

**ASSISTED VENTILATION  
IN  
NEONATES**

# CONTINUOUS POSITIVE AIRWAY PRESSURE (CPAP)

## DEFINITION

Continuous Positive Airway Pressure or CPAP is a modality of respiratory support in which increased pulmonary pressure is provided artificially during the expiratory phase of the respiration in a spontaneously breathing neonate.

It is distinct from Intermittent Positive Pressure Ventilation (IPPV) or Intermittent Mandatory Pressure Ventilation (IMV) in which breathing is taken over by the ventilator machine completely and the increase in pulmonary pressure occurs during both inspiratory as well as expiratory phases.

## DEVICES OF PROVIDING CPAP

- Nasal prongs
- Nasopharyngeal prongs
- Endotracheal tube

Nasal prongs are the most popular, convenient and practical method of providing CPAP. Nasopharyngeal prongs are also a convenient method but not so popular. Face chamber and face mask CPAP is no longer in use.

Table shows relative advantages and disadvantages of nasal prongs and endotracheal tube as CPAP devices. The place of endotracheal CPAP is very limited in current neonatal practice.

**Table: Advantages and disadvantages of CPAP systems**

Feature	Nasal Prongs	Endotracheal Tube
Advantages	<ul style="list-style-type: none"> <li>• Simpler device</li> <li>• Ease of application</li> <li>• Mouth leak provides pressure relief</li> </ul>	<ul style="list-style-type: none"> <li>• Most efficient</li> <li>• Fixation is easy</li> <li>• No leaks</li> <li>• Low gas flow can be used</li> <li>• High CPAP can be attained</li> </ul>
Disadvantages	<ul style="list-style-type: none"> <li>• Difficult to obtain good fit</li> <li>• Needs frequent oral suction</li> <li>• Difficult to apply in very small baby</li> <li>• Crying leads to loss of pressure</li> <li>• Needs high gas flow</li> </ul>	<ul style="list-style-type: none"> <li>• Invasive procedure</li> <li>• Endotracheal intubation is a difficult skill</li> <li>• Baby breaths through a 'straw' hence it increases work of breathing</li> <li>• Baby cannot grunt</li> </ul>

	<ul style="list-style-type: none"> <li>• May cause trauma to nasal septum/ turbinates</li> <li>• May increase work of breathing</li> <li>• Liable to obstruction in prongs, if gases are not humid</li> </ul>	<ul style="list-style-type: none"> <li>• Can cause tracheal trauma</li> <li>• Risk of infection</li> </ul>
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## PHYSIOLOGIC CONSIDERATIONS

The principal effects of CPAP administered in the optimum range are:

1. Recruitment of atelectatic alveoli
2. Increase in functional residual capacity (FRC)
3. Improved compliance
4. Decrease in airway resistance by increase in airway caliber due to pressure.
5. Conservation of surfactant
6. Stabilization of chest and diaphragm especially in tiny infants with highly compliant chest.

## EFFECT ON BLOOD GASES WITH OPTIMUM CPAP

### 1. Oxygen

CPAP improves oxygenation by increase in FRC through recruitment of atelectatic alveoli.

### 2. Carbon dioxide

CPAP decreases CO<sub>2</sub> because of availability of greater surface area for gas exchange with recruitment of alveoli. Excessive CPAP, however, causes overdistension of alveoli and inadequate emptying in expiration leading to CO<sub>2</sub> retention.

**Note:** *It should be remembered that CPAP is essentially a modality for improving oxygenation. The CO<sub>2</sub> advantages are seen only in the moderate range of CPAP (5-6 cm water).*

## ADVERSE EFFECTS OF EXCESSIVE CPAP

### 1. Cardiovascular

- Increased intrathoracic pressure which causes diminished venous return leading to a decrease in cardiac output
- Increased central venous pressure
- Increased pulmonary vascular resistance

## 2. Pulmonary

- Overdistension
- Diminished compliance
- Air leak when endotracheal CPAP is used

## 3. CNS

- Increased intracranial pressure
- Decreased cerebral perfusion

## 4. GIT

- Bowel distension with nasal prong CPAP due to swallowed air
- Decreased GI blood flow

## 5. Kidneys

- Diminished blood flow

## CONTROL OF CPAP THERAPY

### 1. CPAP Ranges

A neonate produces a physiological end expiratory pressure of about 3 cm H<sub>2</sub>O, that, therefore may be taken as the lower limit of CPAP.

The upper limit of CPAP is 10 cm H<sub>2</sub>O. Hence, CPAP has three broad ranges:

Range	Endotracheal cm H <sub>2</sub> O	Nasal cm H <sub>2</sub> O	Comment
Low	3-4	4-5	CPAP of less than 3 is never given
Medium	5-7	6-8	Good range, best results
High	8-10	9-11	Adverse effects become increasingly bothersome

As specified above, it is conventional to add 1 cm of additional pressure to the endotracheal ranges when nasal/ nasopharyngeal CPAP is used.

By and large, nasal CPAP is provided in the range of 5-8cm of H<sub>2</sub>O.

Often the starting endotracheal CPAP is 5-6cm of nasal CPAP.

### 2. FiO<sub>2</sub>

CPAP is used in conjunction with oxygen. Thus, the concentration of oxygen in inspired air (FiO<sub>2</sub>) is another parameter controlled during CPAP therapy from room air (FiO<sub>2</sub> 0.21) to 100% (FiO<sub>2</sub> 1.0).

## INDICATIONS OF CPAP

1. Respiratory distress, moderate or severe : retractions/ grunt
2. Recurrent apnea
3. PaO<sub>2</sub> below 60 torr with FiO<sub>2</sub> over 0.6 (60%) in oxygen hood.

## GUIDELINES FOR INITIATION OF CPAP

The following guidelines essentially apply to a baby with Respiratory Distress Syndrome (RDS) due to mild or moderate Hyaline Membrane Disease (HMD).

For practical purposes, it is the **nasal CPAP** which is most relevant to neonatal care.

- Start with **nasal CPAP** of 5-6cm H<sub>2</sub>O and FiO<sub>2</sub> 0.4-0.5
- If oxygenation is inadequate, increase CPAP by 1cm H<sub>2</sub>O, as required
- Reach a CPAP level of 8-9 cm H<sub>2</sub>O
- Now increase FiO<sub>2</sub> in steps of 0.05 (i.e. 5%) to a maximum of 0.8

Obtain blood gases after initial stabilization and then as required.

The aim is to achieve a satisfactory respiratory status clinically and on blood gases (see below).

