

# Comparison of three Methods of Weaning Patients from Mechanical Ventilation

*Thesis*

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## *List of Abbreviations*

A/C	Assist controlled
ABG	Arterial blood gases
APRV	Airway pressure release ventilation
ARDS	Acute respiratory distress syndrome
ARF	Acute respiratory failure
ASV	Adaptive support ventilation
ATC	Automatic tube compensation
BiPAP	Biphasic positive airway pressure
CHF	Chronic heart failure
CINMA	Critical illness neuromuscular abnormalities
CPAP	Continuous positive airway pressure
CMV	Controlled mandatory ventilation
COPD	Chronic obstructive pulmonary disease
CO <sub>2</sub>	Carbon dioxide
CROP	Integrative index of compliance, rate, oxygenation, pressure
Crs	Respiratory system compliance
DEC	Dynamic effective compliance
DH	Dynamic hyperinflation
FRC	Functional residual capacity
FiO <sub>2</sub>	Fraction of inspired oxygen
fR	Respiratory frequency
GCS	Glasgow coma scale
GI	Gastro-intestinal
H <sub>2</sub> O	water
H <sub>2</sub> O <sub>2</sub>	Hydrogen peroxide
HCPs	Health care professionals
HFOV	High frequency oscillatory ventilation
IC	Inspiratory capacity
ICU	Intensive Care Unit
IRV	Inspiratory reserve volume
IPPV	Intermittent positive pressure ventilation
KPa	Kilo Pascal
MDI	Meter dose inhaler
MIP	Maximal inspiratory pressure
MRSA	methicillin-resistant staphylococcus aureus
NAVA	Neurally adjusted ventilator assist
NIV	Non-invasive ventilation
NIP	Negative inspiratory pressure
NPPV	Non-invasive positive pressure ventilation
NAMDRC	National Association for medical direction of respiratory care

P0.1	Ratio of airway occlusion pressure 0.1 s after the onset of inspiratory effort
PaCO <sub>2</sub>	Partial pressure of arterial carbon dioxide
PAO <sub>2</sub>	Partial pressure of alveolar oxygen
PaO <sub>2</sub>	Partial pressure of arterial oxygen
PAV	Proportional assist ventilation
PB	barometric pressure
PCV	Pressure controlled ventilation
PEEP	Positive end expiratory pressure
PEEP <sub>i</sub>	Intrinsic positive end expiratory pressure
pH	Power of hydrogen
P <sub>I</sub> max	maximal inspiratory pressure
PMV	Prolonged mechanical ventilation
PRVC	Pressure regulated volume control
PSV	Pressure support ventilation
RV	Residual volume
RSBI	Rapid shallow breathing index
RR	Respiratory rate
SaO <sub>2</sub>	Arterial oxygen saturation
SBT	Spontaneous breathing trial
SIMV	Synchronized intermittent mandatory ventilation
SvO <sub>2</sub>	Mixed venous oxygen saturation
SWUs	Specialized weaning units
VAP	Ventilator-associated pneumonia
VALI	Ventilator-associated lung injury
VILI	Ventilator-induced lung injury
VE	Minute ventilation
VILI	Ventilator-induced lung injury
VSV	Volume support ventilation
VT	Tidal volume
WOB	Work of breathing

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## **Introduction**

Mechanical ventilation is one of the most challenging tasks facing physicians in the ICU. Weaning from mechanical ventilation is defined as the gradual process of transferring the respiratory work of breathing from the ventilator to the patient. It is easily obtained in about 70-80% of the patients. However 20–30% present with difficult weaning (*Goldstone, 2002*).

The respiratory system is divided into ventilatory organs (upper and lower air passages) and the alveoli. Regarding the internal structure of the lungs, respiratory bronchioles divide into terminal bronchioles, each leading into two alveolar ducts, which lead into alveolar sacs, which contain the alveoli, in which gas exchange takes place (*Hasan ,2010*).

Breathing is regulated by the respiratory center in the medulla. Chemoreceptors sense the arterial PaO<sub>2</sub>, PaCO<sub>2</sub>, and pH. Aortic bodies and carotid body respond to reduction in arterial PaO<sub>2</sub>. Central chemoreceptors respond to raised carbon dioxide concentration and fall in blood pH. The driving forces for the exchange of gases between the alveoli and the ambient air are pressure differences (*MacIntyre et al 2005*).

