INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is now recognized as an inflammatory disease of the airways. The new American Thoracic Society (ATS)/European Respiratory Society (ERS) definition reflects these scientific advances: Chronic Obstructive Pulmonary Disease (COPD) is a preventable and treatable disease characterized by airflow limitation that is not fully reversible. The airflow limitation is usually progressive and is associated with an abnormal inflammatory response of the lungs to noxious particles or gases, primarily caused by cigarette smoking ***(Pauwels et al., 2001).***

In the presence of high resistance to expiratory flows and short expiratory time, the expiratory system is unable to return to its resting volume at the end of exhalation. The positive pressure within regions of hyper-inflated lung raises the mean intrathorathic pressure and causes the inspiratory muscles to operate at a higher than resting lung volume.Thus dynamic hyper-ventilation places the respiratory muscles at a considerable mechanical disadvantage and further impairs respiratory muscle function. Intrinsic positional end expiratory pressure (PEEPi) also imposes a substantial inspiratory threshold load ***(Brochard, 2002).***

Several factors contribute to development of gas exchange abnormalities in patients with obstructive lung disease. Airway obstruction produces regional hypoventilation that produces ventilation / perfusion mismatch and hypoxemia. Loss of capillary bed due to emphysema or compression of pulmonary capillaries by over inflated alveoli also trends to increase dead space, and this wasted ventilation further compromise the ability of the respiratory muscles to provide adequate ventilation ***(Mountain and Sahn, 1988).***

Optimal oxygenation depends on the match of ventilation (V) to perfusion (Q) ratio, with optimal oxygenation, occurring when the best ventilated areas are best perfused. Therefore, proper positioning of patients may promote oxygenation in a less traumatic, less invasive and less expensive manner than high tech-treatment ***(Yeaw, 1992).***

Acute exacerbations of chronic obstructive pulmonary disease (COPD) are a frequent cause of admission to hospital and the intensive care unit (ICU). Despite a well conducted medical treatment, worsening can occur in patients with acute exacerbations of COPD and lead to a de-compensation phase. Acute respiratory failure can lead to the requirement of mechanical ventilation; in these cases, non-invasive ventilation (NIV) must be considered in order to avoid invasive mechanical ventilation and its related complications ***(Brochard, 2000).***

PRINCIPLES AND MODES OF MECHANICAL VENTILATION

The mechanics of respiration:

Inspiration results from the contraction of the diaphragm and intercostal muscles. The rib cage swings upwards and outwards. The enlarged cavity housing the lungs undergoes a pressure reduction (-3 mm Hg) with respect to the pressure existing outside the body. Since the lungs are passive (no muscle tissue), they expand due to the positive external pressure, e.g. if the environmental pressure is 760 mm Hg, the lung pressure is 757 mm Hg upon inspiration ***(Williams and Wilkins, 1998).***

Expiration results from the relaxation of the diaphragm and intercostal muscles. The rib cage moves inward and downwards. The elastic recoil of the lungs creates a higher than atmospheric intrapulmonic pressure (plus 3 mm Hg) that forces air out of the lungs ***(Marini, 1990).***

Parameters of respiration include:

- *Tidal volume:* The volume of gas inspired or expired during each respiratory cycle. Typically 500 ml.
- *Inspiratory reserve volume*: The maximum amount of gas that can be inspired from the end-aspiratory position.

- *Expiratory reserve volume*: Amount of air that can be forced out of lungs after normal expiration typically 1200 ml
- *Residual volume:* The volume of gas remaining in the lungs at the end of a maximum expiration. Typically 1200 ml ***(Pride and Milic-Emili, 2003).***
- *Vital capacity*: The maximum volume of gas that can be expelled from the lungs following a maximum inspiration. It includes tidal volume, plus inspiratory reserve volume, plus expiratory reserve volume. Typically 4800 ml.
- *Inspiratory capacity*: The maximum volume of gas that can be inspired from the resting expiratory position. Typically 3600 ml.
- *Inspiritory reserve volume*: Additional volume that can be inspired after a normal inspiration. Typically 3100 ml.
- *Functional residual capacity:* The volume of gas remaining in the lungs at the resting end-expiratory position. Typically 2400 ml.
- *Minute volume*: The total volume of air ventilated over a minute period. It should be qualified either inspiratory or expiratory.
- *Maximum voluntary ventilation*: The maximum volume of air that can be ventilated per minute (also referred to a Maximum Breathing Capacity).

