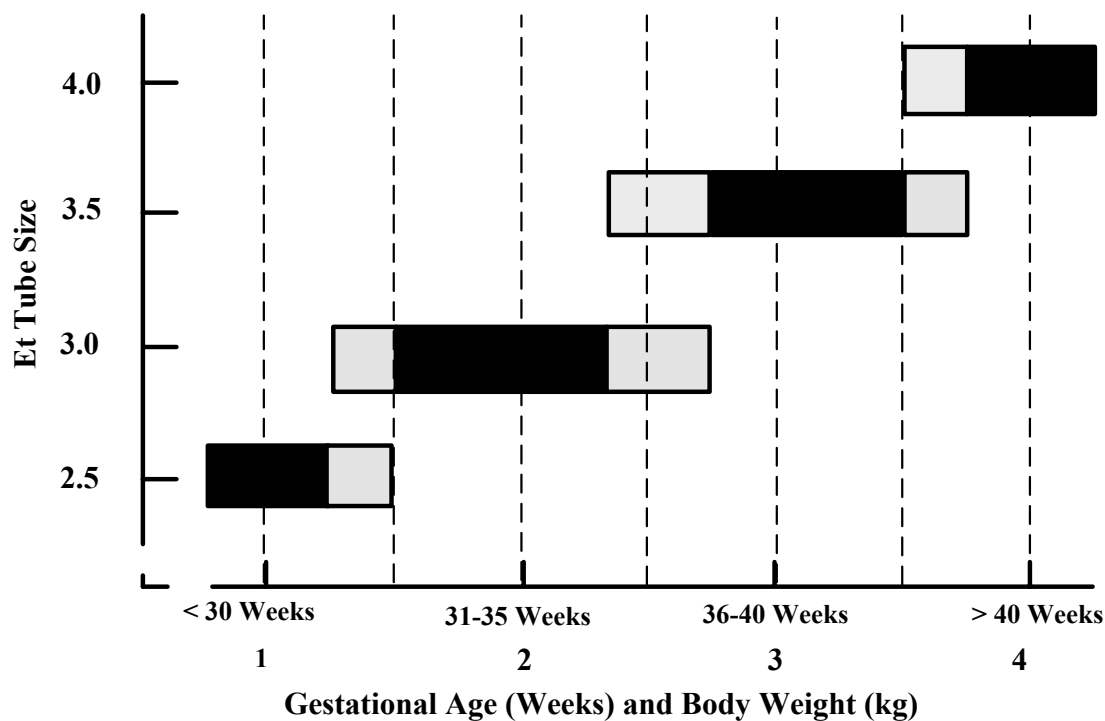


Figure 1: Top: Solid bars, usual size of tube to be used for infants of the corresponding birth weight and gestational age; shaded bars, range of bigger and smaller infants in which that size of tube may be needed on occasion.

Bottom: Distance from the infant's lip to the tip of the tube when the tip is in the midtrachea. Most endotracheal tubes have numbered centimeter marks on the sides indicating the distance to the tip. The appropriate number should be even with the infant's lip. These are guidelines. There will be some variation among infants.

TRACHEAL INTUBATION: (Many patients die from lack of oxygen, but few die from lack of an endotracheal tube.)

- A. Before attempting tracheal intubation, ventilate the patient's lungs by mask and bag with sufficient O₂ to raise PaO₂ or SpO₂ to normal.
- B. With elective or semi-elective intubation and if the baby is hemodynamically stable, give morphine (0.1 mg/kg) and/or lorazepam (0.05 mg/kg) IV to facilitate intubation, to prevent increases in intracranial pressure, and decrease stress responses due to intubation. Monitor blood pressure; even these low drug dosages can produce hypotension if the infant is hypovolemic.
- C. **Muscle relaxants are almost never necessary.** Do not administer them unless (1) the infant resists vigorously after sedation has been given and (2) you can effectively ventilate the patient's lungs with mask and bag before administering the muscle relaxant. **Succinylcholine may cause cardiac arrest when the serum K⁺ concentration is elevated or when there is CNS or muscle injury.**
- D. See **Figure 1 for appropriate size of endotracheal (ET) tube.** Tube size is determined by infant's weight and also by gestational age. Always use an ET tube with an internal diameter (I.D.) <1/10 of the infant's gestational age (*i.e.*, if gestational age is 35 weeks, use a 3.0 I.D. tube, not a 3.5 tube).
- E. Use an ET tube that has only an end hole. **Do not use tubes with a side hole (Murphy Eye) close to its tip, as they are prone to occlusion by secretions and are associated with subglottic stenosis.**
- F. Laryngoscope: Use Miller #1 blade for term infants and Miller #0 for smaller infants.
- G. **Empty the stomach** to reduce the risk of vomiting and aspiration.
- H. Position the patient's head close to the end of the bed with the **head in the "sniffing position."** Avoid hyperextension or flexion of the neck, since either may occlude the larynx and make intubation more difficult.
- I. During tracheal intubation, place **head in neutral position facing straight forward**, insert laryngoscope along right side of the tongue, and move tongue towards the left side of the mouth. Advance tip of the laryngoscope blade into the vallecula and pull upward and caudad at a 45° angle. About 90% of the laryngoscope blade should be within the mouth when the blade is appropriately positioned. This puts the light where needed and allows for maximal control of the blade. Do not apply pressure on the gums with the laryngoscope blade, as this may permanently injure the teeth.
- J. Hold laryngoscope with thumb and index finger of left hand. Hold chin with ring and middle fingers, and push on the hyoid bone with small finger of the left hand. This allows head, hand, and laryngoscope to move as a unit if patient's head moves, and prevents pharyngeal injury by the laryngoscope blade. Pushing on the hyoid bone moves the larynx posteriorly and improves visualization of the larynx.
- K. Insert the ET tube under direct vision. While visualizing the larynx, **insert the ET tube through right side of the mouth to the right of the laryngoscope**; watch the ET tube tip pass between the vocal cords. Do not insert ET tube through the laryngoscope. This blocks your vision and increases the likelihood of esophageal intubation and injury to the vocal cords. Advance the ET tube until the heavy black line is at the vocal cords.
- L. **BE GENTLE! DO NOT USE FORCE!**

