Special Article Indian J Pediatr 1995; 62 : 395-419

Ventilatory Support for Infants in Emergency and in the Intensive Care Unit

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Abstract. Pediatric anesthesia and intensive care management has improved dramatically over the past two decades. Improved understanding of the pathophysiology underlying newborn surgical emergencies, new medications and new modes of ventilatory support have all contributed to better patient outcome. The authors have reviewed the anatomy and physiology of the infant airway, indications for and principles of endotracheal intubation, the management of newborn surgical emergencies, indications for post-operative ventilatory support, different modes of mechanical ventilation available, complications of mechanical ventilation with weaning parameters and extubation criteria. The introduction of nitric oxide and the implications of extracorpreal membrane oxygenation in the management of newborn emergency refractory to conventional ventilation are discussed. **(Indian J Pediatr 1995; 62 : 395-419)**

Key words : *Endotracheal intubation; Newborn surgical emergencies; Post-operative respiratory care; Nitric oxide.*

The evaluation of a newborn scheduled for emergency surgery requires an understanding of the physiology and the disease entities that predispose newborns to acute respiratory events in the immediate postnatal period. The practice of pediatric anesthesia and the management of these neonates have changed over the past two decades and altered their outcome. Several characteristics of the newborn make him/her vulnerable to acute events. Physiologically there are changes in the oxygen consumption, respiratory gas exchange, circulation, temperature homeostasis, glucose homeostasis and calcium homeostasis that make the newborn different from the older infant and child. An understanding of anatomical and physiological changes will aid the anesthesiologist/intensivist care for these sick infants.

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Mechanics of the Infant Respiratory System

There are a number of differences between the infant and adult respiratory system that place infants at a disadvantage when faced with increased respiratory demands. While physiologic differences are often emphasized, we will focus primarily on the less appreciated differences in anatomy between the two systems. (Table 1)

The infant's head is larger in proportion to the rest of the body compared to adults. In the supine position, the large head results in flexion of the neck that can occlude the trachea or upper airway. A towel

TABLE 1. Differences in the Infant Airway and Lung

(i)	Large head
(ii)	Narrow nasal passages
(iii)	Abundant lymphoid tissue
(iv)	Large tongue
(v)	Relative retrognathia
(vi)	Cephalad larynx
(vii)	Long, narrow, angled epiglottis
(viii)	Sublglottic narrowing at cricoid cartilage
(ix)	Short, narrow trachea
(x)	Cartilaginous, compliant chest wall
(xi)	Large abdominal contents
(xii)	Immature diaphragm & intercostal muscles
(xiii)	Smaller functional residual capacity
(xiv)	Immature central respiratory drive
(xv)	Higher minute oxygen consumption

placed underneath the shoulders is sometimes necessary to offset this obstruction. The nasal passages are narrower in infants and hence more easily blocked by secretions or edema. This is important because many infants are obligate nasal breathers until approximately 3-5 months of age. Because there is less distance between the mouth and palate, the oral airway is smaller. Also, there is an immaturity of coordination in the early months of life between respiratory efforts and oropharyngeal sensorimotor input increasing the likelihood of soft tissue obstruction when awake or sleeping especially in older infants.

The tongue is larger in an infant and more likely to cause obstruction in the oral activity. It can also be more difficult to manipulate and stabilize the tongue with a laryngoscope blade. The infant is also born with a relative retrognathia, or receding chin. This can make intubation more difficult because there is less potential space to anteriorly displace the soft tissue structures of the upper airway when trying to visualize the vocal cords.

The larynx is more cephalad in the infant, usually between the 2nd and 4th cervical vertebrae, making it more difficult to visualize during laryngoscopy. As the cervical spine develops, the larynx enlarges and moves caudally, reaching the adult level of C-5 or C-6 by about 4 years of age.[2] The infant epiglottis is longer, narrower and angled about 45 degrees from the axis of the trachea. This shape makes it more difficult to stabilize the epiglottis with a laryngoscope blade. The angulation can interfere with visualization of the vocal cords.

The vocal cords are angled such that the anterior attachment is lower or more caudal. This can cause the endotracheal tube (ETT) to impinge on the anterior commissure during passage through the larynx, particularly with nastoracheal intubation attempts. The trachea is also directed somewhat posteriorly, relative to the adult trachea. Cricoid pressure is sometimes needed to displace the cephalad portion of the trachea posteriorly to better align the trachea for (ETT) passage. This angulation is outgrown by 10 to 12 years of age.

The subglottic area is narrowest at the cricoid cartilage, as opposed to the vocal cords in adults, meaning an ETT must be sized not only to pass the vocal cords but also the cricoid cartilage in an infant. The trachea is also obviously smaller, both in length and diameter. Subglottic edema in an adult that would be asymptomatic can

be life threatening in an infant. Because resistance to airflow is inversely related to the 4th power of the radius, even 1 mm of circumferential edema can significantly impair airflow and gas exchange. The 57 mm average length of the neonatal trachea predisposes the infant to accidental extubation or endobronchial intubation with movement of the ETT tip that occurs with changes in head position.[14,15]

The infant thoracic cage also differs significantly from that of an adult. The ribs are positioned in a more horizontal fashion, resulting in less anteroposterior movement of the chest wall during inspiration. This decreases the contribution of the intercostals to ventilation and makes gas exchange primarily reliant on the diaphragm. Diaphragmatic movement itself can be impeded by the relatively large abdominal cavity and contents in infants. This is further worsened if the infant swallows large amounts of air, or if the stomach is distended by positive pressure mask ventilation.

The thoracic wall is soft, cartilaginous and more compliant, and can retract or collapse when faced with increased pulmonary resistive forces. Infant respiratory musculature is also less mature. Only about 25% of the diaphragm and 45% of the intercostal muscles are the desired Type I slow twitch, fatigue resistant fibres. The adult levels of 55% and 65% respectively, are not reached until 8 month to 2 years of age.[3] There are also fewer alveoli for gas exchange. A full term infant is born with approximately 25 million alveoli. The adult number of 300 million is not reached until 8 years of age.

The work of breathing is the same in a term infant and adult, about 1-2% of minute oxygen consumption, but can be as high as 6% in a preterm infant. Minute oxygen consumption itself is also approximately twice as high in infants as in adults, due to a higher metabolic rate. The infant compensates for this in large part with a higher respiratory rate. This higher oxygen consumption predisposes the infant to more rapid desaturation. A second factor which compounds this tendency to rapid desaturation is the smaller functional residual capacity (FRC) of an infant (adjusting for body weight). A smaller FRC means that a smaller reservoir of air is available to meet systemic oxygen demands, especially with hypoventilation or periods of apnea. In reality, however, dynamic FRC in spontaneously breathing infant is maintained at around 40% of TLC, a value similar to adults.

Preterm infants and term infants in the first weeks of life have an immature central respiratory drive and may respond to hypoxia with a pradoxical respiratory depression. Their ventilatory drive is also worsened in the face of hypothermia, emphasizing the importance of keeping the infant warm and in a neutral thermal environment.

