Indian Journal of Emergency Pediatrics
Volume 2 Number 3, July - Sept 2010

# Protecting the pediatric lung in emergency room: Practical measures

**Giuseppe A Marraro, MD**

**ABSTRACT**

Baro- and volutrauma, surfactant deficiency, oxygen toxicity, and the development of atelectasis have been investigated in depth in recent years in order to protect the lung during ventilation and reduce the risk of ventilation induced lung injury (vili). Protective lung strategies have been implemented in a variety of clinical contexts that require transferring to emergency room., Pressure ventilation can control the risk of elevated airway pressure (pip) but does not assure less damage to the lung. Tidal volumeappears to be more damaging for the lung as it can favour lung over-distension or create hypoventilation, both harmful clinical conditions for the lung. Peep plays an important role in avoiding the closure and re-opening of the terminal bronchioles implicated in lung damage, and in maintaining the alveolus continuously open. Peep improves oxygenation (increase of functional residual capacity – frc) and can reduce the need for high $fio_2$ (less oxygen toxicity). Maintaining the lung distended for 8-15 seconds at the end of inspiration appears to be helpful in lung recruitment strategy and in the resolution of atelectasis., Ventilation of a child in emergency needs skill and competence that must be acquired in ordinary routine and not in critical care.

**Key words**: emergency, emergency room, lung protective strategy, ventilation, baro-volutrauma, oxygen toxicity, atelectasis, infant, children3

## INTRODUCTION

Air flows into the lung from the external environment as a result of the decrease in intra-thoracic pressure and leaves the lung passively on recoil of chest. No positive pressure is applied to the airways during the inspiratory phase to favor the entry of air towards the lungs. After respiratory exchange has taken place in the alveolus the air exits the lung passively.

The quantity of air required per minute is regulated by the organism in relation to the quantity of oxygen to be taken in and to the elimination of $co_2$. While it is necessary to increase functional residual capacity (opening up of a greater number of alveoli) for the diffusion of oxygen, the elimination of $co_2$ from inside the lung is achieved by the alternation of the respiratory act (entry, or inspiration, and exit, or expiration, of air to the lung).

In normal conditions the organism is able to increase current volume by means of one or more respiratory acts for the purposes of increasing gas exchange and preventing the formation of atelectasis.

Ventilating artificially, the introduction of a quantity of air into the lung (tidal volume) is defined *a priori* and is pushed into the airways by the application of positive pressure, known as insufflation pressure. Positive pressure during inspiration must be sufficient to overcome the resistance that the air meets in the airways before reaching the alveolus.

Respiratory rate is defined also *a priori* on the basis, initially, of the patient's theoretical physiological values and of his/her age, and subsequently with reference to the values recorded for $pao_2$ and $paco_2$ in the blood, or arterial blood gas (ABG).

**Author's Affilication:** Associate Professor Anesthesia and Intensive care, University of Milan, F. Director of Anesthesia and Intensive care Department & Pediatric Intensive Care Unit Fatebenefratelli and Ophthalmiatric Hospital, Milan - Italy, E-mail: gmarraro@picu.it

**Reprint's Request: Giuseppe A. Marraro, MD,** Associate Professor Anesthesia and Intensive care, University of Milan, F. Director of Anesthesia and Intensive care Department & Pediatric Intensive Care Unit Fatebenefratelli and Ophthalmiatric Hospital, Milan - Italy, E-mail: gmarraro@picu.it

**(Received on 17.10.2010, Accepted on 31.10.2010)**

Introducing the current volume of air required for gas exchange into the airways, this volume follows the path of least resistance offered by the airways and by lung compliance. This explains why the better ventilating areas are more easily and more completely filled with air in comparison to the less ventilating areas. As a result, certain areas, particularly those which are dependent, may close against ventilation and become atelectasic.

To avoid atelectasis and maintain $pao_2$ and $paco_2$ in normal range gas exchange, large tidal volume and low respiratory rate strategy has been used in the past.

Various undesired effects have been considered in relation to the application of mechanical ventilation starting from when it was first used [1,2]. In particular, lung barotrauma has been connected with the pressure used to introduce tidal volume, and the appearance of emphysema and lung rupture (pneumothorax) were evident clinical indicators of the undesired effects of mechanical ventilation. This led to the introduction and development of controlled positive pressure ventilation, both manual and artificial, as a protective ventilatory mode for the lung.