- M. If intubation is difficult and **bradycardia +/- or cyanosis occur, stop the procedure.** Ventilate the patient's lungs with mask and bag until color and heart rate return to normal.
- N. **Reflex bradycardia** is common during tracheal intubation, but heart rate should return to normal quickly with adequate ventilation of the lungs with oxygen.
- O. **Figure 2** is a guide for proper positioning of the ET tube. Carefully monitor tube position until it is securely taped in place. Immediately obtain a chest x-ray to confirm proper position of ET tube (*i.e.*, **tip of ET tube 1 cm above carina**). Important points regarding proper ET tube placement are:
- 1) Position of infant's head: **Neck flexion advances tube down airway; neck extension withdraws tube.** Try to take x-ray with head in neutral position.
 - 2) Tension on ET tube (With loose tape, tube can move up to 1 cm in or out.
 - 3) Principal focus of x-ray beam.
 - 4) Position and alignment of the clavicles on x-ray.
 - 5) **Tip of ET tube should be between T1 and T2** (except with congenital diaphragmatic hernia, when carina may be more cephalad than normal).
- P. The bevel on the ET tube tip must face ventrally, or the tube may obstruct. If the **blue line running lengthwise on the tube is to the left, the bevel will face ventrally.**

Complications of Tracheal Intubation:

- A. With the most common complication, **intubation of the esophagus**, SpO₂ and heart rate do not increase with bag and tube ventilation, the abdomen rapidly distends, and breath sounds are louder over the stomach than axillae. Withdraw the ET tube and ventilate with a bag, mask and oxygen.
- B. Advancing the ET tube too far, so that its **tip is in the right mainstem bronchus**, is a common and serious complication. As soon as the ET tube is in place and with head in the neutral position, begin gentle bag and tube ventilation. Observe the upper chest for chest movement. Another person should auscultate the chest to ensure that heart rate returns to normal quickly and that breath sounds are equal (not just present) bilaterally. If breath sounds are unequal (usually the left is decreased), the tube is in too far (or there is a pneumothorax). While continuing to ventilate the lungs and to auscultate the chest, withdraw the ET tube slowly until breath sounds are equal bilaterally. When the tube is in appropriate position, note a mark (letter, number) on the tube that is even with the upper lip. Fix the tube in place keeping the tube in the same position.
- C. **Bleeding**, especially if the patient has a coagulopathy. Bleeding can be avoided by using gentle, appropriate techniques for tracheal intubation.
- D. **Bradycardia and hypoxemia** (See above under Tracheal Intubation)
- E. **Subglottic stenosis**, a late complication occurs from a tight fitting tube that occludes blood flow to adjacent soft tissues. This infrequent, but serious, complication can usually be prevented by ensuring that there is a small gas leak between endotracheal tube and trachea when ventilatory pressures are 15-30 cmH₂O.

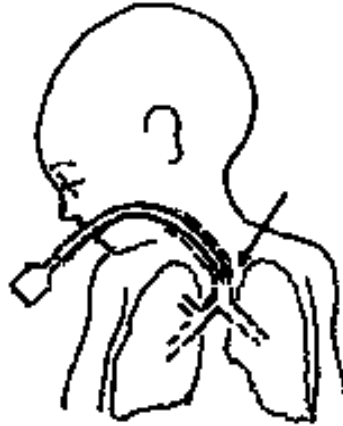


Figure 2. Diagram of proper position of tip of endotracheal tube.