## WEANING FROM CPAP

- Reduce nasal CPAP to a level of 8 cm H<sub>2</sub>O
- Reduce FiO<sub>2</sub> by 0.05 decrements to reach FiO<sub>2</sub> of 0.4
- Now reduce CPAP by 1 cm H<sub>2</sub>O decrements
- Reach a level of CPAP of 4 cm water and FiO<sub>2</sub> of 0.4
- Remove CPAP, place the baby in the oxygen hood

## ADEQUACY OF CPAP (SATISFACTORY CARDIORESPIRATORY STATUS)

1. Comfortable baby
2. Absence of retractions, grunt
3. Absence of cyanosis
4. Capillary refill time of 3 sec or less
5. Oxygen saturation 90-93%

6. Blood gases: PaO<sub>2</sub> 60-80 torr, PaCO<sub>2</sub> 40-55 torr, PH 7.30-7.40

### **FAILURE OF CPAP**

1. Continuing retractions or grunt
2. Apnea on CPAP
3. PaO<sub>2</sub> less than 50 torr in FiO<sub>2</sub> of over 0.8 with nasal CPAP of over 9 cm water
4. CO<sub>2</sub> retention (more than 55 torr)
5. Baby not tolerating CPAP prongs despite best efforts

In these situations mechanical ventilation (IMV) should be initiated.

### **MONITORING DURING CPAP**

#### **(a) Clinical**

- Comfort/ restlessness
- RR, grunt, retractions (Silverman/ Downe's scores)
- Cyanosis
- Heart rate, pulse
- Capillary refill time, blood pressure
- Temperature, cold stress
- Abdominal girth
- CPAP device: dislocation, blockage, undue local pressure
- Urine output

#### **(b) Pulse oximetry**

Pulse oximetry is invaluable in managing neonates with RDS on oxygen/ CPAP. Ensure oxygen saturation in the range of 90-93 percent. Set alarm at 88 percent (lower limit) and 95 percent (upper limits).

#### **(c) Blood gases**

Blood gases are required after initial stabilisation and then as the baby's condition demands.

### **Important practical considerations**

1. Warm the gases to 34-37°C

2. Humidify the gases
3. Use appropriate sized prongs
4. Keep gas flow at about 5-8 litre/minute
5. Ensure that there is no blockage in prongs due to secretions or kinking by periodic observation
6. Suction the oral cavity, if there are secretions (often bubbles)
7. In order to decompress the swallowed air, pass orogastric catheter and keep the proximal end open
8. Look for blockage of nares. Gentle suction may be done. Instill a drop of normal saline, if necessary
9. Change CPAP prongs/circuit every 3 days
10. Stabilise the head of the baby by suitable padding, ensure that there is no undue pressure on the soft tissues
11. Ensure asepsis

## **CPAP IN DIFFERENT CLINICAL SITUATIONS**

### **1. Respiratory Distress Syndrome (RDS)**

- RDS or Hyaline Membrane Disease (HMD) is an excellent indication of CPAP. CPAP is ideally suited to RDS of mild to moderate severity. The most important consideration is that CPAP must be started early. This helps in preventing alveolar collapse and thereby conserving surfactant
- The guideline given above primarily apply to HMD
- Early and liberal use of CPAP as the primary mode of management of RDS has been shown to be not only highly effective, but also associated with low rates of chronic lung disease.

### **2. Delayed adaptation**

- The cases of delayed adaptation are clinically akin to that of HMD. Here again one must begin early.

### **3. Meconium Aspiration Syndrome (MAS)**

- MAS is a reasonable indication of CPAP. A nasal CPAP of 4-7 cm water often helps these babies and is not associated with risks of overdistension of air leak
- MAS is a disease of term babies and sometimes they don't tolerate the irritation of nasal CPAP device. Mild sedation with triclofos may be tried. But if the infant is still restless, it may be wise to switch over to IMV.

#### **4. Apneic spells**

- CPAP helps neonates with apneic spells in many ways: by improving oxygenation, by splinting the diaphragm, by distending the airway and overcoming the obstructive element and by regularisation of respiration
- True indication of CPAP is apnea of prematurity. Secondary apneic spells should be treated by managing the underlying condition. However, secondary apneic spells of respiratory origin (e.g. pneumonia) may also respond to CPAP
- For this indication, nasal CPAP 4-6 cm water CPAP is generally enough

#### **5. For – extubation**

- Endotracheal CPAP has been used as an intermediate step between IMV and extubation. A recent metaanalysis, however, does not support this practice.
- Nasal CPAP, however, is recommended after extubation from IMV. This prevents post extubation atelectasis. Often 4-5 cm water CPAP is adequate in this condition.

#### **6. Pneumonia**

- A neonates with pneumonia may be helped by CPAP to some extent. CPAP will help recruit alveoli if there is atelectasis/consolidation. It will perhaps also prevent/treat associated apneic spells to some extent
- In sick neonates with pneumonia, especially those with systemic manifestations, CPAP would not work

#### **7. Other indications**

- Other indication of CPAP are post-operative cases, sleep apnea and bronchomalacia

### **CPAP DELIVERY SYSTEMS**

#### **1. Ventilator**

Ventilator is ideal system to provide CPAP, but is expensive. It has blender for oxygen-air mixing , FiO<sub>2</sub> dial, humidifier, safety feature and a system to warm the gases. One simply has to switch over to CPAP mode and attach the baby.

#### **2. CPAP system**

CPAP system which deliver pressure and gases are appearing on the Indian scene. An ideal system must have the following capabilities:

1. End expiratory pressure of 0-15 cm water.

2. Humidification of upto 100%
3. Gas flow 5-8 l/min
4. Warming of gases to 34-37°C.
5. Blending of oxygen air mixture (FiO<sub>2</sub> range of 0.21-1.0)
6. Display of FiO<sub>2</sub>
7. Safety device against excess pressure
8. Tubing made of medical grade material with low dead space
9. Patient outlet to fit on to standard nasal prong system
10. Sterilizability of tubings etc.
11. Low noise compressor
12. Capability to run continuously for days and weeks
13. Good aesthetics, easy caring
14. Easy maintenance
15. Reasonable cost

Unfortunately none of the CPAP recently marketed in India have the above features.

### **3. Improvised system**

Several books show a simple CPAP system using under-water system. In principle this system is workable, albeit cumbersome. But, in India, it will have to be used with 100% oxygen only because air-oxygen blenders are not available. This means that we will always have 100 percent oxygen with CPAP which is not rational. It is, therefore, not a good method to be used in practice.

#### **Further Reading**

1. Goldsmith JP Karotkin Ett. Assisted ventilation of the neonates. Philadelphia: WB Saunders 1996.
2. Hansen TN, Cooper TR, Weisman LE. Contemporary diagnosis and management of neonatal respiratory disease. Newborn Handbooks in Health Care, 1995.