The evaluation of harm incurred by lung tissue during the application of artificial ventilation has been systematically evaluated and ample clinical experience is available as well as an extensive consensus view regarding ventilator-induced lung injury (VILI) and ventilation associated lung injury (VALI), whether in normal or pathologic lung in anesthesia and intensive care. In large studies the injury sustained at birth by newborns during resuscitation following manual ventilation even if of short duration, is clearly implicated in the pathogenesis of bronchopulmonary dysplasia (BPD) [3,4].

It is a logical consequence that the evidence from ventilation support and early lung damage may be extended to apply to infants and children and from anesthesia and intensive care to the emergency room.

## VENTILATION MODES IN EMERGENCY

A patient's spontaneous breathing can be partially assisted or totally controlled. In the first case the child starts the inspiratory phase and supplementary tidal volume is insufflated to obtain suitable ventilated tidal volume. In this condition the work of breathing is shared between the operator and the patient. In the second case, the operator supports the patient's respiration and work of breathing totally.

In emergency room in general two devices are used for ventilation: auto-inflating bag and flow-inflating bag (*figure 1*). Facial and nasal masks, laryngeal mask and endotracheal tube are used as interfaces to connect the child to the inflating bag. Intubation is a more invasive method compared to mask ventilation but protects the airway from aspiration, enables correct lung ventilation avoiding gastric distension and favors bronchosuction [5].