Suctioning of Endotracheal Tube:

- ET tube obstruction** is a constant threat; signs of occlusion include an increase in PaCO₂ or tcPCO₂, decreased breath sounds, inability to pass suction catheter through ET tube, and increase in the pressure required to ventilate the lungs.
- Endotracheal suctioning is necessary because the **ET tube reduces mucus transport in airways**. However, suctioning decreases lung volume and causes atelectasis. After suctioning, the lungs must be re-expanded using gentle pressure.
- Patients with **Respiratory Distress Syndrome may need no suctioning in the first 24h**. Suctioning may be required 2-3 times/day on the 2nd day and q4-12h after that.
- See section on Respiratory Distress Syndrome (P. 79) for suctioning after surfactant administration.
- Infants with **aspiration syndromes will need more frequent suctioning** (at least q12h).
- Suctioning is a **two-person procedure**, and must be performed gently.
- Many infants tolerate the suctioning procedure and require no changes in ventilation or oxygenation. However, some infants may require increased respirator settings (PIP, rate and FIO₂) during and after the procedure, because **suctioning often reduces FRC**, which recovers very slowly unless the lungs are re-expanded. Judge the need for hand ventilation after the suctioning procedure on an individual basis. Some infants may be managed more effectively by adjusting the ventilator.
- Orders for needed changes in FIO₂ during suctioning must be written daily. If transient ventilator changes are needed for the infant to tolerate suctioning, the settings should be returned to baseline as soon as possible.
- For infants who do not tolerate the suctioning well (*e.g.*, SpO₂ decreases significantly, recovery takes a long time), discuss the case with Attending Physician or Neonatology Fellow and then write orders appropriate for the infant's care.

Extubation of the Trachea:

- A. **Empty stomach** before extubating the trachea. Do not feed patient for at least 4 h after extubation, especially if trachea has been intubated for more than 24 h.
- B. Remove ET tube when it is clear that the infant no longer needs tracheal intubation (*i.e.*, PIP <20 cmH₂O, ventilator rate <10, and PEEP ≤4 cmH₂O).
- C. Suction the trachea and re-expand the lungs.
- D. Remove ET tube with lungs in **full inspiration** and with positive pressure applied to the lungs to prevent aspiration of secretions when ET tube is removed.
- E. With extubation, **increase inspired O₂ concentration ~5%**; then decrease it based on SpO₂.
- F. After tracheal extubation, monitor the infant carefully for early signs of **respiratory distress and hypoventilation** (that may be immediate or progressive) including:

•Grunting	•Nasal Flaring	•Stridor
•Restlessness	•Retractions	•Cyanosis
•Irritability	•Tachycardia	•Hypertension
•Tachypnea	•CO ₂ retention	•Need for increased O ₂
- G. For **stridor** (usually due to laryngeal edema), give inhalations of the vasoconstrictor, **racemic epinephrine** 2.25% (0.2-0.25 mL). For bronchospasm, give inhalations of a bronchodilator, either **metaproterenol** (Alupent) 5% (0.1-0.2 mL) or **albuterol** (Ventolin) 0.5% (0.1-0.4 mL).
- H. When there is progressive or severe respiratory worsening after extubation, reintubate the trachea early. **Do not wait for respiratory failure.** After reintubation, it is often necessary for a time to use higher ventilator pressures (to re-expand areas of atelectasis) than were needed just prior to extubation. Later, the pressures can be reduced. It may be useful to obtain a chest x-ray to rule out post-extubation atelectasis (4-8 h after extubation).

METHODS of RESPIRATORY SUPPORT

General Principles:

- A. The aims of ventilatory support are to maintain adequate oxygenation and ventilation, to reduce respiratory work and to prevent lung injury.**
- B. With mechanical ventilation, use small or normal tidal volumes and the lowest effective ventilator pressures. Both large tidal volumes and high pressures cause lung injury and inflammation, especially in preterm infants.**
- C. PEEP is critical for maintenance of FRC. PEEP is the main factor that influences \bar{P}_{AW} , a major determinant of oxygenation.**
- D. Minute ventilation (the amount of gas moved in and out of the lung per minute) is the product of respiratory rate and tidal volume.**

Continuous Positive Airway Pressure (CPAP):

- A. CPAP, used during spontaneous breathing, increases FRC, lowers airways resistance, and has variable effects on respiratory rate, minute ventilation and compliance.
- B. Application of CPAP by ET tube is the best way to ensure that the desired pressure is applied to the lungs.
- C. Application of CPAP by mask or nasal prongs avoids the need for an ET tube, but does not ensure that the desired pressure is applied. These forms of CPAP are useful to prevent re-intubation of the trachea in infants recovering from lung disease. In some cases, NCPAP is applied in the delivery room shortly after birth to reduce the need for tracheal intubation; the efficacy of this is unproven.
- D. Gastric distention by nasal or mask CPAP may interfere with ventilation.
- E. The amount of pressure applied to the airway by NCPAP is not constant. The pressure is decreased (even to atmospheric) when the mouth is open or the nasal prongs become dislodged.
- F. NCPAP usually is not effective if >8 cmH₂O pressure is required.
- G. Flow rates of 6 L/min are used during the application of CPAP.
- H. In some cases of apnea, CPAP is useful as a respiratory stimulant.