The main objectives of mechanical ventilation are to reverse hypoxemia, to reverse acute respiratory acidosis so as to relieve life-threatening acidemia rather than to normalize PaCO<sub>2</sub>, and to relieve respiratory distress and elevated work of breathing (*Pierce ,2007*).

Complications of mechanical ventilation include complications of intubation, ventilator-induced lung injury, ventilator-associated pneumonia, oxygen toxicity, and intrinsic PEEP. The process of weaning

begins with assessment of readiness for weaning, followed by a spontaneous breathing trial. For many patients, discontinuation of sedation is a critical step. The decision to remove the artificial airway in patients successfully passing an SBT requires further assessment of the patient's ability to protect the airway (*Hasan ,2010*).

**Some of the objective parameters to predict weaning success include:**

- PaO<sub>2</sub>/FiO<sub>2</sub> ratio >150-200.
- Level of PEEP between 5-8 cm H<sub>2</sub>O .
- FiO<sub>2</sub> level <50%.
- pH > 7.25.
- Ability to initiate spontaneous breaths.

**Some of the subjective parameters include:**

- Hemodynamic stability.
- Absence of active myocardial ischemia.
- Absence of clinically significant, vasopressor-requiring hypotension.
- Appropriate neurological examination.
- Improving or normal appearing chest radiogram.
- Adequate muscular strength allowing the capability to initiate/sustain the respiratory effort.

**Recent guidelines for weaning include the following:**

- Patients should be categorized into three groups based on the difficulty and duration of the weaning process.
- Weaning should be considered as early as possible.
- A spontaneous breathing trial is the major diagnostic test to determine whether patients can be successfully extubated.
- The initial trial should last 30 min and consists of either T-tube breathing or low levels of pressure support.

- Pressure support or assist–control ventilation modes should be favored in patients failing initial trials.
- Noninvasive ventilation techniques should be considered in selected patients to shorten the duration of intubation but should not be routinely used as a tool for extubation failure.

Difficult weaning results from the impairment between the load imposed on the respiratory system and the capacity of the respiratory muscle to perform this increased work of breathing. Factors that limit the weaning process include oxygenation, respiratory load and capacity of the respiratory muscle to accomplish this load, cardiovascular performance, and psychological factors (*Chan et al., 1999*).

Prolonged mechanical ventilation is defined as the need for continual assistance from a mechanical ventilator for at least 6 hours per day for at least 21 days. Weaning strategy in the PMV patient should be slow-paced and should include gradually lengthening self-breathing trials (*MacIntyre et al., 2005*).

Tracheostomy has become an increasingly common intervention in ICUs with the introduction of percutaneous techniques performed by the intensivist at the bedside. Rehabilitation is the process of restoring health or normal life by training and therapy after illness (*Chan et al., 1999*).

Specialized weaning units offer specialized teams (e.g. nurses, physiologists, respiratory therapists, nutritionists, etc.) and an appropriate “bridge to home” environment for such patients and their families (e.g. privacy, daytime activity, longer visiting hours and undisturbed sleep). They also relieve pressure on scarce ICU beds (*Vassilakopoulos et al., 2006*).

## **Aim of the Work**

Comparison between Pressure support ventilation (PSV), Synchronized intermittent mandatory ventilation (SIMV) and Biphasic Positive Airway Pressure (BIPAP) as three weaning modes of mechanical ventilation in Type I Respiratory failure.

## **Modes of Mechanical Ventilation**

Mechanical ventilation in itself is not a cure for respiratory failure it should be thought as a method to support patients and enabling survival. It is proposed that mechanical ventilation is not indicated in moribund patients in whom alleviation of the precipitating factor is not anticipated. In addition, when considering initiation of mechanical ventilation, much thought must be given to the harmful ventilation-related consequences that may complicate the course of the patient's illness (*Hamed et al., 2006*).