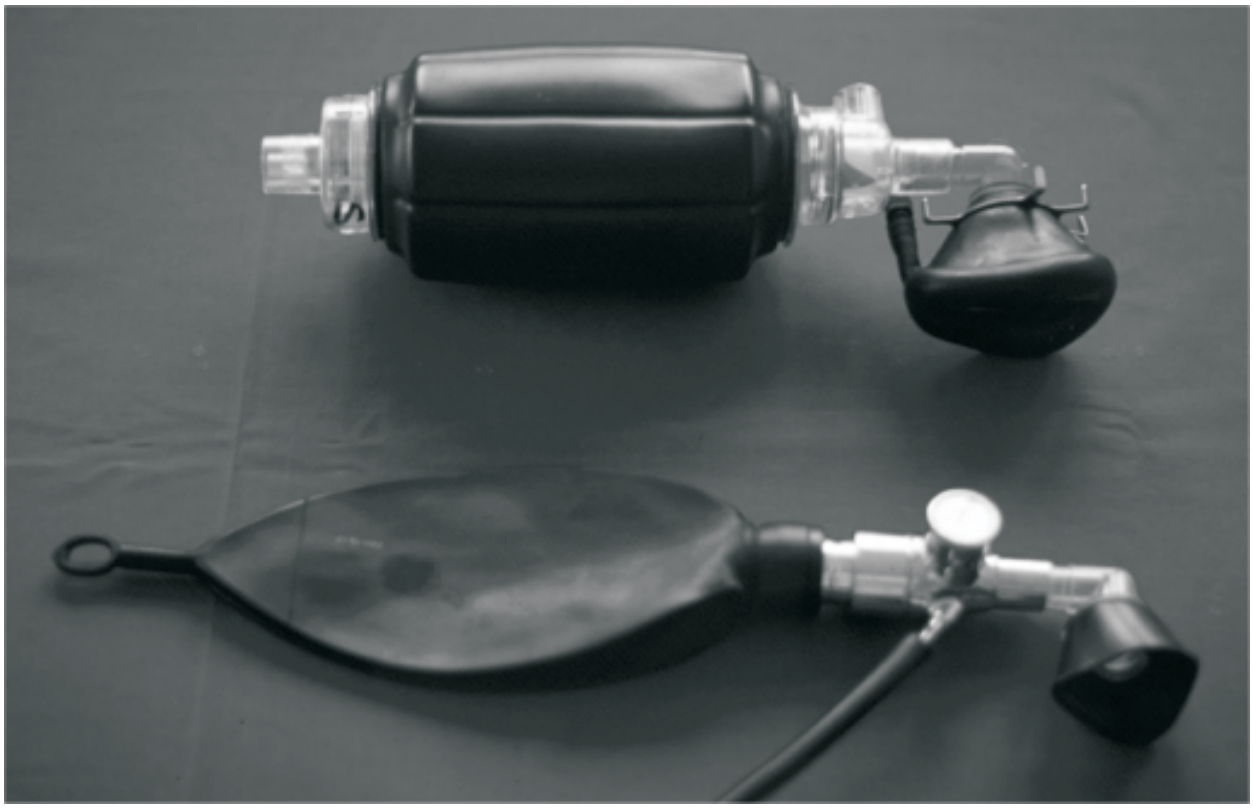
### 1. Auto-inflating bag

This device incorporates an adapter to connect a mask, an endotracheal or tracheostomy tube, an auto-inflating bag, a pressure-relief, non-rebreathing valve, and a port for gas inflow. The volume of the bag varies from about 0.250 ml to 1 liter for pediatric application. The device appears to be safest for avoiding lung overexpansion but in some circumstances it is difficult to deliver a volume suitable for pediatric patients. The unidirectional valve does not allow pressure over 30 to 35 cm of $h_2o$, which can be ineffective in cases of need of higher pressure to expand the lung (e.g. Low compliance), in the presence of endotracheal tubes of small diameter (higher resistance) and in severe lung pathology.

**The main advantages of this system are**

1. Does not need a gas source to inflate;
2. Remains inflated at all times irrespective of oxygen or gas source;
3. Pressure release valve to protect from high peak inspiratory pressure;
4. Easy to use.

**Figure 1: Auto-inflating bag (above) and flow-inflating bag (below)**



Several disadvantages are connected to this system. The self-inflating bag gives no indication of leaks and will inflate even without adequate seal and no flow return from the lungs. The automatic re-expansion of self-inflating bag may falsely reassure even though a large proportion of delivered breath may lost through a leak around the mask. It does not provide peep and cannot deliver a sustained prolonged inflation (one second or longer) useful to alveolar recruitment and cannot be used to deliver 100% free flow oxygen. It requires attachment of an oxygen reservoir to deliver 100% oxygen.

**2. Flow-inflating bags**

These devices are continuous-flow, semi-open breathing systems and non-rebreathing depends on the location of the fresh gas inflow, overflow valves, rate of fresh gas flow, respiratory rate, tidal volume and whether ventilation is spontaneous or controlled. Most devices employ the mapleson d circuit with the fresh gas source attached just distal to the point of connection to the patient. They are more frequently used in anesthesia.

During expiration, the patient's exhaled tidal volume mixes with fresh gas flowing into the system and accumulates in the tubing and bag. With sufficiently high fresh gas flow, alveolar gas is washed to the overflow valve and eliminated from the circuit. They may apply high volume inflation according to volume of ventilated gas (generally oxygen) and presence of a pressure-regulating valve.

The gas and valve are regulated manually by the operator. The bag can be fitted with a manometer and a pressure pop-off. If the valve is not adequately regulated, a large volume of gas can reach the lung, over-distending it. A protective strategy suggests using low flow and a fully open valve, increasing the flow progressively and regulating the opening of the valve in relation to the efficacy of insufflation.

**The main advantages of this system are**

1. It can produce a peak inspiratory pressure (PIP) of any level suitable to reopen the lung;

2. It can be used to deliver prolonged inflation in recruiting lung maneuvers;
3. It can provide peep by controlling the rate of gas escape at the outlet from the bag and maintaining a positive pressure in the system during expiration. Maintaining the bag distended at the end of exhalation (PEEP) can be of benefit in different obstructive and low compliance lung pathologies (e.g. RDS, ARDS, bronchiolitis and asthma).

## OTHER ADVANTAGES ARE

1. Possibility of delivering 100% oxygen at all times;
2. Easy to determine the adequacy of seal and reduce gas leakage;
3. Possibility of evaluating the "stiffness" of lung, compliance and resistance;
4. Can be used to deliver 100% free flow oxygen.

The main disadvantages of this system compared to the self-inflating bag are that a source of compressed gas is required and the absence of safety pop-off valve. Its correct use requires more experience and training.

## RECENT ACQUISITIONS ON LUNG DAMAGE FROM VENTILATION

Over the past 10 years greater attention has been paid to damage associated with baro- and volutrauma, with type ii alveolar cells and to the surfactant produced by them, with side effects of high levels of $fio_2$, and the development of atelectasis. Direct damage connected with artificial ventilation is still under-investigated, despite the fact that all the knowledge to transfer what shows up in intensive care into the emergency room is available [6, 7].