Method of Endotracheal Intubation

Any discussion of endotracheal intubation would be incomplete without some discussion of the indications for intubation. It is best to categorize these indications not by the numerous disease states and clinical conditions, but by the underlying physiologic derangements common to them. Using this classification scheme, there are four indications : (1) the relief of airway obstruction; (2) protection of the airway; (3) facilitation of tracheal toilet or suctioning; and (4) facilitation of artificial

ventilation.[4]

Preoxygenation

Preparation for intubation starts with preoxygenation of the patient with the highest percentage of oxygen available. Concerns about oxygen toxicity in infants, such as retinopathy of prematurity, are outweighed by the immediate importance of ensuring adequate oxygenation during intubation. Although 3 to 5 minutes of preoxygenation is recommended, comparable levels of arterial oxygenation have been achieved in cooperative adults by taking 4 maximal deep breaths of 100% oxygen through a tightly sealed mask over 30 seconds.[5] The crying newborn is breathing at close to vital capacity, allowing adequate preoxygenation if a tight mask fit is maintained. While an infant or child may be unable or unwilling to cooperate with either method, and the urgency of intubation in situations such as cardiopulmonary arrest may not allow it, the importance of preoxygenation can not be overemphasized and should be routinely done prior to intubation.

If the source of oxygen is a wall-mounted flow meter, check to make sure the tubing supplying the reservoir bag is correctly attached to the oxygen flow meter, rather than one supplying air or other gases. If a portable cylinder is being used, be aware that green is the colour of oxygen cylinders in the United States, while white is the internationally accepted cylinder color for oxygen.[6]

Also ensure that the oxygen flow meter is turned on. This is immediately apparent if an "anaesthesia", Rusch or similar reservoir bag is being used, as oxygen or other fresh gas flow is required to inflate the bag. However, self-inflating reservoir bags will re-inflate in the absence of fresh gas flow, and will work if the source of supplemental oxygen is disconnected or turned off. Six to ten liters/minute of oxygen flow is generally adequate.

In addition, if a self-inflating bag is used, the value on some models between the reservoir bag and face mask will not allow for spontaneous ventilation. Those with a spring-loaded disk or ball-operated outlet valve may not open with patient inspiration, and will only deliver gas with positive pressure compression of the reservoir bag. Even bag-value devices with a "fish mouth" or "leaf flap" operated outlet that allow oxygen delivery during spontaneous ventilation can be problematic. Infants may not sustain the increased work of breathing required to open these valves. Thus, bag value devices are not as useful a source of supplemental oxygen in infants and smaller children.

The face mask used for preoxygenation and/or mask ventilation must be sized properly. If an adequate seal is not maintained, the fresh gas flow to the mask is diluted by room air during spontaneous respiration and assisted or controlled ventilation is more difficult. The correctly sized mask should extend from the bridge of the nose to the cleft of the chin, encompassing the mouth and nose, but avoiding compression of the eyes.

Equipment

In addition to the reservoir bag and face mask, immediate availability of other equipment is essential to minimize the risk of patient injury during intubation (Table 2).

Oro-and nasopharyngeal airways can be

TABLE 2. Equipment for Endotracheal Intubation

(i)	Supplemental oxygen source
(ii)	Reservoir bag
(iii)	Face masks
(iv)	Oropharyngeal/nasopharyngeal airways
(v)	Laryngoscope
(vi)	# 0, # 1 Miller laryngoscope blades
(vii)	Selection of endotracheal tubes
(viii)	Stylet
(ix)	Suction
(x)	Medications
(xi)	Monitors

invaluable in establishing airway patency prior to intubation. The curved body of the oropharyngeal airway (OPA) is designed to fit over the back of the tongue, preventing the tongue and hypopharyngeal structures from collapsing against the posterior pharyngeal wall. It is generally only tolerated in unconscious or sedated patients, since it can induce gagging and vomiting. OPA's range in size from 40 to 100 mm.

A nosopharyngeal airway (NPA) is a soft rubber or plastic tube that is placed through the nares into the posterior pharynx to prevent soft tissue structures from occluding the airway. It is lubricated and advanced gently to prevent mucosal trauma and bleeding and may need to be suctioned to remove adenoid tissue that can plug the NPA. Sizes from 12 F to 36 F are available. It is more likely than the OPA to be tolerated in the more conscious or less sedated patient. Although more commonly used in the operating or recovery room setting, familiarity with the use of the OPA and NPA is recommended for those managing the airway in any setting, as they can sometimes relieve severe airway obstruction prior to intubation or after failed intubation.

The laryngoscope consists of a battery operated handle and a selection of detachable different-sized straight and curved blades. It is used to allow direct visualization of the glottis. The blade is inserted in the right side of the mouth, moving the tongue to the left, placing the blade tip in the vallecula or directly under the epiglottis, and displacing the tongue and soft tissues of the upper airway anteriorly into the floor of the mouth. Two laryngoscopes should be available for intubation in case one should fail, and both should be checked to make sure the light sources is functioning. Generally, a Miller #1 (straight) or Macintosh #2 (curved) blade is used for the majority of intubations in infants and children. "Oxyscope" modifications are available for the Miller #0 and #1 blades. The oxyscope provides attachment of an oxygen source at the proximal end of the blade, with a distal delivery port for the oxygen near the tip of the blade. It may reduce the incidence of hypoxemia during laryngoscopy in infants.

Endotracheal tubes (ETT) come in half sizes from 2.0 to 10.0. The numbers refer to the internal diameter of the ETT in millimeters. Cuffed ETTs are generally used from 7-8 years of age onward. (Table 3) Use of cuffed ETTs in younger patients is possible, but a smaller lumen ETT is then required to accommodate the presence of the cuff. Most of the formulas developed to estimate ETT size in a given patient are based on patient's age. One of the more commonly used formulas[7] for children between 2-8 year of age is :

TABLE 3. . Endotracheal Tube Sizes (Internal Diameter, mm)

Premature infants	
< 1000 grams	2.5
1000-2500 grams	3.0
Term infant	3.5
6-12 month old	4.0
2-8 years old	[age (yrs)/4] + 4
> 8 years old	> 6.0 cuffed

Tube size (mmID) = [Age (yrs)/4] + 4.

A lubricated, malleable stylet inserted to (but not beyond) the tip of the ETT should be used in emergency intubations to facilitate ETT passage though the vocal cords. ETTs that are 0.5 mm smaller and larger than the estimated appropriate size should be readily available. Suction should be set up at the bedside to clear secretions, blood, emesis or other matter that may impair laryngoscopy.

Medications

The use of medications, if any, to facilitate endotracheal intubation depends on multiple factors. The availability of drugs, the physician's familiarity in using them, the urgency of securing the airway, the patients airway anatomy, underlying medical conditions and the physician's airway skills are all considerations in planning the proper approach.