The main objectives of initiating mechanical ventilation are to reverse hypoxemia, to reverse acute respiratory acidosis, and to relieve respiratory distress and elevated work of breathing. From these objectives are derived the classical indications for initiation of ventilatory support (*Hamed et al., 2006*):

- Arterial PaO<sub>2</sub> < 60mmHg (on supplemental oxygen).
- Alveolar-to-arterial oxygen difference of more than 350 mmHg (on FiO<sub>2</sub> = 1).
- Arterial PaCO<sub>2</sub> > 50mmHg (in the absence of chronic disease).
- Evidence of elevated work of breath (WOB)
- Respiratory rate of more than 35 breaths per minute.
- Tidal volume of less than 5 ml/kg.
- Vital capacity of less than 15 ml/kg.
- Maximum inspiratory pressure of less than 25 cm H<sub>2</sub>O.
- Presence of retractions or nasal flaring.
- Paradoxical or divergent chest motion.
- Bradypnea or apnea with respiratory arrest, including cases from intoxication.
- Acute lung injury (including ARDS, trauma).
- Chronic obstructive pulmonary disease (COPD).
- Clinical deterioration.
- Respiratory muscle fatigue.

- Obtundation or coma.
- Hypotension including sepsis, shock, congestive heart failure.
- Neuromuscular diseases such as muscular dystrophy, amyotrophic lateral sclerosis.

**I) Invasive modes of mechanical ventilation:**

**A) Common modes of ventilation:**

**1-Pressure Support Ventilation (PSV) (Fig.1):**

It is a mode of ventilator operation in which the patient's inspiratory effort is assisted by the ventilator up to a preset level of inspiratory pressure. Inspiration is terminated when peak inspiratory flow rate reaches a minimum level or a percentage of initial inspiratory flow. Simply, PSV is patient triggered, pressure limited, and flow cycled. This allows patients to determine their own frequency, inspiratory time, and tidal volume. All PSV breaths are spontaneous. However, because the inspiratory pressure is greater than the baseline pressure, breaths are considered supported. The difference between a spontaneous breath and a supported breath is that in the former, inspiratory pressure equals baseline pressure, and in the latter, inspiratory pressure is greater than baseline pressure (*Branson and Campbell, 2009*).

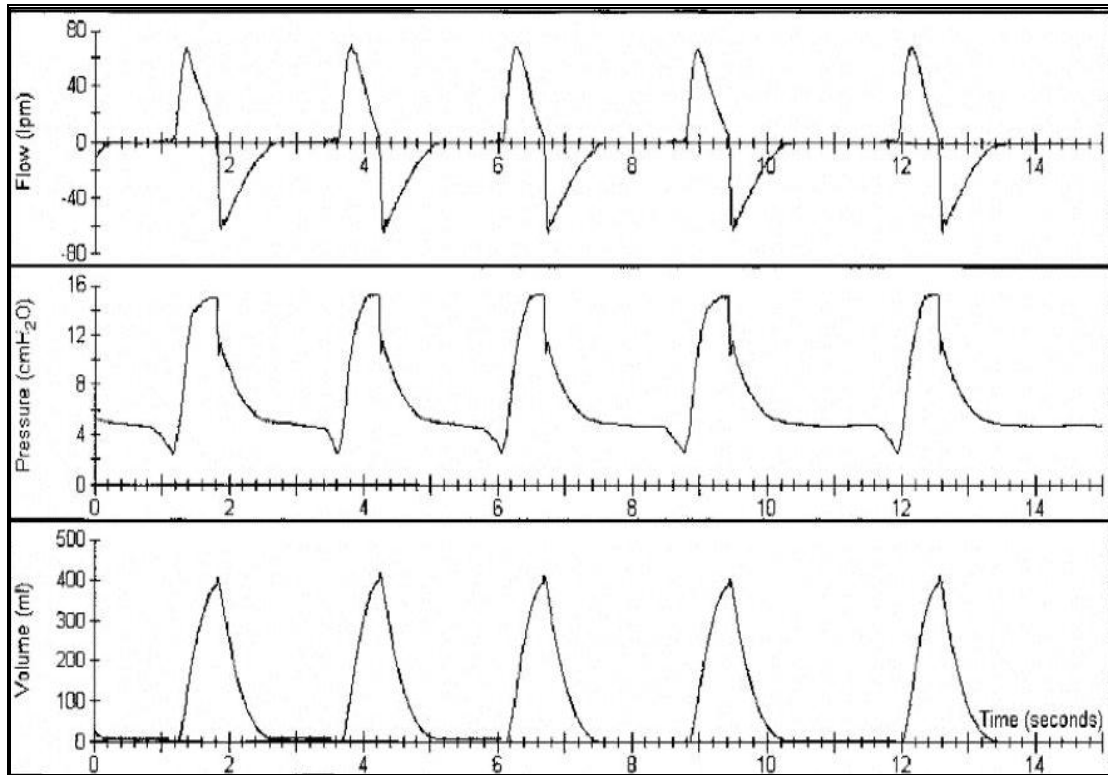


Fig.(1): Pressure Support Ventilation (*Branson and Campbell, 2009*)