1. Structural lung damage directly connected to ventilation support
2. Internal homeostasis alteration with reduction of cilia mobility and stiffening of secretions;
3. Surfactant impairment from high $FIO_2$, cold and dry gases, and ventilation modes;
4. Baro-volutrauma creating emphysema up to pneumothorax;
5. Side effects and complications
6. Primary or secondary aspiration due to lack of protective control of airway in cases of predisposing pathology, seizures and coma in brain trauma;
7. Damage from oxygen toxicity;
8. Damage to larynx, trachea, main bronchi and esophagus in performing traumatic intubation (e.g. Use of unsuitable endotracheal tubes and laryngeal mask).

Other factors that contribute to, or aggravate, lung injury include preexisting lung damage and/or inflammation, high oxygen concentration, reduction in secretion removal, use of inadequately humidified and warmed gases, level of blood flow, and the local production of systemic release of inflammatory mediators (biotrauma).

**The state of the art with respect to main acquisitions is as follows**

1. Not only the pressure used to introduce the air into the lung creates barotrauma but the quantity of air introduced for each breath (tidal volume) also plays an important role in lung damage;
2. More damage is created ventilating dis-homogeneous and/or uni- plurilobar lung patology. In these cases higher opening pressures must be applied to re-ventilate closed areas. These higher pressures are damaging to the normo-ventilating lung regions;
3. Repeated alveolar collapse and re-opening (shearer forces) due to low end-expiratory pressure: application of peep reduces shearer forces and enables continuous maintenance and recruitment of a greater number of alveoli to ventilation;
4. Atelectasis can be present or may develop rapidly in sedated, paralyzed and

mechanically ventilated children (8). Non ventilating lung areas can be reopened using recruitment maneuvers including peep application and maintaining lung insufflation at end of inspiration for seconds (8 - 12??) (redistribution of air in the alveoli and recruitment);

5. High $fio_2$, especially if oxygen is used cold and dry, modifies lung homeostasis, creates stiffening secretions and toxic free radicals that play an important role in the genesis of biotrauma [(9)].

This knowledge, preferentially acquired in intensive care, in ventilation of premature newborns, in neonatal resuscitation and in anesthesia leads to considerations and advice which prove extremely important in lung protective strategies of ventilation support in emergency room.

## PRACTICAL MEASURES

## ASPIRATION

Two essential maneuvers are suggested to protect from aspiration: 1. Lateral positioning of the child and 2. Direct visualization of upper and lower airway before starting manual ventilation in case of suspected or confirmed aspiration.

Aspiration may occur before and after mask and bag ventilation. The passage of air into the stomach in case of incorrect ventilation predisposes to gastro-esophageal reflux and promotes the passage of regurgitated material from the stomach into the pharynx, from where it can easily pass into the main airways. Laryngeal mask ventilation does not avoid the risk of aspiration and its positioning can stimulate vomiting in case of active swallowing reflex. Tracheal intubation is the ideal protective maneuver for avoiding the risk of aspiration and removing aspired material by bronchosuction [(10,12)].

### Lateral positioning

One side lateral decubitus is a protective posture applied when it is necessary to protect lower airways from the risk of aspiration and from the obstruction of upper airways due to obstacles to pharynx and larynx. The position favors spontaneous elimination of matter from the mouth and the nose and allows improvement in ventilation. It is advisable in all comatose patients, in patients with insufficient muscle tone of the neck and in those awakening from narcosis.

### Airway inspection

Before proceeding with insufflation of the lung it is necessary to ascertain that the airways are open and free of material that could pass the trachea. Airway inspection must be performed in cases of suspected aspiration, in coma and/or seizures. In the event of certainty of aspiration, if the patient is in apnea, proceed with intubation and broncho-aspiration before starting ventilation, in order to remove aspirated material rapidly from the trachea and bronchi and prevent the risk of it spreading to the whole lung.

A recent report[(13)] demonstrated the possibility of selective or total lung broncholavage with saline plus surfactant supplementation during or after lavage, in cases of aspiration. The benefits of such an approach are: the removal of material obstructing the airways, the limitation of the diffusion of the pathology to the controlateral lung, the recruitment of lung areas to ventilation through mechanical airway clearance, resolution of possible atelectasis and an improved stability of the small airways and of the terminal bronchiole in cases in which surfactant is used during lavage.