Atropine is often given, particularly in newborns and younger infants, to offset the reflex bradycardia that can be seen with suctioning of the airway, laryngoscopy or intubation. The usual dose is 10 ug/kg intravenously or 20 ug/kg intramuscularly. Atropine may impede detection of hypoxemia by preventing or delaying the onset of bradycardia, a sign of hypoxemia. Atropine will also decrease secretion formation.

The fast-onset, short-acting muscle relaxant succinylcholine may be used to provide immobility and muscle relaxation for intubation. Of utmost importance, one must first assess the likelihood of either mask ventilation or intubation of the patient before giving any muscle relaxant or other medication that will take away the patient's ability to breath on his own! Failure to do this can make a bad situation worse and put the patient's life at risk. The intravenous dose of succinylcholine is 2 mg/kg in infants and younger children and 1 mg/kg in older children. If intravenous access is not available, a dose of 4-5 mg/kg can be given intramuscularly. Onset of intravenous succinylcholine is usually seen within 15-30 seconds and last 3-8 minutes.

Patient factors influencing the use of narcotics, benzodiazepines, barbiturates or other medications to facilitate intubation include the presence of elevated intracranial or intraocular pressure, reactive airways disease, hypovolemia and cardiac dysfunction. Because of the complex interactions between providing sedation or anaesthesia with these drugs and their physiologic effects, the practitioner must make their choices on a patient-by-patient basis.

Monitoring

The use of monitors is dictated by the clinical situation, most notably the urgency of intubation and the immediate availability of monitors. While electronic monitoring is helpful, much can be gained by simple

observation of respiratory pattern and rate, skin or mucous membrane color, level of consciousness, presence and strength of carotid, brachial or peripheral pulses, and auscultation of the chest.

If available, continuous electrocardiography, blood pressure measurement, pulse oximetry, and capnography (end-tidal carbon dioxide) should be used. Pulse oximetry and capnography provide excellent noninvasive monitoring of the respiratory system, are an indirect monitor of the cardiovascular system, and have been shown alone and in combination to reduce the frequency and severity of desaturation and potentially life-threatening events.[8]

Technique of Intubation

While the technique of intubation can not be mastered simply by reading about it, and more in-depth reviews exist,[7,9] several points deserve emphasis.

The axes of the mouth, pharynx and larynx must be aligned to directly visualize the vocal cords. This is done by placing the patient in the "sniffing" position, in which the neck is flexed and the head is extended at the atlanto-occipital joint. The position is so-named because it is the position assumed when leaning forward to sniff a flower. Because of the large size of the infant head relative to the body, the neck is already flexed with the infant supine, and the head is moderately extended beyond the neutral position to optimize visualization. If there is a possibility of cervical spine instability, the head is maintained in the neutral position with manual in-line cervical traction.

Cricoid pressure (the Sellick manoeuvre) is employed if the patient has a full stomach, to minimize the likelihood of regurgitation of gastric contents into the tracheobronchial tree.[10] Direct gentle pressure over the cricoid ring displaces the larynx posteriorly, occluding the compliant esophagus. This posterior laryngeal displacement can also move the vocal cords into better view for intubation.

Intubation is often being undertaken to improve oxygenation of the patient, and this goal should not be forgotten! Close attention should be paid to the patient's vital signs, and if available, the oxygen saturation. If it is not possible to intubate the patient readily, laryngoscopy should be discontinued, and the patient mask ventilated with 100% oxygen before additional attempts, to avoid or minimize hypoxemia and its consequences during intubation.

Many other techniques exist for intubation. One of the more commonly used alternatives is fiberoptic bronchoscopy. Bronchoscopes small enough to thread through the lumen of a 3.0 ETT are now in use. An airway free of secretions and blood is desired, as is relative patient immobility, for successful intubation with the bronchoscope.

With uncuffed ETTs an audible air leak should be present at airway pressures of 20-30 cm of water. This will minimize the likelihood of post-extubation croup.[11] With cuffed ETTs, the cuff should be inflated just until there is a loss of air leak, and not any further.

Assessing Tube Position

The importance of ascertaining correct ETT position can not be overstated. Unrecognized esophageal intubation remains a problem, and can happen even in experienced hands. Multiple means of assessing ETT should be used, including looking for

TABLE 4. Assessment of Endotracheal Tube Position

(i)	Direct vocal cord visualization
(ii)	End tidal carbon dioxide measurement
(iii)	Equal bilateral breath sounds
(iv)	Symmetric chest rise with ventilation
(v)	Epigastric auscultation and observation
(vi)	Pulse oximetry
(vii)	Reservoir bag compliance and refilling
(viii)	Quality of air sound escaping around tube
(ix)	Condensation on inner wall of tube
(x)	Chest radiography
(xi)	Fiberoptic bronchoscopy

chest rise, listening for breath sounds, listening over the stomach and watching for epigastric distension, looking for condensation on the inner wall of the ETT, checking a chest radiograph, and perhaps most importantly, using a copnograph to quantify the presence of carbon dioxide exiting the ETT with exhalation (Table 4).

Pulse oximetry provides a late sign of ETT misplacement. Recognize that almost every means of assessing ETT position has been shown to fail in certain circumstances.[12] Esophageal intubation has even gone undiagnosed on follow-up chest radiography.[13] It is also important to make sure the ETT tip is positioned in the middle third of the trachea to avoid inadvertent extubation (with head extension) or endobronchial intubation (with head flexion). This is particularly important in infants. The average length of the neonatal trachea (from vocal cords to carina) has been shown to be 57 mm.[14] Todres et al has documented as much as a 28 mm movement of the tracheal tube tip from full neck flexion to extension in a study of neonates.[15] The "rule of 7-8-9" is useful and reliable in neonates. The ETT is positioned 7 cm at the lips of a 1 kg infant, 8 cm at the lips of a 2 kg infant, or 9 cm at the lips of a 3 kg infant. Using this formula, with the head in the neutral position, the ETT should be in the midtrachea 95% of the time.[16] An alternative is to identify the carina by advancing the ETT until breath sounds become unilateral, note ETT position at the lips, then withdraw the ETT 2 cm and secure it. When viewing the chest radiograph, remember that the infant vocal cords overly C-3 or C-4, and the carina, if not readily visible due to the quality of the radiograph, is at T-4 to T-6 level.

The ETT should be well-secured with tape after a liquid adhesive has been applied to the face. Patient restraints, sedation and/or paralysis should be considered to minimize accidental extubation. Patient monitoring and ventilator alarms should be employed to assist in the detection of a ventilator circuit disconnect or extubation.

PRE-OPERATIVE MANAGEMENT OF THE INFANT

Monitoring During Surgery

These infants are particularly vulnerable to complications during their stay in the operating room and the ICU that can be prevented or at least treated aggressively if diagnosed early. The monitoring of an infant should not only revolve around his/her cardiac status but also the temperature and the respiration. Some of the commonly used monitors are (Table 5).