- *Total lung capacity*: Amount of gas contained in lungs at end of maximum inspiration typically 6000 ml ***(Tobin, 1990).***

Lung compliance:

Lung compliance is the pulmonary volume change per unit pressure change. Essentially, lung compliance is the ability of the alveoli and lung tissue to expand on inspiration. In clinical terms it is defined as the volume increase in the lungs per unit increase in the lung pressure. The stiffer the lung, the less the compliance. Compliance is reduced by diseases which cause an accumulation of fibrous tissue in the lung or by oedema in the alveolar spaces. It is increased in pulmonary emphysema and also with age, probably because of alterations in the elastic tissue in both cases ***(Hopin, 1999).***

There are two types of compliance, *static* and *dynamic*. The *static compliance* of the lung is the change in volume for a given change in transpulmonary pressure with zero gas flow.

Dynamic compliance measurements are made by monitoring the tidal volume used, while intra thoracic pressure measurements are taken during the instance of zero air flow that occurs at the end inspiratory and expiratory levels with each breath.

Lung compliance varies with the size of the lungs; a child has a smaller compliance than an adult does. Furthermore the volume-pressure curve is not linear; hence compliance does not remain constant. Fortunately, over the tidal volume range in which dynamic compliance measurements are usually performed, the relationship is approximately linear and a constant compliance is assumed. Compliance values are given as liters per cm of water ***(MacIntyre, 2005).***

Airway resistance:

Airway resistance relates to the ease with which air flows through tubular respiratory structures. Higher resistance occurs in smaller tubes such as bronchioles and alveoli that have not emptied properly. It is a pneumatic analogy of hydraulic or electrical resistance (R=V/I) and, as such, is a ratio of pressure to flow. Thus for the determination of airway resistance, intra alveolar pressure and airflow measurements are required. As was the case with compliance, airway resistance is not constant over the respiratory cycle. As pressure in the thoracic cavity becomes more negative, the airways are widened and the resistance is lowered. Conversely, during expiration, when the pressure in the thorax becomes positive, the airways are narrowed and resistance is increased. The intra alveolar pressure is given in cm water and the flow in liters per second; the airway resistance is expressed in cm water per liter per second ***(Habib, 1990).***

Lung elasticity:

Lung elasticity is the ability of the lung elastic tissues to recoil during expiration. The lungs should return to rest state easily to ensure sufficient exhaust of gas. Intra-thoracic pressure is the positive and negative pressure occurring within the thoracic cavity. These are critical to proper inspiration (negative internal pressure) and expiration (positive internal pressure). Intra alveolar pressure is of importance in maintaining proper respiration and gas exchange to and from the blood.

Only a portion of the air entering the respiratory system actually reaches the alveoli. The volume of air that is not available for gas exchange with the blood resides in the conducting spaces, known as 'dead air' and fills dead spaces consisting of approximately 150 ml ***(Brusasco et al., 1999).***

Mechanical ventilation:

Mechanical ventilators connected to the patients airway and are designed to replace or augment the patients ventilation automatically. They are used with a mask, endotracheal tube, (within the trachea) or tracheostomy tube (through an artificial opening in the trachea via the throat).

Classification of ventilation:

Ventilation can be classified into *negative, positive and extracorporeal ventilation,* also it can be classified into *invasive and non invasive ventilation.*

A- Negative pressure ventilation:

Simple and don't require intubation of the airway. The iron lung, also know as the Drinker and Show tank, was one of the first negative pressure machines used for long term ventilation (Figure 1). The machine is a large elongated tank, which encases the patient up to the neck. Negative-pressure ventilation (NPV) was the primary mode of assisted ventilation for patients with acute respiratory failure until the Copenhagen polio epidemic in the 1950s, when, because there was insufficient equipment, it was necessary to ventilate patients continually by hand via an endotracheal tube. Thereafter, positive-pressure ventilation was used routinely (Table 1).