Positive Pressure Ventilation (PPV):

- A. PPV by mask and bag is useful to stabilize the patient's condition until the trachea can be intubated and the lungs mechanically ventilated.
- B. In infants, PPV is usually pressure-limited (not volume-limited as in older patients) and time cycled. This means that no more than the preset pressure can be generated and that respiratory rate is set by adjusting inspiratory (Ti) and expiratory (Te) times.
- C. With each breath there is a PIP, a PEEP, and a \bar{P}_{AW} .
- D. Raising PEEP increases FRC (in most cases) and reduces/prevents atelectasis. If PIP is not changed, raising PEEP reduces tidal volume and lowering PEEP increases tidal volume, when ventilation is pressure-limited.
- E. Prolonging Ti allows more time for expansion of the lungs and is useful to treat widespread atelectasis. With localized atelectasis, a long Ti may worsen the infant's condition by over-expanding non-atelectatic areas of lung and reducing venous return and pulmonary blood flow.

- F. **High inspiratory flows may injure the lungs.** Consequently, it is seldom necessary to use gas flows >10 L/min. Flows of 6 to 8 L/min are usual; some very small babies with mild lung disease can be ventilated with 4 L/min. Assess flow rates at start of PPV, with changes in respirator settings, and if the patient is not improving.
- G. Ventilation pressures should be monitored continuously. Guides to adequate ventilation are normal chest movement and blood gas tensions.
- H. Tidal volume is generated by the difference between PIP and PEEP. Changing PIP or PEEP independently of the other may increase or decrease tidal volume.
- I. Oxygenation is primarily a function of F_{iO_2} and \bar{P}_{AW} , “the area under the curve.” **Figure 3** shows the effects on \bar{P}_{AW} during a single breath of changing each of the following: (1) inspiratory flow, (2) PIP, (3) T_i , and (4) PEEP. Note that when inspiratory flow is increased, PIP is reached earlier and the pressure wave becomes more “square,” but the durations of T_i and T_e do not change. Also, (not shown in Figure 3) \bar{P}_{AW} increases when the respiratory rate is increased, because T_e decreases.
- J. Respiratory rate is altered by adjusting T_i and T_e . A very **short T_e leads to gas trapping** within the lung. The minimal required T_e varies with the disease state of the lungs but usually should not be <0.6 sec with standard mechanical ventilation.
- K. T_i is usually set at 0.3 to 0.4 sec (almost always <0.5 sec). T_e will then be related to the respiratory rate. For example, if $T_i = 0.4$ sec and respiratory rate is 60/min, then each respiratory cycle lasts 1.0 sec; therefore, T_e will be 0.6 sec. If respiratory rate is 30/min with the same T_i (0.3 sec), each respiratory cycle lasts 2 sec and T_e will be 1.6 sec. (Note: the “I to E ratio” is **calculated** from the above. In the first example I:E = 1:1.5; in the second example I:E = 1:4. **Do not manage ventilation by the I:E ratio.** The actual T_i (to facilitate lung inflation), the actual T_e (to avoid gas trapping) and the respiratory rate should guide ventilator management.
- L. The **time constant (TC)** of the lung is a measure of the time necessary for the alveolar pressure to reach 63% of the change in applied airway pressure. For example, if $T_i =$ one TC, only 63% of the pressure difference applied by the ventilator will be equilibrated at the alveolar level, and the delivered tidal volume will be proportional to the equilibrated pressure. TC is a function of lung compliance and airways resistance. When lung disease is not uniform throughout the lung, TC will vary in different parts of the lung. The longer the duration allowed for pressure equilibration (*i.e.*, during T_i and T_e), the greater the equilibration that will occur. Equilibration of pressures will be 86% complete when T_i (or T_e) = 2TC and 95% complete when T_i (or T_e) = 3TC. Further prolongation has little effect. If T_i or T_e as set on the ventilator is not $\geq 3TC$, there may be incomplete delivery of tidal volume (leading to hypoxemia and/or hypercarbia) or incomplete exhalation (leading to gas trapping, increased FRC, inadvertent PEEP and hypercarbia). **TC varies with the state of the lung** (*i.e.*, type of lung disease). Examples include:

<u>Lung Condition</u>	<u>TC (sec)</u>
Normal newborn	0.12
Hyaline membrane disease (HMD)	0.025*
Meconium aspiration syndrome	0.28

*TC increases markedly with recovery from HMD and with surfactant treatment.

Ventilators also have a TC; for most ventilators, complete exhalation requires 0.3 sec.