(i) *Electrocardiogram :* This is useful to de-

TABLE 5. Monitoring of Infants in the Perioperative Period

Electrocardiogram	
pulse oximeter	– Preductal
	– Postductal
Temperature	– Rectal
	– Esophageal
Arterial waveform	– Umbilical
	– Radial arterial
Airway pressure monitor	
Glucose	
Calcium	

tect bradycardia. The infant is dependant on his/her heart rate for their cardiac output and hence any decrease in heart rate should be detected early and corrected using appropriate measures. Although dysrhythmias are uncommon, SVT or PVC's occasionally can cause rapid deterioration in infants.

(ii) *A pulse oximeter* can be very valuable in determining rapid changes in the oxygen saturation. In infants prone to develop persistent fetal circulation, a pulse oximeter probe in the preductal area, (i.e., right hand) and one in the post-ductal area, (i.e., foot) may be helpful to determine shunting of blood and can alter therapeutic techniques to provide the infants with adequate care.

(iii) *Umbilical arterial lines* are useful and provide a method for drawing blood gases and checking the acid-base status. In addition the arterial waveform tracing can change with respiratory excursions in patients who are hypovolemic. Radial arterial lines can also be used for monitoring using a 22 F or 24 F catheter.

(iv) *Constant monitoring* of peak airway pressures in infants help determine the efficacy of ventilation and acute decreases in functional residual capacity (e.g., patient with a large gastroschisis who has his bowels reduced). An esophageal pressure monitor can be used to determine the closure of the abdomen in these cases, but requires cumbersome equipment.

(v) *Accurate assessment of volume status* has to be determined in infants and fluid replacement should not only be aimed at the volume status, but also the maintenance of glucose and calcium homeostasis.

Persistent Fetal Circulation

Certain infants are prone to develop persistent fetal circulation or persistent pulmonary hypertension. Intense pulmonary vasoconstriction causes right to left shunting of blood through the ductus arteriosus, foramen ovale, or both.[17] This can be caused by pulmonary aspiration of meconium, polycythemia, pulmonary hypoplasia, (as in diaphragmatic hernia), sepsis or idiopathic causes.

The excessive thickness of the medical smooth muscle causes intense pulmonary

TABLE 6. Pathophysiology of Persistent Pulmonary Hypertension :

Polmonary vasoconstriction
↓
R-L shunting of blood through PFO & PDA
↓
Right ventricular hypertension
↓
Hypoxemia
↓
Pulmonary vasoconstriction

vasoconstriction and increases pulmonary vascular resistance. Blood then proceeds from the right side of the heart to the left through a patent foramen ovale and through the ductus arteriosus. This also causes right ventricular and right atrial hypertension. This leads to severe hypoxemia and perpetuates the cycle. Tachypnea usually accompanies if the child is not already ventilated due to the stimulation of pulmonary parenchymal receptors (Table 6).

The treatment of persistent pulmonary hypertension (PPH) attempts to induce relaxation of intense pulmonary vasoconstriction (Table 7). Factors such as metabolic acidosis, hypoxia, hypercarbia, stress including pain precipitate persistent pulmonary hypertension and must be avoided. Mechanical ventilation is usually necessary with hyperventilation, 100% oxygen and narcotics to allay pain. Pulmonary vasodilating agents have also been used. Tolazoline was used extensively in the past. It has the disadvantage, common to most vasodilators, that it is not an exclusive pulmonary vasodilator but also causes systemic vasodilatation.[18] This may not favor systemic pressures which have to be supported using pressors. Other drugs that have been used included nitroglycerine, PGE_1 infusions and more recently nitric oxide. Nitric oxide needs special mention since this seems to be a better drug to decrease pulmonary vascular resistance. (See page : 114).

TABLE 7. Management of Persistent Pulmonary Hypertension

Prevent	
(i)	Metabolic acidosis with the addition of bicarbonate
(ii)	Hypercarbia by hyperventilation
(iii)	Stress by sedation
(iv)	Pulmonary vasoconstriction with – Tolazoline – Nitroglycerine – PGE_1 infusions – Nitric oxide

Management of ventilation in neonates in the operating room and in the intensive care unit requires a basic understanding of the physiology of neonatal airway. In addition to this, the pathophysiology of the disease status itself lends to the alteration in management in the pre-operative period. All newborns that undergo surgical procedures may not have to be mechanically ventilated in the post-operative period. We will discuss briefly the pathophysiology of some neonatal surgical emergencies that will require or may predispose an infant to be ventilated in the post-operative period. The common neonatal emergencies that require mention are tracheoesophageal fistula, diaphragmatic hernia, gastroschisis, omphalocele and neonatal bowel obstruction.

(a) *Tracheo-esophageal Fistula*

This is a rare congenital anomaly with an incidence of about 1 in 4000 live births. This condition is usually associated with other congenital anomalies.[19] (VATER : Verterbral anomalies; Imperforate anus; Tracheo-esophageal fistula; Radial dysplasia; Renal anomalies). There is a 20-25% association with cardiac defects particularly ventricular septal defect and Tetralogy of Fallot. These infants are likely to be born preterm which predisposes them to hyaline membrane disease that may require ventilation in the pre-operative period. The other complication that can arise from not

diagnosing the anomaly early is aspiration pneumonitis. Most of these children are preferentially extubated at the end of the surgical procedure, since an endotracheal tube left in place can cause a disruption in the suture line.

Complications in the post-operative period :

(i) Esophageal stricture
(ii) Tear along the suture line leading to pneumothorax/pnuemopericardium
(iii) Recurrent respiratory infections
(iv) Obstruction or restrictive lung disease.

(b) *Congenital Diaphragmatic Hernia*

This is perhaps the one neonatal surgical emergency that continues to carry a significant mortality despite the changes in the anaesthetic management and the post-operative care in the past two decades.[20] The reasons for this, is the high incidence of persistent pulmonary hypertension (PPH) in the perinatal period. The diagnosis is often made in the delivery room and these infants are intubated soon after birth. It must be noted that this is a group of infants whose survival not only depends on early diagnosis but also active management of the complications that are prone to occurring the early perinatal period. There is data available that suggest a period of medical stabilization prior to surgical intervention.[21] Nitric oxide may be used to stabilize these patients prior to surgery and throughout the pre-operative course.[22] The post-operative period is usually complicated in these infants by the presence of persistent pulmonary hypertension. This is divided into two phases :

(i) Initial honeymoon period : In the immediate post-operative period, the patient appears to be doing very well. Usually in about 12 - 24 hrs, the patient takes a turn for the worse with mounting pulmonary artery pressure.
(ii) Persistent pulmonary hypertension : The major reason for the increased morbidity in CDH is due to the presence of pulmonary hypertension. There is increased right to left shunting of blood in the heart that decreases pulmonary blood flow and leads to further deterioration of the pulmonary status.

PPH - > Hypoxemia - > Acidosis - > Increased pulmonary hypertension.