# **INTERMITTENT MANDATORY VENTILATION (IMV)**

## ABBREVIATIONS

<b>CLD</b>	Chronic Lung Disease
<b>C<sub>L</sub></b>	Compliance
<b>CPAP</b>	Continuous Positive Airway Pressure
<b>FiO<sub>2</sub></b>	Fraction of inspired oxygen
<b>HMD</b>	Hyaline Membrane Disease
<b>IE</b>	Inspiratory – Expiratory ratio
<b>IMV</b>	Intermittent Mandatory Ventilation
<b>IPPV</b>	Intermittent Positive Pressure Ventilation
<b>K<sub>t</sub></b>	Time constant
<b>MAP</b>	Mean Airway Pressure
<b>MAS</b>	Meconium Aspiration Syndrome
<b>NICU</b>	Neonatal Intensive Care Unit
<b>P</b>	Pressure
<b>PaCO<sub>2</sub></b>	Partial Pressure of Carbon Dioxide in Arterial Blood
<b>PAL</b>	Pulmonary Air Leak
<b>PaO<sub>2</sub></b>	Partial Pressure of Oxygen in Arterial Blood
<b>PEEP</b>	Positive End Expiratory Pressure
<b>PIP</b>	Positive Inspiratory Pressure
<b>R</b>	Resistance
<b>RDS</b>	Respiratory Distress Syndrome
<b>RR</b>	Respiratory Rate
<b>T<sub>i</sub></b>	Inspiratory rate
<b>T<sub>e</sub></b>	Expiratory rate
<b>T<sub>tot</sub></b>	Total time of respiratory cycle
<b>T<sub>v</sub></b>	Tidal volume
<b>V</b>	Volume
<b><math>\dot{V}</math></b>	Flow

## Part I

# VENTILATORS

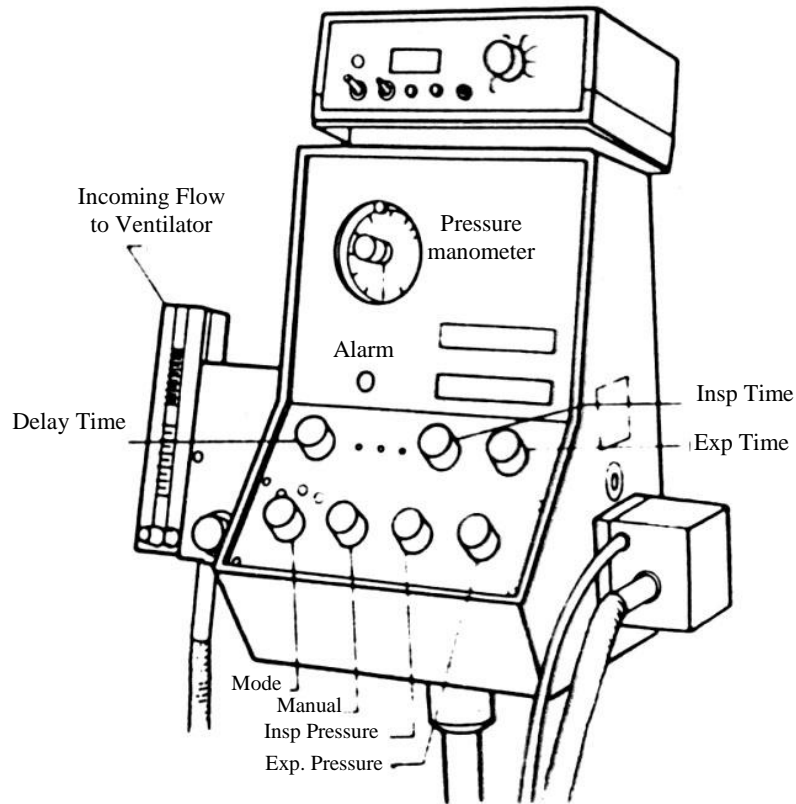
### 1. POSITIVE PRESSURE VENTILATORS

Positive Pressure Ventilators are devices which, when connected to the respiratory tract of the patient, deliver air/oxygen under pressure at a preset frequency. They are classified by clinicians as either pressure type (i.e. pressure-limited) or volume type (i.e. volume-limited). The pressure-limited ventilators generate a predetermined inspiratory or inflating pressure, whatever the resultant tidal volume. In contrast, the volume-limited ventilators aim at delivering a predetermined tidal volume, whatever the required inflating pressure. While both types of ventilators have relative merits and demerits (Table 1), most neonatologists prefer pressure-limited ventilators.

**Table 1: Relative merits and demerits of pressure-limited and volume-limited ventilators**

Pressure-limited Ventilators	Volume-limited Ventilators
<i>Merits</i>	
<ol style="list-style-type: none"><li>1. Simple design, low cost, easy operation.</li><li>2. Positive inspiratory pressure (PIP), key parameter related to bronchopulmonary dysplasia is directly controllable.</li><li>3. The inspiratory and expiratory timings also directly controllable.</li></ol>	<ol style="list-style-type: none"><li>1. Because of consistent tidal volume, there is no hypo or hyperinflation with changes in compliance.</li></ol>
<i>Demerits</i>	
<ol style="list-style-type: none"><li>1. The tidal volume depends on the compliance of the lungs, hence, there is likelihood of hyperventilation and overinflation when the lungs become less or more compliant, respectively.</li></ol>	<ol style="list-style-type: none"><li>1. Tidal volume in neonates is small, may be lost in the ventilator circuit.</li><li>2. Since the tidal volume is constant the normally compliant areas tend to get preferentially ventilated; the atelectatic areas (which require higher opening pressure) continue to remain unventilated.</li><li>3. The design is complicated, the cost is high and operation is difficult.</li></ol>

## Line diagram of the Sechrist IV 100B ventilator showing controls



Many of the commonly used neonatal ventilators are pressure-limited ventilators. Their cycling (inspiration-expiration-inspiration.....) is generally governed by the preset inspiratory and expiratory times. They are, therefore, also specified as *time-cycled* ventilators. They also provide continuous flow of gases throughout the respiratory cycle, hence termed *constant-flow generators*.