Saline lavage is not suggested because the saline dilutes the material and favors alveolar absorption. Saline bal, moreover, removes surfactant and exposes alveoli and terminal bronchiole to collapse [(14,15)].

## BAROTRAUMA

The term "barotrauma" refers to pressure-related injury induced by large transpulmonary pressure and appears clinically as pneumothorax, pneumomediastinum, or pulmonary interstitial emphysema. A number of studies have documented an association between the

incidence of barotrauma and high peak airway pressure (PAP).

Minor lung damage could occur and often does not show up even on x-ray or ct scan. Therefore, light lung damage may not be immediately visualized but can have a negative influence on the evolution of treatment as well as the final outcome.

The correlation between PAP and barotrauma can occur at extremely low levels of pap and a complete absence of barotrauma despite very high levels of PAP has been demonstrated. Physiologically, lung distension is minimized if plateau airway pressure (PPLAT) is kept reasonably low, arguing that a pressure limited strategy should be as good as a volume limited strategy.

Advantages and disadvantages in the use of auto- and flow-inflating systems have been previously described in prevention of lung damage created by high peak inspiratory pressure (PIP).

## VOLUTRAUMA

The incidence of barotrauma has been reported to correlate not only with pap, but also with tidal volume (i.e. Volutrauma instead of barotrauma)[16]. A large-scale clinically controlled study[17] confirmed alveolar over-distension rather than high proximal airway pressures as the primary determinant for lung injury, combined with shear stress evoked by repeated alveolar collapse and re-opening due to low end-expiratory volumes. Lung over-distension appears to be the fundamental mechanism underlying ventilation induced lung injury (VILI) and ventilation associated lung injury (VALI)[18]. Lung over-distension appears to be a culprit also in increased alveolar-capillary permeability.

Low tidal volume strategy is suggested as protective ventilation. Hypoventilation deriving from a reduction in tidal volume can be corrected by a peep level which allows the alveolus and terminal bronchiole to be continually distended during the entire ventilatory phase.

A flow-inflating bag does not directly control the quantity of gases for each breath, but enables the modulation of tidal volume according to obtained distension of the chest, acting on the valve which regulates gas exhalation. Maintaining the terminal bronchiole open at the end of expiration, peep allows the possibility of progressively reducing pip. Peep, achieved and regulated by means of the continuous distension of the bag, favors oxygenation and enables application of reduced tidal volume and high respiratory rate (low tidal volume strategy). This ventilatory mode has proved to be also extremely useful and protective in children with obstructive lung diseases (e.g. Bronchiolitis and asthma).

## ATELECTRAUMA

Atelectasis is characterized by and associated with decreased compliance, impairment of oxygenation, increased pulmonary vascular resistance and development of lung injury. Atelectasis development has been demonstrated even if the patient is breathing spontaneously or is sedated and paralyzed and mechanically ventilated. It has been demonstrated that atelectasis can appear within a few minutes of sedation and muscle paralysis (e.g. Induction of anesthesia) [19,20].

Several mechanisms have been suggested in the development of atelectasis and the following have been considered mainly responsible: absorption of alveolar air, compression of lung tissue, and impairment of surfactant function[21]. Atelectasis is traditionally thought of as a consequence of lung region and alveoli collapse and not of intrathoracic fluid accumulation.

In children (aged 1–3 years) atelectasis develops more readily compared to adults due to the greater thoracic wall compliance resulting in less outwardly directed lung distension forces and because airway closure can occur even during tidal breathing (high airway closing volume). Abdominal distention (e.g. Pregnancy) and obesity represent two

important factors in determining gas exchange impairment and atelectasis.

Tidal volume and its stability, and suitable peep levels are important factors in avoiding atelectasis development and gas exchange impairment. When atelectasis does appear, recruiting maneuvers are necessary for its resolution and PEEP alone may be insufficient to re-ventilate atelectasic lung regions.

**Use of continuous peep via flow-inflating bag**

PEEP during resuscitation improves blood oxygenation due to increase of lung volume, surface area and compliance, prevents complete lung deflation during expiration and establishes FRC.

Peep during emergency ventilation in asthma and bronchiolitis allows recruited small airways and alveoli to be kept open by continuously distending the terminal bronchiole. Best emergency ventilation mode in these lung pathologies is low tidal volume strategy, high respiratory rate and application of continuous distending PEEP.