Therefore, post-operatively, these patients are hyperventilated. A critical PCO_2 has been described at which point there is a dramatic drop in the pulmonary vascular resistence. Most studies have found that decreasing the PCO_2 to values below 25 torr will not affect the pulmonary vasculature and might indeed cause cerebral vasoconstriction which may be deleterious to the patient.

One of the predictive measures for the prognosis of patients with PPH is the A-a DO_2 gradient (alveolar-arterial oxygen difference). In fants with an initial postsurgical A-a DO_2 of less than 400 seemed to have a better prognosis than those with A - a DO_2 of greater than 500 mm Hg. Hypercarbia that is unresponsive to vigorous hyperventilation has a mortality rate of over 90%. However, with the introduction of extracorporeal membrane oxygenation (ECMO), the outcome of these infants has changed.[23] However, the mortality in children with CDH has stayed at a

constant 50% despite the major strides in the management of pulmonary hypertension.

(ii) *Post-operative Complications*

(a) *Pneumothorax* : Usually occurs on the contralateral side because ventilation overdistends the normal alveoli on that side, leading to rupture. The placement of a chest tube is warranted as soon as the diagnosis is suspected since these patients deteriorate rapidly when subjected to hypoxemia and acidosis.
(b) Absorption of intrathoracic air after the surgical decompression of the left hemithorax and subsequent mediastinal shift and cardiovascular collapse.

Gastroschisis and Omphlocele

The most common types of gastrointestinal problems that are emergently brought to the operating room are categorized into :

(a) Obstructive
(b) Compromised intestinal blood flow
(c) A combination of the two.

Patients with gastroschisis or omphaloceles present with impaired blood supply to the herniated organs, intestinal obstruction and potential or major intravascular fluid deficits.

The management of these infants usually begins in the delivery room. The exposed bowel is covered with moist warm towels. Intubation is carried out using a rapid sequence induction using pentothal and succinylcholine. Occasionally in the sick infant, we prefere intubating these children awake with an "oxyscope" that insufflates oxygen to oropharynx. This provides a constant source of oxygen to the patient while allowing the patient to spontaneously ventilate.

Closure can be difficult in these patients due to the enormous pressure that the reduced gastric contents have on the diaphragm.[24,25] The pressure of the gastrointestinal contents have the following effects on the patient :

(i) Reduced functional residual capacity, leading to decreased ventilation and oxygenation.
(ii) Compression of the inferior vena cava, leading to decreased preload and cardiac output.

There are a few studies trying to assess the outcome of these children, especially if they had a very large defect. Intragastric and intrabladder pressures have been used to predict the degree of respiratory

TABLE 8. Defferences between Omphalocele and Gastroschisis

	Gastroschisis	Omphalocele
Location	Periumbilical	Within umbilical sack
Etiology	Occlusion of omphalomesenteric artery	failure of gut migration
Associated Lesions	Isolated Prematurity	Beckwith Weidman Syndrome Congenital Heart disease Bladder extrophy

embarrassment.[26] We follow peak airway pressures on the ventilator, along with blood pressures as monitors. If there is a sudden increase in airway pressure, the surgeon is notified and the surgical technique is modified to accommodate the bowel in a Silastic sac.[27] The silo is then gradually closed over a period of several days. This increases the viability of the gut and decreases any chance of compromised perfusion to the bowel. This is a decision that has to be made with the surgeon at the time of the closure of the abdominal wall, since the operative morbidity goes up if this factor is not taken into consideration. Post-operative ventilation is usually carried out at least for a period of two or three days in patients with gastroschisis and omphaloceles. These patients have usually received large volumes of fluid to offset the fluid loss from the exposure of the bowel and are subject to large volume shift in the postoperative period.

Post-Operative Acute Respiratory Failure: Management in the ICU

Acute respiratory failure can develop in any post-operative surgical patient. Patients with underlying lung disease are at increased risk of developing this complication. We will review etiology, recognition, pathophysiology and therapeutic principles of acute post-operative respiratory failure in children.

Etiology

(i) *Neurologic*

(a) Respiratory centre depression by narcotics
(b) Loss of protective airway reflexes
(c) Surgery on cervical spinal cord
(d) Phrenic nerve injury
(e) Neuromuscular disorders

(ii) *Airway*

(a) Instrumentation and subsequent edema
(b) Secretions

(iii) *Surgical manoeuvers*

(a) Major thoracic surgery
(b) Major abdominal surgery

Some of these causes have unique considerations.

(i) Neurologic Causes

(a) Respiratory depression by narcotics :

Narcan can be used to reverse the respiratory depressant effects of narcotics. However, it is important to remember that narcan has a short half-life, requiring repeated dosing to reverse the effect of narcotics. However, if the patients has received a large dose of narcotics, it may be prudent to ventilate the patient in the post-operative period rather than reverse the effects of narcotics.

(b) *Surgical manoevres causing damage to the phrenic nerve :*

Phrenic nerve injury in infants results in diaphragmatic paralysis requiring ventilatory support from a combination of a compliant chest wall and atelectasis. This occurs mainly in patients who have had their chest wall opened or when the dissection is close to the origin of the phrenic nerve.

(c) *Nuromuscular disorders :*

Patients with chronic neuromuscular disorders such as muscular dystrophy may need short term respiratory support following a major surgical procedure.

(ii) Airway Instrumentation

Airway instrumentation, particularly in infants can lead to significant airway edema resulting in severe upper airway obstruction at the level of cricoid cartilage. Medical therapy usually includes inhalation of cool humidified mist, racemic epinephrine 0.05 ml/kg (maximum 0.5 ml) every 2 to 4 hours as needed, intravenous dexamethasone 0.25-0.5 mg/kg given every six hours for twenty four hours. The use of steroids in the management of croup in the pre-operative period has been debated.

(iii) Major Thoracic or Abdominal Procedures

Major thoracic and abdominal surgery results in ineffective cough, sighing and an abnormal respiratory pattern characterized by rapid shallow respirations. This results in a decreased functional residual capacity by almost 50%.[28] These changes lead to atelectasis resulting in hypoxemia from ventilation-perfusion mismatching and intrapulmonary shunting. The accumulated secretions in collapsed lungs forms a focus for bacterial infection. Paralytic ileus resulting from abdominal surgery impedes diaphragmatic movement causing ineffective inspiration. All of the above changes lead to a fall in lung volume, which in turn results in poor lung compliance and increase in the work of breathing.

Therapy

The major therapeutic goal is to prevent atelectasis in the immediate post-operative period by paying close attention to the relief of pain, lung expansion, and removal of secretions. These goals can be accomplished successfully by :

(i) Effective sedation with narcotic analgesics,
(ii) Incentive spirometry in older children,
(iii) Chest physical therapy,
(iv) Removal of secretions,
(v) Bronchodilation,
(vi) Mechanical ventilatory support.