## 2. VENTILATOR MODES

- ***Intermittent Positive Pressure Ventilation (IPPV) or Intermittent Mandatory Ventilation (IMV)***

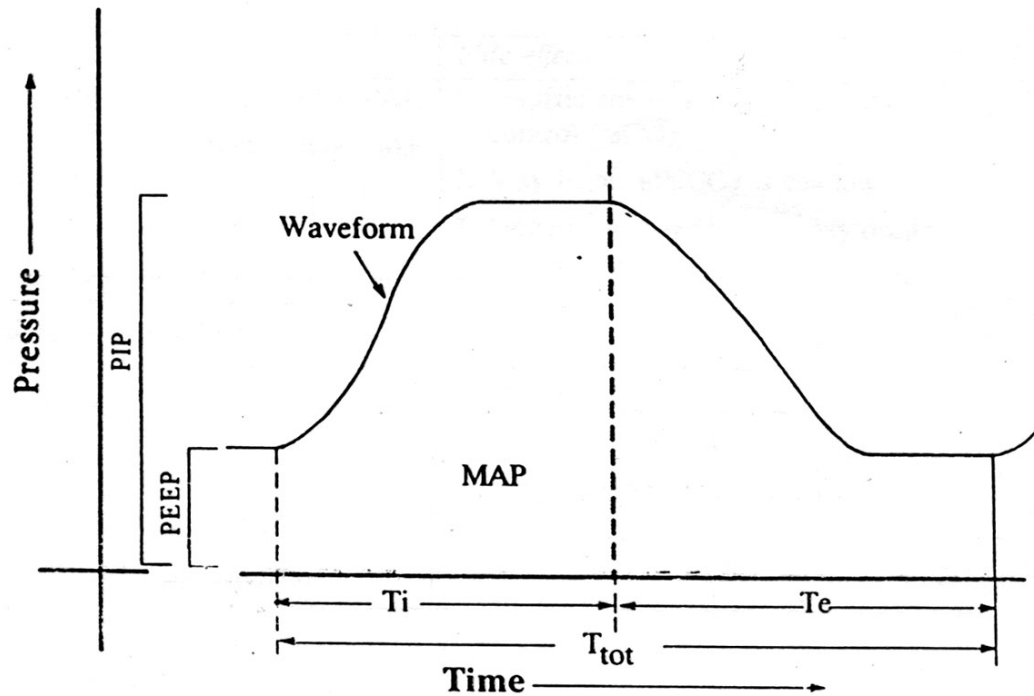
In functional terms, both the IPPV and IMV denote the same ventilators mode wherein the ventilator is set to provide a predetermined number of ventilatory breaths irrespective of the fact whether the infant does or does not breathe spontaneously. Some clinicians reserve use of the term IMV in weaning states when slow ventilator rates are employed encouraging the baby to take spontaneous breaths.

- ***Continuous Positive Airway Pressure (CPAP)***

A mechanical ventilator is not a must to provide CPAP, simpler devices may be satisfactory. However, most present-day ventilators provide CPAP mode. The ventilator generates a constant positive pressure throughout the respiratory cycle in the neonatal respiratory tract (to which it is connected by nasal prongs, nasopharyngeal tube or endotracheal tube) without generating any ventilatory breath. The baby continues to breathe spontaneously.

### 3. VENTILATOR CONTROLS

The key settings that regulate the pressure-limited ventilators are: inspired oxygen concentration ( $FiO_2$ ), peak inspiratory pressure (PIP), positive end expiratory pressure (PEEP), respiratory rate, inspiratory-expiratory ratio (I:E) and flow rate. Flow rate affects the waveform. Mean Airway Pressure (MAP) is the net outcome of all the parameters except  $FiO_2$  and respiratory rate. Figure 2 depicts these parameters in relation to the respiratory cycle.



**Figure 2: Ventilator control in relations to the respiratory cycle**

It needs to be emphasized that in a pressure-limited ventilator the tidal volume is determined by the following factors: compliance of the lungs, PIP,  $T_i$  and flow, of which PIP is the most important.

Table 2 gives advantages and side-effects of different ranges of individual controls. This description helps one select the most suitable combination of ventilator

settings which would meet the physiological needs of the infant at lowest ‘cost’ in terms of adverse effects.

**Table 2: Advantages and side-effects of different ranges of ventilator controls**

**(i) Positive Inspiratory Pressure (PIP)**

- Low ( $\leq 20$  cm H<sub>2</sub>O)

<i>Advantages</i>	<i>Side effects</i>
1. Fewer side effects especially CLD, PAL	1. Insufficient ventilation may not control PaCO <sub>2</sub>
2. Normal lung development may take place faster	2. May have $\uparrow$ PaCO <sub>2</sub> if too low
	3. Generalized atelectasis may occur

- High ( $> 20$  cm H<sub>2</sub>O)

<i>Advantages</i>	<i>Side effects</i>
1. May re-expand atelectasis	1. Associated with PAL, CLD
2. $\uparrow$ PaO <sub>2</sub>	2. May impede venous return
3. $\downarrow$ PaCO <sub>2</sub>	
4. $\downarrow$ Pulmonary artery hypertension	

**(ii) Positive End Expiratory Pressure (PEEP)**

- Low (0-3cm H<sub>2</sub>O)

<i>Advantages</i>	<i>Side effects</i>
1. Used during weaning	1. May be too low to maintain adequate lung volume
2. Maintenance of lung volume in premature infants with $\downarrow$ FRC	2. CO <sub>2</sub> retention

- Medium (4-7 cm H<sub>2</sub>O)

<i>Advantages</i>	<i>Side effects</i>
<ol style="list-style-type: none"> <li>1. Stabilizes areas of atelectasis</li> <li>2. ↑Lung volume in surfactant deficiency</li> </ol>	<ol style="list-style-type: none"> <li>1. May over-distend if lungs have normal compliance</li> </ol>

- High (8-10cm H<sub>2</sub>O)

<i>Advantages</i>	<i>Side effects</i>
<ol style="list-style-type: none"> <li>1. Prevents alveolar collapse in surfactant deficiency with ↓C<sub>L</sub> and lung volume</li> <li>2. Improves distribution of ventilation</li> </ol>	<ol style="list-style-type: none"> <li>1. PAL</li> <li>2. ↓C<sub>L</sub> if lung volume increases too much (over-distention)</li> <li>3. May impede venous return (metabolic acidosis)</li> <li>4. May increase pulmonary vascular resistance</li> <li>5. CO<sub>2</sub> retention</li> </ol>

### (iii) Respiratory Rate (RR)

- Slow (<40 breaths per minutes)

<i>Advantages</i>	<i>Side effects</i>
<ol style="list-style-type: none"> <li>1. Previous studies reported ↑PaO<sub>2</sub> at slower rates</li> <li>2. Used for weaning</li> <li>3. Used with square wave, inverse I:E ratio</li> <li>4. May ↑oxygenation if used with longer inspiratory time</li> </ol>	<ol style="list-style-type: none"> <li>1. To maintain ventilation at slow rates, must use ↑PIP</li> <li>2. Patient may require paralysis</li> </ol>

- Rapid (> 60 breaths per minute)

<i>Advantages</i>	<i>Side effects</i>
1. One study reported ↑PaO <sub>2</sub> at higher rates	1. May have insufficient emptying time at rates greater than 80 (inadvertent PEEP)
2. Rapid rate successful in one uncontrolled series of small infants	2. May exhibit frequency dependence of compliance
3. Hyperventilation useful in PPHN	3. May produce iatrogenic respiratory alkalosis
	4. May result in inadequate TV or minute volume