Table (1): Indications, contraindications and side effects of NPV

Indications	Contraindications	Side-effects
Severe respiratory acidosis	Sleep-apnoea syndrome	Upper airway collapse
Severe hypercapnic encephalopathy	Severe obesity	Back pain
Excessive airway secretions	Severe kyphoscoliosis	Tiredness or depression
Facial deformity	Claustrophobia	Oesophagitis
Inability to fit mask	Rib fractures	Rib fractures
Mask intolerance	Recent abdominal surgery	Poor compliance

(Corrado et al., 2001)

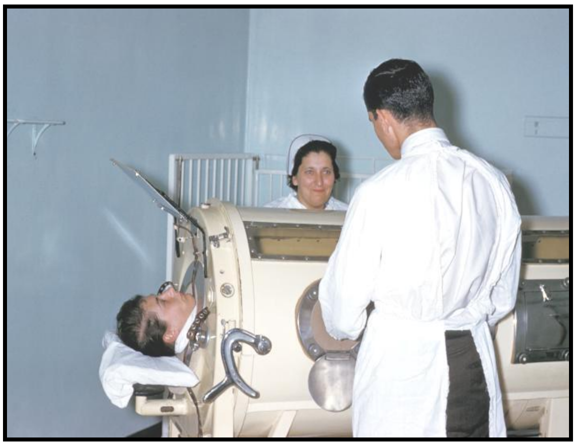

Figure (1): Iron lung ***(Corrado et al., 1994).***

B- Positive pressure ventilation:

This is the type of ventilation most widely used today. The positive pressure allows air to flow into the airway until the ventilator breath is terminated; subsequently the airway pressure drops to zero, the elastic recoil of the chest wall and the lungs push the tidal volume, the breath out through passive exhalation. Most positive pressure ventilators deliver gas up to either a preset pressure (pressure cycled) or volume (volume cycled). Time cycled ventilation is used primarily in infants or in adults who are ventilated at a high rate that precludes pressure or volume cycling. It pushes air into the lungs until a preset time has elapsed ***(Susan, 2006).***

C. Extracorporal ventilation:

Gas exchange takes place entirely or in part outside the body using either extracorporeal membrane oxygenation (ECMO) or extracorporeal carbon dioxide removal ($ECCO_2R$). Both techniques are only occasionally used; ECMO is usually used in neonates and $ECCO_2R$ in patients with Adult Respiratory Distress Syndrome (ARDS) ***(Bartlett et al., 2000).***

Ventilation in clinical use can be classified into two main groups:

A. Invasive mechanical ventilation.

B. Non invasive mechanical ventilation.

A. Invasive mechanical ventilation:

The ventilator mode refers to the manner in which the ventilator breaths are triggered, cycled and limited.

- ***Trigger:*** defines what the ventilator senses to initiate an assisted cycle.
- ***Cycle:*** defines the factors that determine the end of inspiration. For example, in volume cycled ventilation, inspiration ends when a specific tidal volume is delivered to the patient.
- ***Limiting factors:*** defines operator specified values such as airway pressure that is monitored by the ventilator throughout the respiratory cycle. If the specified values are exceeded, inspiratory flow is immediately stopped and the ventilator circuit vented ***(Laureen and Pearl, 2002).***

The common modes of positive pressure ventilation include:

1. Controlled mechanical ventilation (CMV):

The simplest mode of positive pressure ventilation. Breathing is controlled by a timer set to provide the desired respiration rate and either a preset maximum airway pressure or tidal volume. Controlled ventilation is required for patients who are unable to breathe on their own. In this mode, the ventilator has complete control over the patient respiration and does not respond to any respiratory effort on the part of the patient.

Advantages:

Assures a minute ventilation (V_E); can control the inspiratory time (Ti) to maximize passive exhalation in obstructive lung disease state.

Disadvantage:

Patient asynchrony occurs if different respiratory rate (RR) or inspiratory flow rate (Vi) is desired by the patient ***(Gajic et al., 2004).***

2. Assist – control mode ventilation (ACMV):

The ventilator is normally triggered when the patient attempts to breathe (as in assistor mode). However, if the patient fails to breathe within a pre-determined period time, a timer automatically trigger the ventilator to inflate the lungs.