Mechanical ventilation is required for patients who have poor cardiac and pulmonary reserves following major surgical procedures. Artificial airways makes it easy to access mid and lower airways with suctioning and bronchoscopy if needed.[29]

Indications for Establishing Artificial Airway

(i) Excessive airway secretions,
(ii) Loss of protective airway reflexes,
(iii) Increased work of breathing,
(iv) Poor respiratory muscle strength,
(v) Airway obstruction,
(vi) Lung collapse interfering with oxygenation and ventilation.

Mechanical Ventilators

There are several basic principles involved in the application of conventional as well as unconventional modes of mechanical ventilation used in clinical practice. It is important to understand the design and functional aspects of mechanical ventila-

tion. Pediatric ventilators are essentially a modification of available adult and neonatal ventilators.

Positive Pressure Ventilators

Positive pressure ventilators generate a positive pressure in the pleural cavity.[30] A positive pressure ventilator consists of the following basic components.

(i) A drive system
(ii) Power and control systems
(iii) Cycling mechanism
(iv) Mechanism to provide PEEP or CPAP.
(v) Humidifier and Oxygen blender

(i) The drive system is (a) electrically driven, (b) pneumatically driven, (c) spring or piston driven and provides the force to generate a positive pressure gas flow. The driving mechanism and the driving pressure determines the pattern of gas flow from the ventilator into the patient. A *constant* flow is generated during inspiration when driving pressure is very high relative to airway pressure, a *decelerating* flow pattern results when the driving pressure is relatively low, a *variable* flow pattern (sine-wave) results when flow is generated by a piston device. A constant inspiratory flow pattern is used in most ventilators. Average inspiratory flow is about 21/mt. in infants and 25-30 l/mt. in larger children.[31]
(ii) The power and control system is provided by electricity or compressed gases.
(iii) Cycling mechanisms provides a system to switch from inspiration to expiration or expiration to inspiration. A trigger mechanism helps to cycle the ventilator. The trigger for cycling may be determined by:

(a) volume (volume-cycling),
(b) time (time-cycling),
(c) flow (flow-cycling) and
(d) pressure (pressure-cycling).

Time cycled (Bear Cub, Seiman 900) are often used in pediatric patients[29] although some centres have relied on time cycled/constant flow (Baby Bird) ventilators especially in the newborn.

(iv) Positive end expiratory pressure (PEEP) :

The term PEEP is used when positive airway pressure is applied during intermittent mandatory ventilation, whereas continuous positive airway pressure (CPAP) refers to application of positive airway pressure during spontaneous ventilation. PEEP or CPAP is used in conditions that results in hypoxemia from reduction in functional residual capacity (FRC). A decrease in FRC is seen in conditions such as atelectasis, pulmonary edema that are seen in post-operative patients. PEEP or CPAP recruits poorly ventilated alveoli, thus improving ventilation-perfusion matching (V/Q) and hypoxemia.[33] PEEP or CPAP is contraindicated in patients with chronic obstructive pulmonary disease (COPD), since it can cause lung injury.
(v) Humidifier help to humidify inspired gases, since, intubation by-passes the natural warming and humidifying functions of upper airway. This increases patients comfort, prevents insensible water losses and preserves mucociliary function.

Modes of Ventilation

(a) *Control mode :* Control mode is characterized by the lack of interaction between the patient and the ventilator. A tidal breath is delivered at a preset rate. Control

mode is used in patients who are incapable of breathing following deep anesthesia, neurological injury and neuromuscular paralysis. Volume control and pressure control are the two most commonly used modes.

(i) Volume control ventilation is characterized by the delivery of a tidal volume throughout inspiration. Volume controlled ventilation can be either *volume cycled*, where a preset volume terminates inspiration independent of inspiratory time of *volume regulated time-cycled*, where inspiration is terminated by the preset inspiratory time and inspiratory flow rate regulates tidal volume.

(ii) Pressure controlled ventilation can be either pressure cycled or pressure limited and time-cycled. A preset pressure limit terminates inspiration in pressure cycled mode, whereas in pressure limited time-cycled mode, the peak pressure is controlled at a preset pressure with constant inspiratory, expiratory times and inspiratory flow rate. The tidal volume delivered to the patient depends on the compliance and resistance of the patients lungs and ventilators circuit. Infants are usually ventilated using pressure limited time-cycled mode.

(b) *Assist-control mode :* In this mode the patient is able to trigger the ventilator to provide a preset tidal volume. However, if the patient fails to trigger the ventilator within a certain time, the ventilator would deliver a preset tidal volume. Assist-control mode incorporates a *demand flow* system which requires the patient to open an inspiratory demand valve to obtain the set tidal volume. This system can increase work of breathing.[34] A *continuous flow* system on the other hand maintains gas flow throughout the respiratory cycle, thus eliminating the increased work of breathing associated with the demand flow. Most infant ventilators are continuous flow devices.

(c) *Intermittent mandatory ventilation (IMV) :* IMV is a commonly used mode of ventilation. It allows spontaneous ventilation while delivering mandatory breaths at a set rate.[35] Synchronized IMV (SIMV) synchronizes the patient's spontaneous ventilation with mechanical breaths.

Advantage of SIMV

(i) Preservation of spontaneous ventilation decreases V/Q mismatching, since inspired gas is primarily distributed to dependent regions of the lung unlike mechanical breaths.[36]

(ii) Spontaneous ventilation minimizes adverse effects on hemodynamics, since positive pleural pressure generated from mechanical breaths reduces venous return and hence cardiac output.

(iii) Preserves respiratory muscle strength because of continued breathing pattern.

(iv) Patient comfort is improved thus requiring less sedation and paralysis.

(v) SIMV can be used as a mode to wean patients from mechanical ventilation.

(d) *Pressure support :* In this mode, spontaneous inspiration is assisted by a mechanical breath until a preset pressure is reached. The patient determines inspiratory flow, inspiratory time and respiratory

rate. Depending on the preset pressure, patient may receive either partial or total ventilatory support.[37]

Advantages :

(i) Used to wean patients from mechanical ventilation.
(ii) Reduces work of breathing by overcoming resistance due to endotracheal tube and inspiratory demand valve.

(e) *New modes of mechanical ventilation*

(i) Mandatory minute ventilation :

In this mode, the ventilator measures the tidal volume of spontaneous breaths over a predetermined time. Whenever spontaneous volume drops below a preset volume, the ventilator delivers breaths of fixed volume into the circuit until the set minute volume is achieved. This minute volume is distributed between spontaneous and mechanical breaths.[38]

(ii) Airway pressure release ventilation (APRV) :

APRV is a form of CPAP involving intermittent release of CPAP in the expiratory limb of the breathing circuit. CO_2 elimination is optimized by controlling the frequency and duration of pressure release. Patient breathes spontaneously during APRV.

Indication for APRV

Patients on CPAP needing assisted ventilation, but who can not tolerate intermittent positive pressure ventilation.[39]

Advantage of APRV

Pulmonary barotrauma and hemodynamic effects are less, since peak airway pressure never exceeds CPAP level, resulting in lower peak and mean airway pressures.