Setting peep needs early recruitment maneuvers. All children require a minimum of 5-10 cm $h_2o$ peep. 12-15 cm $h_2o$ peep is probably the best in specific clinical setting. Setting peep is in any case always a compromise[22].

**Recruitment maneuvers**

Manual lung recruitment is fundamental in reducing and resolving atelectasis and improving gas exchange [23,24]. Manual ventilation by bag is a simple maneuver and can be applied at the start of artificial ventilation or during the treatment when atelectasis occurs (e.g. After bronchosuctioning). In presence of inhomogeneous lung pathology or when the inflation pressure is not strictly controlled, over-distension of better-ventilated lung units can occur (barotrauma) during recruitment maneuver. At present the safe peak pressure to reach during distention and for how many seconds the lung must be maintained in distention are controversial. In adults some authors suggest applying 40 $cmh_2o$ maintained for 8-15 seconds[8]. Others suggest maintaining plateau pressure <35 cm $h_2o$ and 15 $cmh_2o$ peep to avoid collapse of recruited lung[25].

The same pressures could be applied in severe lung pathology in children and adolescents over 8 years of age. In infants and young children these pressures appear harmful. Our suggestion is the use of 8-10 cm $h_2o$ over preset inspiratory peak pressure[26]. In neonates recruiting pressure must be modulated in order to avoid an increase of intra-thoracic pressure over 35 $cmh_2o$.

## OXYGEN SIDE EFFECTS

Oxygen, particularly when cold and dry, is toxic to the lung epithelium. Its use should be limited to when really needed. There are important changes in the current recommendation of 100% oxygen use and 100% $o_2$ should no longer be routine for newborn resuscitation[27-29].

## RESUSCITATION WITH 100% OXYGEN

1. Produces more evidence of oxidative stress and may be deleterious;
2. Can be a powerful lung irritant and provoke an inflammatory response;
3. Could potentially exacerbate infant and child respiratory disease;
4. There is considerable concern about high arterial oxygen levels in very premature babies and their contribution to retinopathy and chronic lung disease.

Development of atelectasis is consequent to total re-absorption of $o_2$ in the alveoli. Most experience in this field derives from anesthesia. Using high $fio_2$ during pre-oxygenation or $fio_2$ 1.0 before extubation exposes to risk of persistent atelectasis in postoperative care.

To avoid this risk, use the lower concentration of $fio_2$ accepting $pao_2$ values near the lower limit of the range, and sat $o_2$ of 90. To reduce the risk of oxygen toxicity from high $fio_2$, it is recommended to apply suitable procedures that lead to $fio_2$ reduction and

increase in oxygenation: PEEP titration e recruiting maneuvers[22].

Dry and cold oxygen (gas) also favors consolidation of secretions and difficulty in removal with consequent airway trauma and alveolar collapse/closure. Use of humidified and warmed ventilated gases is fundamental in reducing damage connected with bronchosuction in prolonged ventilation support.

Use of high $fio_2$ (>0.4) produces free oxygen radicals which cause direct damage to the lung and favor the release of inflammation mediators and development of multi organ failure (MOF) [30].

## BIOTRAUMA

Biological lung damage is caused on the one hand by the lung pathology itself and on the other by damage to the lung from traumatic ventilation and oxygen supplementation[31].

Studies in animals have demonstrated that over-distension of the lung by mechanical ventilation can cause elevations in inflammatory cytokines, increased endothelial and epithelial permeability, alter lung fluid balance, and result in severe ultra structural tissue damage[32]. It is also certain that oxygen toxicity can cause elevated cytokine levels and therefore the use of oxygen must be carefully evaluated. High $fio_2$ and traumatic ventilation must be strictly evaluated in the realization of biotrauma.

Mediators released by the lung owing to the increased pulmonary stresses entering the circulation could lead to distal organ dysfunction and ultimately mof which seriously limit the patient's chances of recovery[32].

Reduction of lung stress, control of inflammation, reduction of $fio_2$ to minimum level, and use of protective lung strategies that limit end-inspiratory lung stretch in mechanically ventilated patients are fundamental in reducing biotrauma and protecting the lung from ventilation injury.

## SURFACT-TRAUMA

Lack of surfactant activity in the lung can be connected with direct damage to alveolar cells or inhibition/inactivation of normally produced surfactant. Surfactant inhibition and the impossibility of recycling it (90% of surfactant produced is recycled) is a major cause of its loss of activity. There is evidence that alteration of the pulmonary surface may lead to lung inflammation and development of pneumonia[33].