**(iv) Waveform**

- Sine Wave

<i>Advantages</i>	<i>Side effects</i>
1. Smoother increase of pressure	1. Lower mean airway pressure
2. More like normal breathing pattern	

- Square wave

<i>Advantages</i>	<i>Side effects</i>
1. Higher mean airway pressure for equivalent PIP	1. With high flow, the ventilator may be applying higher pressure to normal alveoli resulting in barotrauma
2. Longer time at peak pressure, may open up atelectasis or improve distribution of ventilation	2. Could impede venous return if inverse I:E ratio is used

(v) **Inspiratory-Expiratory Ratio (I:E)**

- Inverse (3:1, 2:1)

<i>Advantages</i>	<i>Side effects</i>
<ol style="list-style-type: none"><li>1. ↑PaO<sub>2</sub> in mild RDS</li><li>2. ↑Mean airway pressure, may improve distribution of ventilation</li></ol>	<ol style="list-style-type: none"><li>1. May have insufficient emptying time with air trapping</li><li>2. May impede venous return</li><li>3. Contraindicated in diseases with increased pulmonary vascular resistance</li></ol>

- Equal (1:1)

<i>Advantages</i>	<i>Side effects</i>
<ol style="list-style-type: none"><li>1. Close to natural frequency</li><li>2. May give best balance at high rates</li></ol>	<ol style="list-style-type: none"><li>1. At high rates may have insufficient emptying time</li></ol>

- Prolonged expiratory (1:2, 1:3)

<i>Advantages</i>	<i>Side effects</i>
<ol style="list-style-type: none"><li>1. Useful during weaning</li><li>2. May be optimal in MAS and obstructive lung disease</li><li>3. May be necessary if ↓ elastic recoil (small premature infants)</li></ol>	<ol style="list-style-type: none"><li>1. Insufficient inspiratory time may cause ↓ tidal volume</li><li>2. May have to use high flow rates, which are not optimal for distribution of ventilation</li><li>3. May be ventilating more dead space</li></ol>

(vi) **Flow Rate**

- Low (0.5 to 3 l/min))

<i>Advantages</i>	<i>Side effects</i>
1. Slower inspiration time, more of a sine wave type inspiration curve	1. Hypercapnia if flow rate is not high enough to remove CO <sub>2</sub> from system 2. At high ventilation rate, low flow rate may not be high enough to reach required PIP

- High (4 to 10 l/min)

<i>Advantages</i>	<i>Side effects</i>
1. For mild RDS produces more square waveform 2. Necessary to attain high PIP with high ventilation rates 3. Prevents CO <sub>2</sub> retention	1. Barotrauma 2. In moderate to severe RDS, square waveform may be contraindicated 3. PAL

## Part II

# APPLIED RESPIRATORY PHYSIOLOGY

### 1. LUNG MECHANICS

- **Definitions**

- *Compliance*

Compliance ( $C_L$ ) measures distensability of a system and is defined as change in volume ( $\Delta V$ ) per unit changes in pressure ( $\Delta P$ ).

$$C_L = \frac{\Delta V}{\Delta P} \quad (\text{litre/cm H}_2\text{O})$$

- *Resistance*

Resistance ( $R$ ) to the flow of gas(es) in the respiratory tract depends on the difference of pressure ( $\Delta P$ ) between the mouth and the alveoli per unit flow ( $V$ ).

$$R = \frac{\Delta P}{V} \quad (\text{cm H}_2\text{O/litre/sec})$$

The flow of gases is inversely related to the power 4 of radius of the passage.

$$\dot{V} \propto \frac{1}{\text{radius}^4}$$

The airway resistance is predominantly contributed by the medium-sized bronchi.

- **Time constant**

Time constant ( $Kt$ ) is the product of compliance ( $C_L$ ) and resistance ( $R$ ).

$$Kt = C_L \times R \quad (\text{sec})$$

$Kt$  determines the time taken for the transthoracic pressure change to be transmitted as volume change in the lungs. A period equal to 5  $Kt$  is required for near-total inflation or deflation of the lungs.

- **Implications for positive pressure ventilation**

Please note the values of  $C_L$ , R and Kt in normal neonates and those having hyaline membrane disease (HMD) and meconium aspiration syndrome (MAS) in Table 3.

- It is evident that HMD is associated with severe reduction in compliance without any change in resistance; while MAS leads to a markedly high resistance with some decrease in compliance.
- In mechanical ventilation, the inspiratory phase is ‘active’ and is associated with relatively high flow of air/oxygen. As flow is inversely related to resistance, Kt is very small. Thus, short inspiratory time may be quite satisfactory in most situations. However, the ventilator expiratory phase is ‘passive’. The Kt values depicted in Table 3 are therefore essentially applicable to the selection of expiratory time. Kt is short in HMD. It follows that it is possible to use short expiratory time in HMD. In MAS on the other hand, long Kt demands prolonged expiratory time to avoid air trapping.

**Table 3: Compliance ( $C_L$ ), resistance (R) and time constant (Kt) in normal and abnormal states in the newborn.**

Condition	$C_L$ (L/cm H <sub>2</sub> O)	R(cm H <sub>2</sub> O/L/sec)	Kt (sec)
Normal	0.005	20	0.10
HMD	0.001	20	0.02
MAS	0.003	100	0.30

## 2. DETERMINANTS OF OXYGENATION AND CO<sub>2</sub> ELIMINATION IN A VENTILATED NEONATE

- **Oxygenation**

PaO<sub>2</sub> of a neonate on a pressure–limited, time–cycled ventilator is directly dependent on two parameters, namely, FiO<sub>2</sub> (fraction of inspired oxygen) and MAP (mean airway pressure). MAP increases with the following settings.

- (i) High PIP
- (ii) High PEEP
- (iii) High I:E, and
- (iv) Square wave.

- **CO<sub>2</sub> elimination**

CO<sub>2</sub> elimination is a function of alveolar ventilation.

Alveolar ventilation = (tidal volume – dead space volume) x respiratory rate.

Dead space tends to be constant in a given situation.

Therefore,

CO<sub>2</sub> elimination  $\propto$  tidal volume x respiratory rate

The product of tidal volume and respiratory rate is called minute ventilation.

Tidal volume in a pressure-limited ventilator is largely a function of PIP.

Hence, CO<sub>2</sub> elimination is dependent on the two following ventilator controls:

- (i) PIP, and
- (ii) Rate.

## Part III

# CASE MANAGEMENT

### 1. INDICATIONS FOR MECHANICAL VENTILATION

The decision to start mechanical ventilation in a neonate should be individualized and based on clinical as well as blood gas parameters. Presence of *two or more* parameters listed in Table 4 will, in general, form an indication for mechanical ventilation.