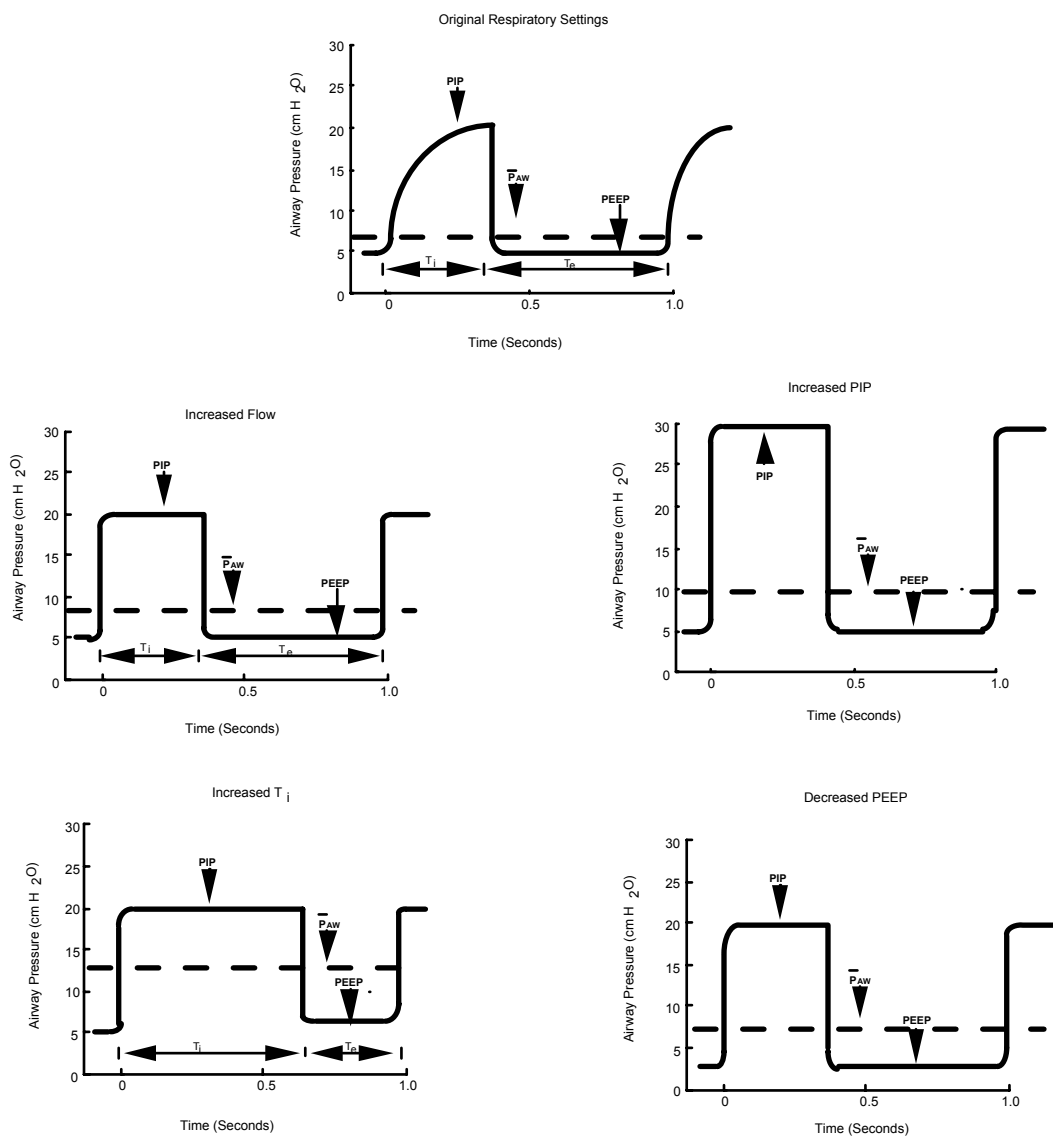


Figure 3. Effects of changing different variables on the ventilator. Please see text for discussion.