### **Advantages and Disadvantages:**

PS may be used to overcome the resistance work associated with moving inspiratory flow through an artificial airway and the ventilatory circuits. PS improves patient-ventilator synchrony and patient comfort because the patient has control over the process of ventilation, the patient determines when to initiate a breath, the timing of inspiration and expiration, and the ventilator pattern. Therefore, the patient also maintains greater control over the PaCO<sub>2</sub> and acid-base balance. The main disadvantage of PS is that the VT is variable and therefore the alveolar ventilation is not guaranteed. If compliance decrease or resistance increase, because of either patient or ventilatory circuitry factors then the VT decreases. PS should be used with great caution in patients who exhibit extremely variable respiratory system impedance, such as broncho-spasme or significant secretions (*Pierce, 2007*).

The ventilator may fail to cycle to expiration if an extensive air leak occurs, either around the airway through broncho-pleural fistulae or in circuit because the flow rate that terminates inspiratory PS will not be reached. This will result in a prolonged inspiratory cycle and application of positive pressure. Most ventilators for safety provide for a time criteria for the termination of inspiration to prevent prolonged inspiration under the condition of flow-cycling and air leak. Finally the use of inline nebulizer should be limited with PS ventilation because the increase flow created by the nebulizer may be erroneously sensed by the ventilator as the patient minute ventilation, this may result in failure to detect apnea. Medication should be administered with meter-dose inhalers (MDIs) to avoid this potential complication (*Pierce, 2007*).

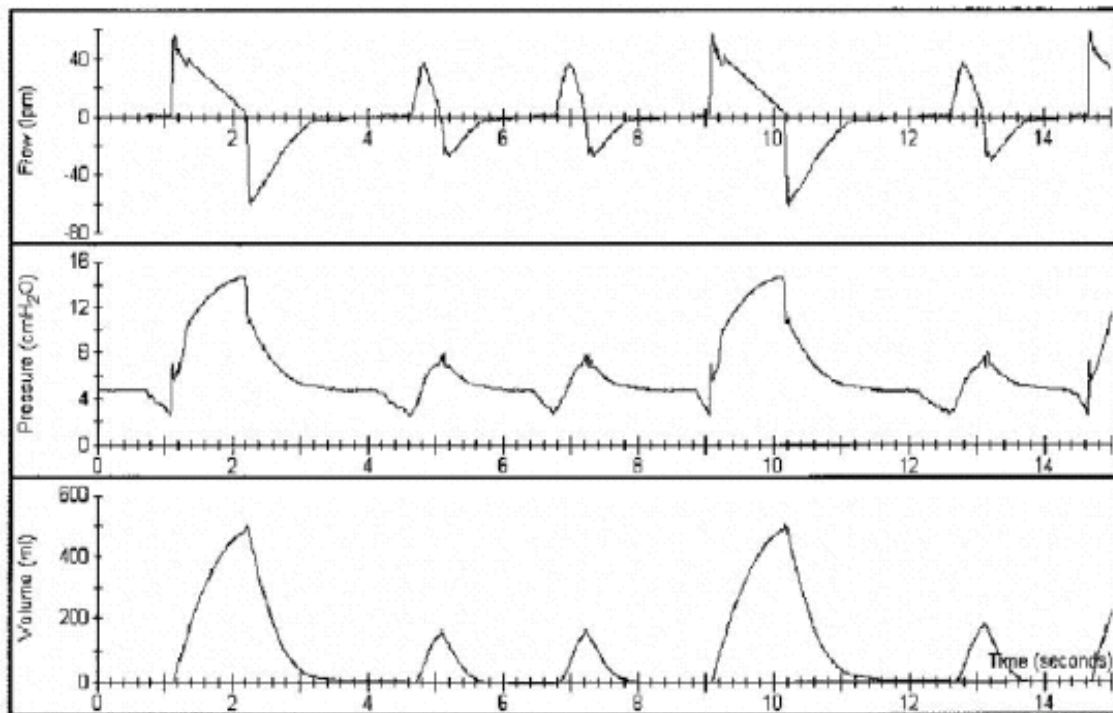
## **2-Synchronized Intermittent Mandatory Ventilation(SIMV)(Fig.2):**