Thus the patient controls his own breathing as long as he can, but if he should fail to do so, the equipment is able to take-over for him. On the other hand, this mode can be used to wean the patient from the controlled ventilation. If the patient attempt to breathe during controlled ventilation, the equipment will sense the attempt and operate in the assist mode immediately, irrespective of which part of the control phase it had reached ***(Hotchkiss et al., 2002).***

Advantages:

Ensures minimum minute ventilation, better patient synchrony if higher minute ventilation is desired. Can still control (Ti) to allow for maximum passive exhalation.

Disadvantage:

Can potentially induce respiratory alkalosis if high respiratory drive (i.e., liver failure). Patient asynchrony and respiratory muscle fatigue can occur if a different inspiratory flow rate (Vi) is required by the patient. I:E ratio can vary because the variable RR can alter the expiratory phase ***(Izurieta and Rabatin, 2002).***

3. Synchronized intermittent mandatory ventilation (SIMV):

SIMV is a hybrid between Intermittent Mandatory Ventilation (IMV) and Assist controlled (AC). Three kinds of breaths may be delivered:

Spontaneous, assisted, and mandatory breath. If no breaths are initiated within a period of time, a mandatory breath will be delivered. If the machine senses that the patient has taken a spontaneous breath just before the mandatory breath, the machine will recycle and then wait for the next spontaneous breath and assist it.

Advantages: ensures a minimum minute ventilation (V_E).

Disadvantages: it has been shown to be the least beneficial weaning mode. Cannot fully control the I:E ratio given the variability in RR and presence of spontaneous breaths ***(Hehta and Hill, 2001).***

4. Continuous positive airway pressure (CPAP):

Occurs when the inspiratory and expiratory limbs are pressurized to a preset end expiratory pressure. CPAP functions primarily as an oxygenation and weaning modality ***(Hess, 2005).***

a. No inspiratory flow is delivered, so it is not a true positive-pressure Mechanical Ventilation (MV) mode. The patient assumes most of the work of breathing by generating his or her own RR, Vi, V_T, and thus V_E, closely simulating spontaneous breathing.

b. Work of breathing (WOB) is reduced compared to complete discontinuation from the MV circuit and delivery of only FiO_2 (T-piece). Application of PEEP stents the airway open and allow for better exhaled V_T. CPAP can be used in coordination with flow-by. Flow-by occurs when a stream of gas is delivered across the ventilator circuit, assisting the patient in drawing his or her own Vi and V_T ***(Hill and Armonk, 2001).***

Expiration positive airway pressure (EPAP):

Only the expiratory phase is pressurized. Compared to CPAP, EPAP has a lower mean airway pressure (MAP) and higher WOB.

For those dependent on MV:

For only oxygenation and not ventilation, CPAP can improve oxygenation without subjecting the patient to the harmful effects of MV ***(Pack, 2006).***

5. Pressure control ventilation (PCV):

PCV is similar to IMV in that control breathes are delivered at a preset time interval, but with a preset pressure limit rather than a preset volume.

Respiratory rate and time to maximal pressure limit are both controlled, and spontaneous breaths can be inspired between the mandatory breaths ***(Yang and Yang, 2002).***

Advantages:

Can limit PIP and plateau pressure (Pplat) to prevent ventilator associated lung injury. Can control or extend Ti for inverse ratio ventilation to increase mean airway pressure

(MAP) and augment oxygenation. Therefore, given these two advantages, this mode is often used for advanced acute lung injury.

Disadvantage:

Cannot ensure minimal V_E with airway obstruction or poor compliance, because delivered volumes may be low if compliance is high. For normal I:E ratios, PC mode are a standard controlled mode and don't need additional sedation. For inverse ratio ventilation. (I:E 4:1), sedation with or without paralysis is necessary because of patient discomfort. Circuit leaks can extend inspiratory time. Exaggeration of inspiratory time can limit time for passive exhalation and induce auto PEEP ***(Brower et al., 2004).***

6. Pressure support ventilation (PS):

Every breath is an assisted breath. Each breath is triggered by the patient respiratory effort. The patient determines the inspiratory flow rate and shape of the wave form as well as the respiratory rate (R.R.) when a preset pressure limit is reached, inspiratory flow slows to less than 0.5 L/ min and the machine cycles off.

Advantages:

Better patient synchrony, patient determines Vi characteristics. Limits PIP. Compliance is easily calculated