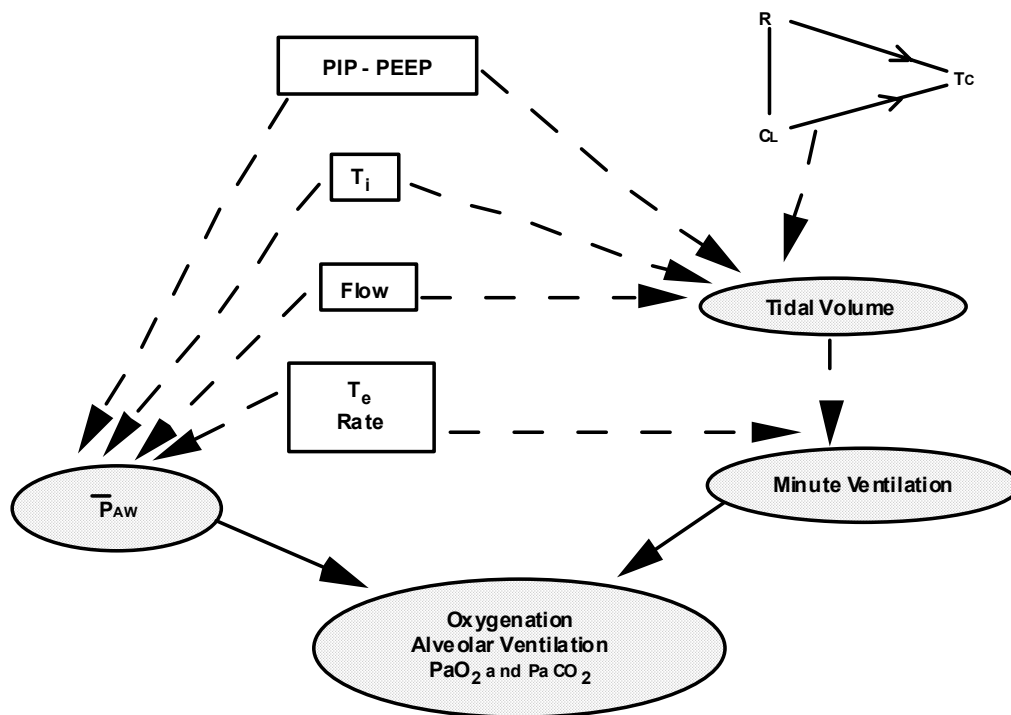
M. Common adjustments in respirator management:

<u>Condition</u>	<u>Management Strategies</u>
High PaCO ₂ (>55 mmHg)	Increase ventilator rate, if Ti & Te are not too short Increase PIP Consider decreasing PEEP, if >5 cmH ₂ O
Low or normal PaCO ₂	Decrease PIP, decrease rate
Low PaO ₂	Increase FiO ₂ (see Table 1) Increase \bar{P}_{AW} by raising PEEP (or Ti, PIP and/or flow)
High PaO ₂	Decrease FiO ₂ Decrease PEEP (see Table 1).

The interrelationship between ventilator controls, pulmonary mechanics and ventilation in a newborn with a pressure ventilator are illustrated in **Figure 4**.

With pressure-limited ventilation, tidal volume depends on PIP – PEEP, lung compliance, and the pressure gradient between airway and alveolar pressures. A short Ti, in relation to the TC, will reduce tidal volume at a given pressure gradient. Lowering flow (L/min) may also decrease tidal volume, depending on Ti and TC.

FIGURE 4



Raising PEEP to >6-7 cmH₂O will rarely increase oxygenation. In fact high PEEP (and \bar{P}_{AW}) may over-distend the lung, leading to increased dead space (hypercarbia) and right-to-left shunting (hypoxemia) and impair venous return and cardiac output. In this last case, PaO₂ may be normal, but O₂ transport and O₂ delivery to the tissues will be reduced.

An additional variable is the **compression volume of the ventilator circuit**, the amount of gas compressed in the circuit with each breath (*i.e.*, a compression volume of 5, a common value, means that for every cmH₂O pressure generated, 5 mL of gas will be compressed in the circuit). Compression volume is not important in pressure-limited ventilation, but is a critical variable for volume ventilation.

- N. As lung disease improves (especially after surfactant administration), reduce ventilator pressures to prevent lung injury. **Table 1** gives guidelines to the relationship between FIO₂ and \bar{P}_{AW} . In general, an infant in lower O₂ should be able to tolerate lower airway pressures.

Table 1: A guide to the relationship between FIO₂ and mean airway pressure.

FIO ₂	Mean Airway Pressure
<0.25	5
0.25-0.30	6-7
0.31-0.40	7-9
0.41-0.50	8-10
0.50-0.60	9-11
>0.6	>10

- O. **Sedation** is usually used to prevent “fighting the ventilator” and to facilitate mechanical ventilation. Initially, use morphine (0.05 - 0.1 mg/kg q3-4h). Other forms of sedation to consider include phenobarbital (2.5 mg/kg/day maintenance) and lorazepam (0.05-0.1 mg/kg q6-12h. Reserve use of muscle relaxants, or paralytic agents, (*e.g.*, pancuronium 0.1 mg/kg IV) for those critically ill neonates who cannot be adequately ventilated. Following administration of sedatives or muscle relaxants, it is often necessary to alter the ventilator settings because oxygenation and carbon dioxide concentrations may change suddenly, in either direction.
- P. With each change in ventilator settings, **document the infant’s responses in tcPCO₂, SpO₂ and arterial blood gas tensions**. Measurements of arterial pH and blood gas tensions should be made 15-30 min after each ventilator change during the acute phase of the disease, particularly when non-invasive monitors (*i.e.*, SpO₂ and tcPCO₂) are not giving reliable results.