Synchronized intermittent mandatory ventilation is a version of intermittent mandatory ventilation in which the ventilator creates a timing window around the scheduled delivery of the mandatory breath and attempts to deliver the breath in concert with the patient's inspiratory effort. This mode uses a conditional variable to determine which type of breath to deliver. If no inspiratory effort occurs during this time, the ventilator delivers the mandatory breath at the scheduled time (time triggered). If the patient initiates an inspiration, the mandatory breath is synchronized with the patient's effort. The classification describes mandatory breaths during SIMV as pressure or volume controlled; machine or patient triggered; and machine cycled. Spontaneous breaths are classified as pressure controlled, patient triggered, and patient cycled because of the synchronization process. (*Branson and Campbell, 2009*).



**Advantages and Disadvantages:**

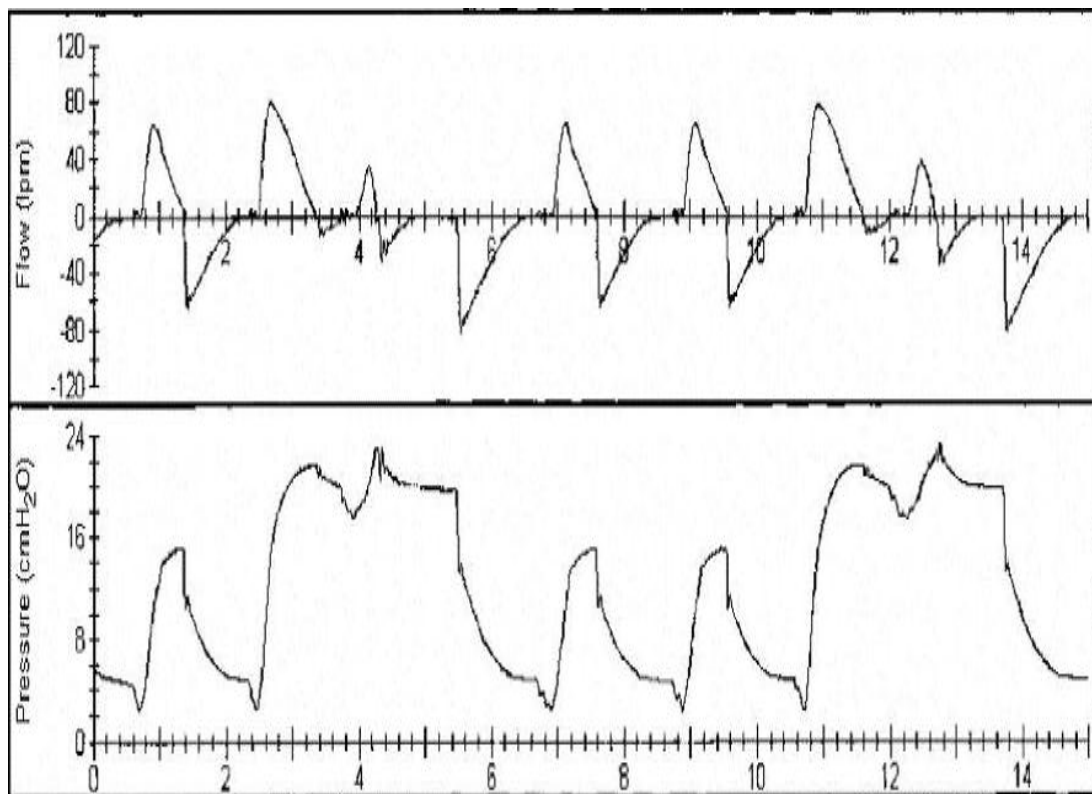
Respiratory alkalosis is less of a problem in this mode than in the A/C mode because the patient can modify rate and volume of spontaneous breathless. Atrophy of respiratory muscles may occur because the patient may participate more in ventilation using the ventilatory muscles to a greater degree than when CMV or A/C is used. The hemodynamic effects of positive-pressure ventilation may be less than other modes because ventilation occur at a lower mean airway pressure when spontaneous breaths are taken. Also, the distribution of gas within the lung is better during spontaneous breathing. IMV fails to monitor the patient spontaneous respiratory efforts and may deliver a mandatory breath during the patient own ventilatory cycle. This may lead to breath staking in which a mechanical breath falls during or at the end of the patient breath. This creates patient-ventilatory dys-synchrony, discomfort, inadequate ventilation, and potentially barotruma (*Pierce, 2007*).