(f) *Unconventional ventilatory modes :*

(i) Inverse ratio ventilation

It is a type of positive pressure ventilation in which inspiratory time is longer than expiratory time resulting in I : E ratio greater than 1 : 1. Such a strategy although unphysiological, increases mean airway pressure, FRC and hence oxygenation. Patients generally require sedation and or muscle relaxants when they receive this mode of ventilatory support. Inverse ratio ventilation is most commonly used with pressure control mode.[46]

(ii) High frequency ventilation (HFV)

High frequency ventilation delivers low tidal volume at frequencies far greater than normal physiological range. High frequency ventilation includes high frequency jet ventilation (HJV) and high frequency oscillation (HFO).

(a) *High frequency jet ventilation :* Inspiratory gases are delivered into the airway via a jet injector at a rate of 100-400 cycles/mt. Delivered tidal volume is usually about 3-5 cc/kg.[40]

(b) *High frequency oscillation :* Ventilation frequencies are in 900-3600/mt. range. Delivered tidal volume is 1-3 cc/kg.[41]

Indications

1. Surgery on airway requiring minimum amount of air movement.
2. Management of bronchopleural fistula.

TABLE 9. Types of Ventilatory Modes

(i)	Control mode	Volume control -- Volume cycled -- Time cycled Pressure controlled -- Presure cycled --Pressure limited & time cycled
(ii)	Assisst control mode	
(iii)	Intermittent mandatory ventilation	
(iv)	Pressure support	
(v)	New modes of ventilation	Mandatory minute ventilation Airway pressure release ventilation
(vi)	Unconvcentional ventilatory modes	Inverse ratio ventilation High frequency ventilation -- High frequency jet ventilation -- High frequency oscillation

3. Acute lung injury[42]

Mechanism of gas flow

Mechanism of gas flow is not definitely known. However two process have been hypothesized to describe gas exchange. One is molecular diffusion and the other is convention (which is the bulk air flow that occurs up to the level of alveoli).[43]

Inhaled Nitric Oxide

Inhaled nitric oxide, an endothelium derived relaxing factor, is a selective pulmonary vasodilator. It is inactivated rapidly in the blood because it binds to hemoglobin minimizing systemic effects. Kinsella et al and Roberts et al reported the use of nitric oxide in the treatment of persistent pulmonary hypertension in the newborn in 1992.[44] Since then, nitric oxide has been used for congenital heart diseases as well as for infants with PPH. There is data available now to show the outcome of infants with diaphragmatic hernia with persistent pulmonary hypertension may do better with pre-oparative stabilization with nitric oxide.[21] This may be an option available before electing to place a patient on ECMO. One of the side effects of the use of nitric oxide is the development of methhemoglobinemia. The limitation to the use of 20 ppm of nitric oxide, along with constant monitoring of methemoglobin levels seems to offset this complication. Discontinuation of nitric oxide is based on the improvement in the A-a DO_2 gradient. We will briefly discuss ECMO.

Extracorporeal Membrane Oxygenation (ECMO)

It is an extension of cardiopulmonary bypass technique that is used in cardiothoracic surgery. ECMO is used to support cardiopulmonary function. A membrane oxygenator used in ECMO

separates the blood and gas phases with a semipermeable membrane, minimizing hemolysis that otherwise was seen with the bubble oxygenator. ECMO is useful to support cardiac function in patients who have cardiac failure following cardiothoracic surgery.[45] Neonates with a high A-a DO_2 (arterial oxygen difference) are placed on this prior to or immediately after the repair of diaphragmatic hernia. There is increasing use of veno-venous bypass rather than the previously used veno-arterial bypass because the incidence of complications are much less. A complete discussion on ECMO is beyond the scope of this article.

Selecting Parameters for Mechanical Ventilation

Parameters are selected to provide adequate oxygenation and ventilation. It is important to clinically assess and closely monitor patients both at the time of instituting mechanical ventilation and throughout its use. Non-invasive monitors, such as pulse oximeter and end tidal CO_2, help to continuously follow oxygenation and ventilation status. Arterial blood gases are done to confirm the adequacy of non-invasive monitors.

FiO_2 : Oxygen is initiated at a level to keep the saturation greater than 95% and PaO_2 greater than 70 torr. Adequacy of oxygen is clinically assessed by the color of mucusmembrane.

PEEP : Initially ventilator is set on a PEEP of 3-5 cm. It can be increased, if needed, to keep FiO_2 in the non-toxic range of 0.5 or less.

Ventilation

(i) *Tidal volume* : Patients are started on a tidal volume of 12 cc./kg. This is much higher than that of spontaneous ventilation in order to compensate for the compressible circuitry volume of the ventilator, increase in dead space ventilation, and the carbon dioxide production that accompanies respiratory failure. Adequacy of tidal volume is assessed by good chest expansion and breath sounds.

(ii) *Rate :* A rate within the physiological range for that age group is selected. Infants are usually ventilated at rates of 20-30/min.

(iii) *I : E Ratio :* I : E ratio of 1 : 2 is usually the initial setting.

(iv) *Adequacy of Ventilation :* Adequacy of ventilation is confirmed by assessing PCO_2 and maintaining it between 38-43 torr.

(v) *Indication for Sedation and Paralysis :* Sedation is indicated when a patient is synchronous with their spontaneous breaths and mechanical breaths, leading to inadequate oxygenation and, ventilation and, possibly, barotrauma. In extreme cases, patients may need muscle paralysis. Infants with evidence of persistent pulmonary hypertension are particularly prone to develop an increase in their pulmonary artery pressures with the infliction of pain. Hence, these infants are generally sedated and with morphine or infusions of fentanyl.

Weaning from Mechanical Ventilation

SIMV is the mode of choice for weaning pediatric patients from mechanical ventilation. Resolution of the primary process which required initiation of mechanical ventilation determines the weaning process. Once it is decided to wean, the following guidelines are helpful.

(i) Decrease FiO_2 to 0.5.

(ii) Ventilator breaths are decreased gradually to 2-4 breaths/mt.
(iii) Mean airway pressure is reduced by decreasing PEEP/CPAP to 3-5 cm.

Mechanical ventilation can be discontinued once patient exhibits adequate oxygenation defined as (a) A PaO_2 of 70 torr and (b) ventilation defined as $PaCO_2$ between 38-42.

Other criteria for adequate oxygenation include

(i) alveolar-oxygen gradient ($AaDO_2$) of 300 or less on FiO_2 of 1.0
(ii) intrapulmonary shunt (Qs/Qt) less than 10-20%
(iii) dead space to tidal volume ratio (Vd/Vt) less than 0.6

Objective criteria are difficult to evaluate in infants and younger children, since they require patients cooperation. These objective criteria include vital capacity (VC) greater than 10-15 cc/kg or a negative inspiratory force (NIF) greater than 30 cm.[47] It is also important that patient exhibit alert mental status, protective airway reflexes and stable hemodynamic parameters before extubation.