High Frequency Ventilation (HFV): including oscillator, flow-interruptor, and jet ventilator:

- A. With these forms of ventilation, the lungs are ventilated at very high rates with **tidal volumes smaller than anatomic deadspace**.
- B. Ventilation rates are very high, about 300 to 900 breaths/min.

- C. HFV is very effective in removing CO₂. Thus, it is easy to hyperventilate the patient. However, because **hypocarbica decreases cerebral blood flow** and may cause brain damage, care must be taken to avoid respiratory alkalosis (*i.e.*, pH>7.5).
- D. HFV is less effective at increasing oxygenation. Therefore, compared to conventional ventilation, a higher \bar{P}_{AW} is required to achieve equivalent oxygenation.
- E. HFV is most commonly used for patients who have air leaks (*i.e.*, pneumothorax or pulmonary interstitial emphysema), pulmonary hypoplasia or severe pulmonary hypertension.
- F. The **oscillator** (SensorMedics) pushes gas into the lung during inspiratory phase and pulls it out during the expiratory phase. This active exhalation may help prevent gas trapping. This ventilator is effective in large infants. Settings that can be adjusted are:
- | | |
|----------------|--|
| Rate | Usually between 6 and 12 Hz (360 to 720 breaths/min) |
| Amplitude | Similar to tidal volume |
| \bar{P}_{AW} | Affects oxygenation |
| Flow | Affects inspiratory flow rate |
- G. The **flow interruptor** (Infant Star Ventilator) allows a rapid inflow of gas for a brief period, and then exhalation is passive. HFV can be used with or without a back-up rate of conventional ventilation. This ventilator is most useful in preterm infants, but is not usually effective in larger infants.
- H. The jet ventilator injects a small volume of gas into the airway through a small tube connected to the endotracheal tube and entrains gas from the endotracheal tube. Gas can easily be trapped within the lung. Currently, jet ventilation is not used in the UCSF ICN.
- I. Early studies suggested a higher rate of intracranial hemorrhage in very low birth weight infants treated with oscillatory ventilation, a finding not seen in later studies.
- J. Because of the noise associated with HFV, it can be difficult to detect air leaks or other lung changes by physical examination and other monitors. Therefore, **obtain a chest radiograph at least daily.**

Synchronized Intermittent Mandatory Ventilation (SIMV): Conventional intermittent mandatory ventilation (IMV) produces mechanical breaths at preset intervals. In a spontaneously breathing infant, many ventilator breaths will be out of phase with the infant's breaths. Consequently, the infant may struggle against the ventilator resulting in decreased oxygenation and ventilation and an increased risk of air leaks, unless the infant is heavily sedated or paralyzed.

SIMV provides mechanical breaths at a preset rate, but the exact timing of the ventilator breath occurs together with spontaneous breaths. SIMV synchronizes the ventilator breaths by **sensing** spontaneous inspiration efforts of the patient, using the "time frame window" concept: if the patient does not breath, the ventilator will deliver a mechanical breath; if the patient breathes too quickly, only a preset number of breaths will trigger the ventilator. The sensing of the spontaneous breath by the ventilator is accomplished either by (a) an abdominal sensor that detects respiratory movement or (b) a pressure sensor attached to a flow transducer on the adapter of the ET tube. With a properly functioning sensor, more than 90% of the ventilator breaths will be synchronized with the infant's breaths, leading to increased oxygenation and ventilation, less need for sedation and less barotrauma to the lungs.

With the current generation of infant ventilators, a variety of ventilatory techniques are possible, including SIMV, pressure support, and volume ventilation. The use and the details of management with these techniques should be discussed with the Neonatology Fellow or the Attending Physician for each individual patient.

Complications of Assisted Ventilation:

A. Ventilator Failure due to

- (1) Accidental **disconnection of the ventilator** from the ET tube (which can rapidly lead to asphyxia) activates the low-pressure alarm of the ventilator.
- (2) **Obstruction of the ventilator tubing** activates the high-pressure alarm. Ventilate the lungs by bag and tube. If no improvement, suspect obstruction of the ET tube. Remove ET tube and ventilate lungs with mask and bag. Reintubate the trachea when the infant's condition is stable.
- (3) Accidental tracheal extubation is usually accompanied by decreasing oxygenation and/or abdominal distension. Remove ET tube and ventilate by mask and bag. Because abdominal distension may prevent effective ventilation, insert an oro-gastric tube to remove gas from the stomach.