**Table 4: Indications for mechanical ventilation in neonates**

- 
1. Retractions: moderate or severe
  2. Respiratory rate greater than 70
  3. Cyanosis with  $\text{FiO}_2$  greater than 0.4
  4. Intractable apneic spells
  5. Impending or existing shock
  6.  $\text{PaO}_2$  less than 50 mm Hg in  $\text{FiO}_2$  greater than 1.0
  7.  $\text{PaCO}_2$  greater than 60
  8.  $\text{PH} < 7.25$
- 

*Note: In general, the presence of two or more of the above parameters in a neonate will be an indication for mechanical ventilation.*

In case blood gas analysis is not available, *it is quite safe, practical and desirable to initiate mechanical ventilation on clinical grounds alone*. Severity of intercostal and subcostal retractions, in particular, is a major indicator of the abnormality in lung mechanics and volume. *Retractions* are one of the first signs of respiratory failure in the neonate as the highly compliant chest attempts (in vain) to keep the poorly compliant atelectatic lungs expanded. Indeed, if severe retractions are evident, a neonate should be started on assisted ventilation (with either CPAP or IPPV) before other parameters become manifest.

### 2. INITIAL SETTINGS

- **General guidelines**

Initial steps in starting positive pressure ventilation include endotracheal intubation, selection of appropriate ventilators settings and evaluation to check adequacy of ventilatory support (Table 5).

**Table 5: Initiation of positive pressure ventilation**

---

1. Intubate baby, fix endotracheal tube. Check ventilator. Air/oxygen should be warmed to 37°C and humidified to 70-100 percent.

2. *Initial settings:*

FiO <sub>2</sub>	0.5
Rate	40-50 per minute
PIP	18-20 cm H <sub>2</sub> O
PEEP	4-5 cm H <sub>2</sub> O
Ti	0.40-0.45 sec

3. Observe infant for cyanosis, absence of retractions, chest wall movement and breath sounds.

4. If ventilation is inadequate, increase PIP by 1 cm H<sub>2</sub>O every few breaths until air entry appears adequate.

5. If oxygenation is inadequate as indicated by presence of cyanosis or poor saturation on pulse-oximeter, increase FiO<sub>2</sub> by 0.05 every minute until cyanosis is abolished or the saturation touches 90-95 percent.

6. Draw arterial blood gas.

---

- **Ventilator settings**

- *Rate*

The ventilator rate is based on the decision whether the ventilator is taking over the work of breathing fully or partially. Since in most situations, at the outset of mechanical ventilation the disease process is still evolving, it is logical to take over the respiration completely. To achieve this, the ventilator rate has to be in the range of or higher than the normal spontaneous respiratory frequency of the neonate. The spontaneous respiratory rate of neonates is usually between 40 to 50 per minute. Therefore, the initial ventilator rate should be between 40 to 50, smaller the neonate, higher the number within this range (*vice versa* for larger neonates)

➤ *Flow*

Initial flow rate should be 5 to 7 liters per minute to ensure adequate CO<sub>2</sub> wash out and a sufficiently high MAP. Flow rate above 10 l/min is dangerous and seldom necessary.

➤ *PIP*

A normal breath necessitates intrathoracic pressure to drop from -1 cm H<sub>2</sub>O to -7 cm H<sub>2</sub>O, i.e., a pressure changes of 6 cm H<sub>2</sub>O. A pressure of 6 cm H<sub>2</sub>O is required to drive the gases through the ventilator circuit. Thus, if a neonate with normal lungs were to be ventilated, a PIP of about 12 cm H<sub>2</sub>O will be required. However, in practice, neonates necessitating ventilation are likely to have poor compliance of varying severity due to the underlying disease (HMD, pneumonia). A higher PIP is therefore indicated. Clinically mild, moderate, severe and very severe respiratory distress will consequently require PIP (cm H<sub>2</sub>O) in the range of 15-19, 20-24, 25-29 and over 30. As mechanical ventilation would be instituted in the evolving stage of disease, mild to moderate in severity, it is logical to start with PIP of about 18-20 cm H<sub>2</sub>O and modify it later. It is also advisable to hand-ventilate the baby using anesthesia-type bag connected to endotracheal tube and to estimate the PIP on a manometer. The inflating pressure that results in adequate chest expansion should be taken as the initial PIP setting.

➤ *PEEP*

Normal physiologic PEEP is approximately 3 cm H<sub>2</sub>O. The initial PEEP is usually 4-5 cm H<sub>2</sub>O. PEEP should not exceed 8 cm H<sub>2</sub>O in most situations.

➤ *T<sub>i</sub>*

The inspiratory time should be in the range of 0.40 to 0.45 seconds close to the physiologic values. At the rates mentioned above, the resultant I:E ratios would range from 1:1 to 1:2.

➤ *FiO<sub>2</sub>*

Initial FiO<sub>2</sub> should be set at 0.5, an intermediate concentration.

### 3. MONITORING ADEQUACY OF VENTILATION THERAPY

The ventilator settings are potentially always in a dynamic state especially in the acute stage making frequent alterations necessary. Judicious clinical monitoring along with pulse-oximetry and periodic blood gas analyses are critical to the success of ventilator therapy. The parameters indicating adequacy of ventilation are listed in Table 6.

**Table 6: Parameters indicating adequate ventilation**

**1. Clinical parameters**

- Comfortable baby
- Absence of cyanosis
- Absence of retractions
- Prompt capillary filling\*
- Normal blood pressure
- Adequate chest expansion
- Adequate air entry

**2. Pulse oximetry**

Saturation 90-93%

**3. Blood gases**

- PaO<sub>2</sub> 60-80 torr
- PaCO<sub>2</sub> Acute 40-50 torr, chronic up to 60 torr
- PH 7:30 – 7:40

- *Capillary filling is normal if after blanching the nail or tip of finger the colour returns on counting 1, 2, pink*

**4. CHANGING VENTILATOR SETTINGS**

Table 7 summarizes the selection of ventilation settings to achieve a desired change in PaO<sub>2</sub> and/ or PaCO<sub>2</sub>.

**Table 7: Desired blood gas status and the possible changes(s) in ventilator settings which will achieve it (using pressure-type ventilator)**

Desired Status	Ventilator Settings				
	Rate	PIP	PEEP	Ti	FiO <sub>2</sub>
Increase PaCO <sub>2</sub>	↓	↓			
Decrease PaCO <sub>2</sub>	↑	↑			
Increase PaO <sub>2</sub>		↑	↑	↑ *	↑
Decrease PaO <sub>2</sub>		↓	↓	↓ *	↓

\* *Fine tuning, sparingly employed*

The changes should be made in short steps. PIP and PEEP should be altered by only 1 cm H<sub>2</sub>O at a time, rate by 2 breaths/minute, FiO<sub>2</sub> in steps of 0.05 and Ti by 0.05 seconds installments. Blood gas estimation should be performed 20-30 minutes after each change.