Surfactant deficiency is connected with various exogenous and endogenous causes. Among exogenous causes, air pollution and the use of certain gases (e.g. Anesthetics, no) are becoming more important. Mechanical ventilation can deteriorate lung surfactant when high tidal volume is used, due to the increased conversion of surfactant from large aggregate to inactive form. Elevated levels of no and reactive oxygen species (free radicals) alter surfactant proteins, reducing its activity.

Suitable ventilation modes, use of not toxic gases, high quality nursing (e.g. No use of saline before aspiration but utilization of humidifiers to maintain fluid secretions) and reduced $fio_2$, are principal factors in surfactant protective strategy[34].

## CONCLUSIONS

Complications and side effects of artificial ventilation cannot be avoided in emergency room but could be reduced by following manner and protocol of application carefully and accurately.

Auto-inflating bag and flow-inflating bag are referential for other systems currently on the market. Both systems can be used in various clinical contexts (e.g. Lung re-expansion after bronchosuctioning and/or treatment of uni-plurilobar atelectasis). Advantages and disadvantages of both systems must be evaluated before their use in order to obtain the best gas exchange with the least pulmonary damage.

The preset pressure control valve and the systems that utilize this valve can avoid the risk of elevated airway pressure (PIP) but are not able to assure lesser damage to the lung. Tidal volume plays a most important role in causing lung damage: it can favour either over-distension or hypoventilation, and both clinical conditions are harmful for the lung. Over-distension results in direct damage to the lung structure while hypoventilation favours the development of non–ventilating and atelectasic areas which complicate the clinical evolution and the final outcome. An important role during ventilation is also played by the correct use of peep: 1. Avoiding the closure and re-opening of the terminal bronchioles can reduce the need for high opening peak pressures; 2. Maintaining the alveolus continuously distended, peep on one hand improves oxygenation (increase of functional residual capacity – frc) and on the other reduces the need for high $fio_2$ (less oxygen toxicity). Maintaining the lung distended at the end of inspiration favours alveolar recruitment when tidal volume is introduced into the lung. The required duration of distension is controversial, although 8-15 seconds appears to be useful in adults and in children.

Ventilation of a child in emergency needs skill as well as adequate and updated knowledge not only to obtain beneficial effects from artificial ventilation but also to reduce side effects connected to incorrect use. It should be borne in mind that even short time ventilation can cause severe damage to the lung, not only immediately and evidently (e.g. Emphysema and pneumothorax) but also in the medium and long term, affecting morbidity and mortality of outcome.

## REFERENCES

1. Kumar a, pontoppidan h, falke kj et al. Pulmonary barotrauma during mechanical ventilation. Crit care med. 1973; 1:181-186.
2. Slutsky as. Lung injury caused by mechanical ventilation. Chest. 1999; 116: 9s–15s
3. Milner a. The importance of ventilation to effective resuscitation in the term and preterm infant. Sem neonatol. 2001; 6: 219-224.
4. *Vyas h*, field d, milner ad, hopkin ie. Determinats of the first inspiratory volume and functional residual capacity at birth. Pediatr pulmonol. 1986; 2: 189-193.
5. Marraro g. - airway management. In "principles and practice of pediatric anesthesia", bissonnette b and dalens bj eds. Ed. Mcgraw-hill, new york. 2001; 778-814.
6. Molloy ej. Possible sequelae of sustained lung inflation in resuscitation of preterm infants. Pediatrics. 2007; 120: 1221-1222.
7. *Jobe ah*, hillman nh, polglase gr, kramer bw, kallapur sg, pillow, jj. Injury and inflammation from resuscitation of the preterm infant. Neonatology. 2008; 94: 190-196.
8. Magnusson l, tenling a, lemoine r,et al. The safety of one, or repeated, vital capacity maneuvers during general anesthesia. Anesth analg. 2000; 91: 702-707.
9. Tremblay ln, slutsky as. Ventilator-induced injury: from barotrauma to biotrauma. Proc assoc am physicians. 1998; 110: 482-488.
10. Mason dg, bingham rm. The laryngeal mask airway in children. Anaesthesia. 1990; 45: 760-763.
11. Mcginn g, haynes sr, morton ns. An evaluation of the laryngeal mask airway during routine paediatric anaesthesia. Paediatric anaesth. 1993; 3: 23-28.
12. Marraro g. Mechanical ventilation in pediatric patients: recent advances and protective lung strategies. Chin j contemp pediatr. 2005; 7: 278-283.
13. Marraro ga, luchetti m, spada c, galassini e, giossi m, monici preti ap. Selective medicated (normal saline and exogenous surfactant) bronchoalveolar lavage in severe aspiration syndrome in children. Pediatr crit care med. 2007; 8: 476-481.
14. Marraro g, bonati m, ferrari a, barzaghi m, pagani c, bortolotti a, galbiati a, luchetti m, croce a. Perfluorocarbon broncho alveolar lavage and liquid ventilation versus saline broncho alveolar lavage in adult guinea pig experimental model of meconium inhalation. Intensive care medicine. 1998; 24: 501-508.
15. Lachmann g, robertson b, vogel j. In vivo lung lavage ad an experimental model of the