B. Pulmonary Tamponade occurs when lungs become over-expanded by gas trapped within the lung. Causes include: excessive PIP or PEEP, Te that is too short, air leak or a partially blocked ET tube. Effects of pulmonary tamponade **include decreased chest movement, hypercarbia and hypoxemia**. Severe tamponade impedes venous return and decreases cardiac output, **causing blood pressure to decrease**. If you suspect pulmonary tamponade and there is an indwelling arterial catheter, **disconnect ventilator from ET tube for ~5 sec** while carefully observing the blood pressure tracing. If tamponade is the problem and is due to maladjustment of the ventilator, **the blood pressure will increase within a few heartbeats**. Correct the problem by ventilator adjustment (*e.g.*, lengthen Te, lower PIP and/or PEEP, shorten Ti).

C. Air Leaks

(1) Pneumothorax

- A **tension pneumothorax** is an emergency heralded by a fall in SpO₂ and a rise in PaCO₂. Arterial pressure increases with a small pneumothorax, but with a large tension pneumothorax arterial pressure falls, pulse pressure narrows and central venous pressure increases.
- The ipsilateral hemithorax is hyperinflated (expanded), moves poorly with ventilation and may have decreased breath sounds. Heart sounds and maximal cardiac impulse may be shifted to the contralateral side.
- Increased transillumination on the affected side, but is not a constant finding.
- If pneumothorax is suspected, order **stat chest x-ray** (AP & cross-table lateral)
- If the patient's condition rapidly worsens, insert a 22 gauge angiocath between **3rd and 4th ribs (midclavicular line over the superior aspect of the 4th rib)** into the pleural space. Attach syringe and 3-way stopcock; then aspirate with the syringe. If gas is obtained, continue to remove gas from the chest, emptying the syringe through the 3-way stopcock.
- For long-term removal of air, insert an 8-10 Fr thoracostomy tube through the 5th interspace in the mid axillary line, directing the tube anteriorly. Remember that the **intercostal neurovascular bundle is on the inferior surface of the ribs**, so pass the tube over the top of the 6th rib. If the patient's condition

allows it, give 0.1 mg/kg of morphine IV and local anesthesia with 1% lidocaine (Do not give >5 mg/kg.). Once inserted, connect the chest tube to suction of 5-10 cmH₂O in the suction chamber. In some cases of rapid air leak, it is necessary to place an anterior chest tube in the midclavicular line.

Avoid inserting this catheter through the breast bud, nipple or areola.

-Suture the chest tube in place and apply a gas-tight dressing.

-When there has been no gas leak for 24 h, turn off the suction on the chest tube.

Do not clamp the tube; leave it to underwater seal. If no gas accumulates in the pleural space after several hours, rapidly remove the chest tube at end-inspiration to prevent air from being sucked into the pleural space as the catheter is removed. Cover the wound immediately with a 2x2 gauze with bacitracin ointment on it to provide a seal, then close the chest tube hole with sutures or a clip, and obtain a repeat chest x-ray.

(2) Pneumopericardium

-A pneumopericardium seldom causes problems for an infant.

-Rarely, a tension pneumopericardium causes **cardiac tamponade**, obstructing venous return and decreasing cardiac output. When this emergency occurs, **immediately call the Neonatology Fellow or Attending and Cardiology.** If the infant is rapidly worsening, insert a 22 gauge angiocath beneath the sternum just lateral to the xiphoid aiming towards the left shoulder. Apply negative pressure as the angiocath is advanced. **As soon as air is obtained, stop advancing the needle** or you risk injuring the heart. Withdraw the needle and leave the angiocath in place connected to a stopcock to allow evacuation of the gas. If there is time, insert the catheter into the pericardium under echocardiographic guidance.

-It is rarely necessary to insert a larger tube into the pericardium to remove air.

(3) **Pneumomediastinum** seldom causes distress or requires treatment in infants. If it does, have the surgeons insert a mediastinal tube.

(4) **Pneumoperitoneum** results from perforation of a hollow viscus or from dissection of air from the mediastinum into the abdomen. Differentiation between these may be difficult, but can usually be resolved by the following:

-Patients with **bowel perforation often appear toxic** with discoloration of the abdomen, leukocytosis and a left shift of the white blood cell count.

-**Chest x-ray:** A patient with dissection of gas from the mediastinum will almost always have lung disease with a pneumomediastinum or air seen in the inferior pleural ligament (“behind the heart”).

-**Abdominal paracentesis:** With bowel perforation, stool-like material can usually be aspirated. When pneumoperitoneum results from dissection of gas from the thorax, only gas can be aspirated.

-**Measure PO₂ of the aspirated gas.** If infant is breathing >30% O₂, the PO₂ of the gas will usually be >150 mmHg if the gas is from the thorax. With bowel perforation, PO₂ of the aspirated gas is almost always <100 mmHg.

Occasionally, enough gas dissects into the abdomen to restrict ventilation. If this occurs, insert a catheter or tube into the peritoneal cavity to drain the gas.

D. Chronic Lung Disease most commonly occurs in very preterm infants or after ventilation with very high pressures and FiO₂ (See Chronic Lung Disease, P. 93)