In an effort to minimise the adverse effects of any one extreme ventilator parameter, it is believed that the various settings should be stepped up or stepped down hand in hand. For instance, it would be considered inappropriate to have FiO<sub>2</sub> 0.95, PIP 18 cm H<sub>2</sub>O, PEEP 4 cm H<sub>2</sub>O to achieve optimum blood gases. It can be seen that FiO<sub>2</sub> is at near-maximum, while PIP and PEEP settings are at near-minimum. It is advisable to switch over to lower FiO<sub>2</sub> and higher PIP or PEEP settings (provided no contraindication such as pneumothorax exists).

PEEP requirements go in consonance with FiO<sub>2</sub> as follows:

<b>FiO<sub>2</sub></b>	<b>PEEP (cm H<sub>2</sub>O)</b>
0.3	3
0.4	4
0.5	5
0.6	6
0.7-0.8	7
above 0.8	8

## **5. ENDOTRACHEAL SUCTION**

Endotracheal suction is necessary to maintain patency of the tube. On first few days, it may be required only occasionally. More frequent suction is indicated during subsequent days as more and more mucus and debris needs clearing. At this stage, in general, chest physiotherapy should precede suction. Chest physiotherapy is contraindicated in the presence of PAL.

Suction is carried out in 3 positions of the head, namely, straight, right rotation and left rotation. Choose appropriate suction catheter. Instil 0.5-1.0 ml of normal saline into the trachea. Hand-ventilate for 60 seconds at the PIP and rate that the baby was on , but using FiO<sub>2</sub> higher by 0.1. Insert the catheter and apply suction (80 mm Hg) while pulling it out. Undertake the procedure in all the 3 head-positions.

Throughout the procedure the neonate should be carefully watched. It is ideal to use pulse-oximeter for continuous monitoring.

## **6. WEANING**

Weaning is a delicate procedure and should be undertaken with utmost caution (Figure 3). Natural history of the underlying disease dictates the possible age at which weaning can be initiated. For instance, in hyaline membrane disease, there is

no question of weaning on the first day; process is generally initiated on 3<sup>rd</sup> or 4<sup>th</sup> day concomitant with point of maximum diuresis that heralds recovery. Infants with HMD may be off the ventilator by 5<sup>th</sup>-8<sup>th</sup> day unless they develop chronic lung disease. On the other hand, babies with uncomplicated meconium aspiration or pneumonia can be weaned off much earlier.

- The first setting to be reduced is PIP, by 1 cm H<sub>2</sub>O decrements, to 25 cm H<sub>2</sub>O. High PIP is the major predisposing factor for CLD.
- At this stage, PIP and FiO<sub>2</sub> (decreased by 0.05 at a time) are reduced alternately till a relatively safe level of 20 cm H<sub>2</sub>O and 0.6, respectively, is reached.
- Now weaning moves in 3 simultaneous channels (Figure 3). First, FiO<sub>2</sub> and PEEP are decreased hand in hand (as referred to in the previous section) depending on the oxygenation status i.e. the pulse-oximeter and the PaO<sub>2</sub> values. Second, PIP is linked to the PaCO<sub>2</sub> values and reduced accordingly. Third, a decrease in rate is also initiated at this stage in short decrements of 2 breaths/min.
- Rate is usually the last parameter to be weaned off. The principal consideration for decrease in rate is the clinician's decision as to how much breathing effort is to be permitted on the part of the baby. A premature decrease in rate may lead to excessive work of breathing which may cause metabolic acidosis, apneic spells or growth failure. The decrease in rate is mostly achieved by prolonging the expiratory time. However, a slow decrease in inspiratory time (Ti) also follows the declining rate as shown below:

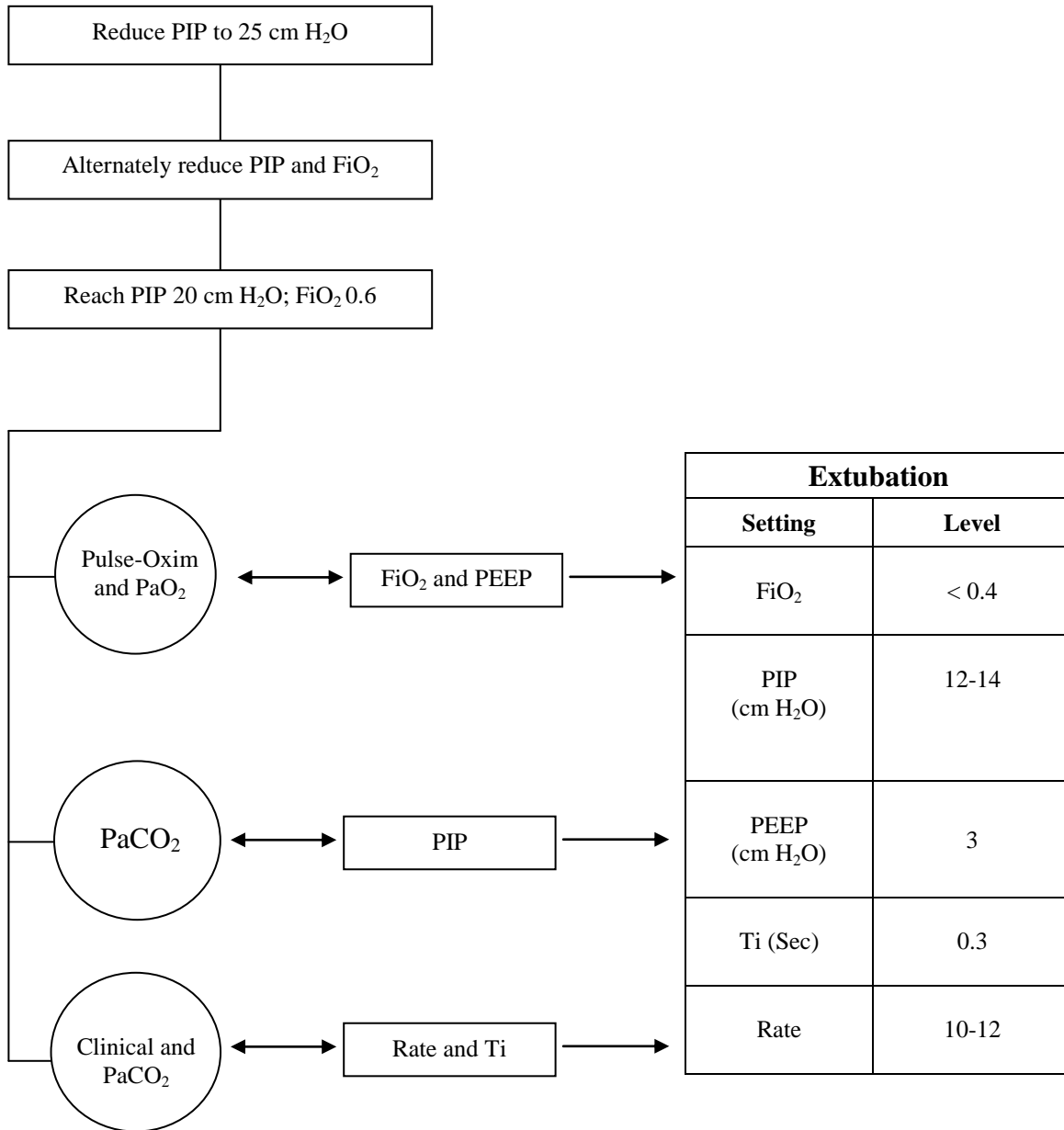
Rate (per min)	Ti (sec)
60	0.50
50	0.45
40	0.40
30	0.35
20	0.30