respiratory distress syndrome. Acta anaesth scand. 1980; 24: 231-236.

16. Dreyfuss d, saumon g: barotrauma is volutrauma, but which volume is the one responsible? Intensive care med. 1992; 18: 139-141.
17. Ards network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N engl j med. 2000; 342: 1301-1308.
18. Auten rl, vozzelli m, clark rh. Volutrauma. What is it, and how to avoid it? Clinical perinatol. 2001; 28: 505-515.
19. Hedenstierna g, edmark l. The effects of anesthesia and muscle paralysis on the respiratory system. Intensive care med. 2005; 31: 1327-1335.
20. Serafini p, cornara g, cavalloro f. Mori a, fore r, marraro g, braschi a. Pulmonary atelectasis during anaesthesia: ct scan evaluation and effect of positive endexpiratory pressure (peep). Paediatric anaesthesia. 1999; 9: 225-228.
21. Duggan m, kavanagh bp. Pulmonary atelectasis. A pathogenic perioperative entity anesthesiology. 2005; 102: 838-854.
22. Suarez-sipmann f, böhm sh, tusman g, pesch t, thamm o, reissmann h, reske a, magnusson a, hedenstierna g. Use of dynamic compliance for open lung positive end-expiratory pressure titration in an experimental study. Crit care med. 2007; 35: 214-221.
23. Hess dr, bigatello lm. Lung recruitment: the role of recruitment maneuvers. Respir care. 2002; 47: 308-318.
24. Rimensberger pc, et al. Lung recruitment during small tidal volume ventilation allows minimal positive end-expiratory pressure without augmenting lung injury. Crit care med. 1999; 27: 1946-1952.
25. Tusman g, böhm sh, tempra a, melkun f, garcía e, turchetto e, mulder pg, lachmann b. Effects of recruitment maneuver on atelectasis in anesthetized children. Anesthesiology. 2003; 98: 14-22.
26. Marraro g. Protective lung strategy during artificial ventilation in children. Paediatric anesthesia. 2005; 15: 630-637.
27. Vento m, asensi m, sastre j, garcia-sala f, pallardo fv, vina j. Resuscitation with room air instead of 100% oxygen prevents oxidative stress in moderately asphyxiated term neonates. Pediatrics. 2001; 107: 642-647.
28. Saugstadt od. Is oxygen more toxic than currently believed? Pediatrics. 2001; 108: 1203-1205.
29. Saugstad O.D. Optimal oxygenation at birth and in the neonatal period. Neonatology. 2007; 91: 319-322.
30. Plotz fba,slutsky as, van vught aj, heijnen cj. Ventilator-induced lung injury and multiple system organ failure: a critical review of facts and hypotheses. Intensive care med. 2004; 30: 1865-1872.
31. Slutsky as. Ventilator-induced lung injury: from barotrauma to biotrauma. Respir care. 2005; 50: 646-659.
32. Richard jd, dreyfuss d. Cytokines during ventilator-induced lung injury: a word of caution. Anesth analg. 2001; 93:251-252
33. Verbrugge s j, bohm s h, gommers d et al. Surfactant impairment after mechanical ventilation with large alveolar surface area changes and effects of positive end-expiratory pressure. Br j anaesth. 1998; 80: 360-364
34. Sosnowski tr, gradon l, marraro ga. Direct interactions between nitrous oxide and exogenous pulmonary surfactant in vitro. Experimental lung research 2004; 30:1-8