Complications from Mechanical Ventilation

Complications includes injury to the airway and lungs as well as hemodynamic dysfunction (Table 10).

(i) *Airway* : Airway injuries results from the presence of an endotracheal tube. These include performation of the palate, laryngeal injury, tracheomalacia and tracheal stenosis. These injuries can be decreased by using an endotracheal tube of appropriate size, avoiding cuffed tubes below 7-8 years of age, and preventing excessive movement of the tube within the airways by appropriate restraints and sedation.

(ii) *Lungs* : Multiple factors are involved in precipitating pulmonary complications. These factors include toxicity from oxygen, overdistension of alveoli from high intrathoracic pressure, and mucociliary dysfunction. These factors can precipitate pulmonary barotrauma, resulting in pneumomediastinum, pneumothroax, or pneumopericardium.[49] Avoiding high levels of FiO_2 and overdistension of alveoli by accepting certain degree of respiratory aci-

TABLE 10. Complications from Mechanical Ventilation

Organ Damaged	specific Injuries	Prevention
Airway	Laryngeal Injuries Perforation of the palate Tracheomalacia with Tracheal perforation	Right size ET tube Prevent movement with Adequate sedation
Lungs	Oxygen toxicity Barotrauma Mucociliary dysfunction	Decrease the inspired O_2 Allow permissive hypercapnea Humidify the gases
Hemodynamic Effects	Decreased venous return	Increase intravascular volume

dosis termed *permissive hypercapnea* prevents lung injury[49] in selected patients.

(iii) *Hemodynamic effects :* Positive airway pressure decreases venous return, increases pulmonary vascular resistance, and diminishes cardiac output. Hemodynamic changes can be effectively treated by intravascular volume expansion with fluids and by the appropriate use of inotropic agents to increase cardiac output[50]

Extubation Criteria in Infants and Children

There are several criteria by which a pediatric anesthesiologist or an intensivist decides to extubate an infant who has undergone surgery. (Table 11)

(i) The anesthesia technique used e.g., narcotic based anesthesia
(ii) The use of non depolarizing muscle relaxant
(iii) Physiological changes that will be altered by spontaneous respiration e.g., PPH
(iv) Timing of extubation
(v) Technique of extubation

We will elaborate briefly some of the concerns prior to extubating an infant.

(i) *Anesthetic technique :* With the advent of high dose narcotic techniques for managing hemodynamically unstable patients in the operating room, the incidence of postoperative ventilation is much higher. These patients will have to be extubated when the narcotic effect of sedation and respiratory depression seem to diminish. This may be many hours after the procedure.

(ii) *Use of neuromuscular blocking drugs :* The criteria for adequate recovery from neuromuscular blocking drugs that has been reported in adults has to be modified in infants and children due to the inability to respond to verbal commands. Before tracheal extubation, the following criteria should be met.

(a) Maintain adequate, non paradoxic chest excursions.
(b) Generate negative inspiratory pressure of -20 to -30 cm H_2O
(c) Sustain tetanic contraction with 50 Hz

When the child is awake, he should :
(a) Open the eyes wide
(b) Sustain leg flexion and elevation
(c) Cough effectively.

The anesthesiologist has to make the decision to extubate the child based on clinical judgement. Paradoxic breathing usually indicates the inadequate reversal of neuromuscular blockade.

(iii) *Physiological changes that are altered by spontaneous ventilation :* Persistent Pulmonary hypertension (PPH) requires attention to the ventilatory status. These infants have a higher predisposition to increased pulmonary artery pressures and hypoxia, which in turn, leads to greater pulmonary artery pressures. These infants are elec-

TABLE 11. Extubation Criteria : Considerations

(i)	Assess the effect of narcotics
(ii)	Reveresal of non-depolarizing muscle relaxant
(iii)	Alteration of physiological state due to spontaneous ventilation, e.g., PPH
(iv)	Timing of extubation
(v)	Technique of extubation

tively intubated and hyperventilated after the surgical procedure.

Increase intrathoracic pressures as a result of replacement of bowel contents following gastroschisis or omphalocele repair can result in decreased functional residual capacity and hypoxia. These infants are best left intubated in the post-operative period and can be extubated when the oedema in the bowel subsides. This period could last from 3-4 days to weeks. One other aspect that should be considered is the presence of hyaline membrane disease in the premature baby may necessitate continuation of mechanical ventilation beyond the post-operative period.

(iii) *Timing of cxtubation* : In small children, extubation during residual light anesthesia is often followed by breath holding or apnea, leading to arterial desaturation and bradycardia. A fully awake infant not only moves his extremities but also opens his eyes, awakening.

(iv) *Technique for extubation* : There is a few steps one should follow prior to the extubation of the infants

(a) Nitrous oxide is replaced with 100% oxygen at least three minutes prior to extubation. This will prevent diffusion hypoxia.
(b) Secretions are suctioned from the stomach so the infant does not regurgitate and aspirate just after extubation.
(c) The lungs are inflated adequately to open up any atelectatic alveoli. This prevents the occurrence of ventilation-perfusion mismatch and hypoxia especially in the newborn.
(d) The anesthesia bag is held at end expiration at about 15-20 cm H_2O to maintain a high lung volume as the child is extubated. This will provide the infant with adequate oxygenation in the event of breathholding laryngospasm. It has been shown , in puppies, that the stretching of the airways abolishes laryngospasm in lightly anesthetized plane,[51] though the significance in humans is unclear.
(e) Any secretions in the oropharynx are suctioned out as the tube is removed.
(f) Once the endotracheal tube is removed, a mask with 100% oxygen is held over the patient. This can be gently applied to the patient's face and positive pressure applied. This can help reduce the occurrence of laryngospasm.

Monitoring the patient after extubation

The patients is monitored using continuous pulse oximetry in the post-operative period. It has been shown that a pulse oximeter is a more sensitive indicator of hypoxemia than clinical signs and symptoms.[8] Emergence from general anesthesia is as important and is a critical and potentially hazardous period. Preparation prior to extubation is the crucial element that will prevent any complications including laryngospasm and aspiration.

Conclusion

Caring for the sick neonate and infant is perhaps one of the most rewarding experiences in clinical medicine. The combination of safe and good anesthetic care and astute management of the patient in the intensive care unit in the post-operative period will reduce the morbidity and mortal-

ity of these infants considerably. An understanding of normal physiology of a newborn will help us determine the physiological needs of this special group. Many, but not all newborns, can benefit from post-operative ventilation. In the older children the use of incentive spirometry and chest physical therapy along with the management of pain can prevent shallow respirations thereby preventing atelectasis. Careful management of fluid in the preoperative period can prevent volume loading thus leading to pulmonary edema. The ultimate management of these infants and children rests with a keen sense of observation and physical examination. An astute clinician should be able to judge his/her course of action from all the available data.

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