- Increase in Te and decrease in Ti results in progressive change in I:E from 1:1 or 1:2 to 1:3, 1:4, 1:5, 1:7 and so on. The long expiratory phase provides opportunity to the neonate to breathe on its own. This change in I:E is also essential for ensuring adequate deflation during recovery phase when the time constant becomes longer due to improving compliance.

It needs to be underlined that the above description should serve only as a general guide. Every case should be individualized and considered in totality.

Ultimately, it is the clinical and blood gas monitoring that should support decisions on the steps of weaning.

**Figure 3: Summary of guidelines for weaning from positive pressure ventilation**



**7. EXTUBATION**

The criteria for extubation is given in Figure 3. It is advisable to start aminophylline 24 hours before the expected time of extubation. Infant should be placed in oxygen-hood with 0.4-0.5 FiO<sub>2</sub> after extubation.

Extubated baby should be carefully monitored clinically and by estimating frequent arterial blood gases. One or more x-rays of chest should be obtained to rule out post-extubation atelectasis.

## 8. SOME DIFFICULT SITUATIONS

### ➤ Metabolic acidosis

In a neonate with RDS the presence of metabolic acidosis means one or more of the following conditions:

- (i) Hypovolemia, shock
- (ii) Excessive work of breathing
- (iii) Hypoxia, and
- (iv) Excessive PEEP
- (v) Anemia

Metabolic acidosis is a key trigger for pulmonary vasoconstriction which would result in right to left shunting. The latter may initiate a vicious cycle of hypoxia, more acidosis, more shunting and so on.

If hypoxia (as shown by pulse oximeter or PaO<sub>2</sub> values), excessive PEEP (over 8 cm H<sub>2</sub>O) or excessive work (as indicated by retractions) do not explain acidosis, it is good policy to infuse 10 ml/Kg of saline over 20-30 minutes and repeat the blood gases. Intra-arterial BP monitoring is difficult and the non-invasive BP monitoring is quite unreliable. Metabolic acidosis may be the first indication of poor peripheral perfusion.

Correction of metabolic acidosis using sodium bicarbonate infusion is undertaken as per standard recommendations if base deficit is 10 mmol/l or more. It *must* be realised that the use of sodium bicarbonate to correct acidosis is no more than symptomatic treatment. There is no escape from identifying the underlying cause and managing it.

### ➤ Right to left shunting

Functional **R** → **L** shunt at the intrapulmonary, atrial or ductal level occurs quite often during the course of ventilatory management of neonates with RDS. Neonatal pulmonary vasculature is exquisitely sensitive to hypoxia and acidosis triggering vasoconstriction. The resulting increase in pulmonary vascular resistance predisposes to **R** → **L** shunting, which in turn predisposes to further hypoxia and acidosis, thus, perpetuating a vicious cycle. Sustained **R** → **L** shunting may lead to a full-blown syndrome of persistent pulmonary hypertension of the newborn (PPHN).

The importance of maintaining normal PaO<sub>2</sub> and pH in any neonate with RDS cannot be overemphasized.

➤ **Ventilator settings in MAS and PAL**

Following guidelines are used in the above circumstances:

PIP (cm H <sub>2</sub> O)	minimum possible
PEEP (cm H <sub>2</sub> O)	0 to 3
I:E	Prolonged T <sub>e</sub> , hence I:E of 1:3 or 1:4 etc.
FiO <sub>2</sub>	High, as required

➤ **Excessive CO<sub>2</sub> retention**

Excessive CO<sub>2</sub> retention may indicate the following:

- (i) Severe RDS
- (ii) Tube-block
- (iii) Increased dead space, and
- (iv) Impending opening of the ductus arteriosus.

# APPENDICES

## Appendix I

- Normal blood gases in neonates

Sample	PH	PCO <sub>2</sub> (torr)	PO <sub>2</sub> (torr)
Arterial	7.35-7.45	35-45	>90
Capillary	7.30-7.35	40-45	Unreliable
Venous	7.25-7.30	45-50	Unreliable

## Appendix II

- Recommended size of endotracheal tubes and suction catheters

Birth wt. (g)	Endotracheal tube (size)	Suction catheter (Fr.)
<1000	2.5	5.0
-2000	3.0	6.5
-3000	3.5	6.5
>3000	4.0	8.0

## Appendix III

- Recommended distance of insertion of endotracheal tube as measured from lips to T2 level (i.e. 2 cm above carina)

Birth weight (g)	Distance (cm)
1000	7
2000	8
3000	9

## Appendix IV

- Recommended position of umbilical arterial and venous catheters

Catheter	Recommended position
Umbilical arterial c. (high)	At T <sub>6</sub> to T <sub>9</sub> vertebrae
Umbilical arterial c. (low)	At L <sub>4</sub> to L <sub>5</sub> vertebrae
Umbilical venous c.	At 0.5 to 1.0 cm above diaphragm

## CLINICAL MONITORING FOR SEVERITY OF RDS

### I. Downe's Score

<b>Sign</b>	<b>0</b>	<b>1</b>	<b>2</b>
RR	<60	60-80	>80 or apnea
Cyanosis	None	In room air	In 40% oxygen
Grunt	None	Audible with stethoscope	Audible without stethoscope
Retractions	None	Mild	Moderate severe
Air entry on crying	Good	Delayed or decreased	Barely audible

### II. Silverman Score

<b>Sign</b>	<b>0</b>	<b>1</b>	<b>2</b>
Upper chest	Synchronised	Lag on inspiration	See-saw
Lower chest retractions	None	Just visible	Marked
Xiphisternum	None	Just visible	Marked
Nares flaring	None	Minimal	Marked
Expiratory grunt	Good	Audible with stethoscope	Audible without stethoscope