**Fig.(2):** Volume controlled synchronized intermittent mandatory ventilation decelerating ramp flow (*Branson and Campbell, 2009*)

**3-Biphasic Positive Airway Pressure (BIPAP) (Fig. 3) :**

Bi-level, or biphasic, ventilation is a relatively new mode of ventilation that has recently gained popularity. The ventilator is set at 2 pressures (high CPAP, low CPAP), and both levels are time cycled. The high pressure is maintained for most of the time, while the low pressure is maintained for short intervals of usually less than 1 second to allow exhalation and gas exchange to occur. The patient can breathe spontaneously during high or low pressure. This mode has the benefit of alveolar recruitment. Its disadvantage is that the tidal volume is variable. The clinician must be constantly aware of the patient's minute ventilation to prevent severe hypercapnia or hypocapnia (*Byrd and Roy, 2008*).

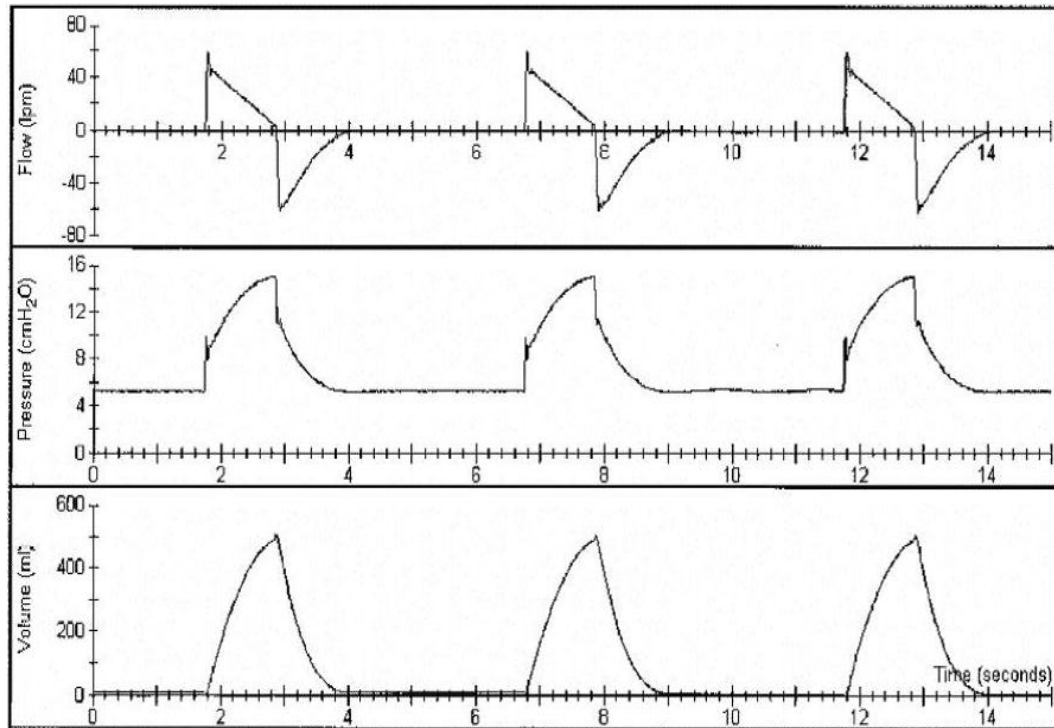


**Fig.( 3):** Biphasic Positive Airway Pressure (*Byrd and Roy, 2008*)

**4-Controlled Mandatory Ventilation ( CMV) (Fig. 4):**

It is a mode of ventilator operation in which all breaths are mandatory and are delivered by the ventilator at a preset frequency, volume or pressure, and inspiratory time. CMV is classified as volume or

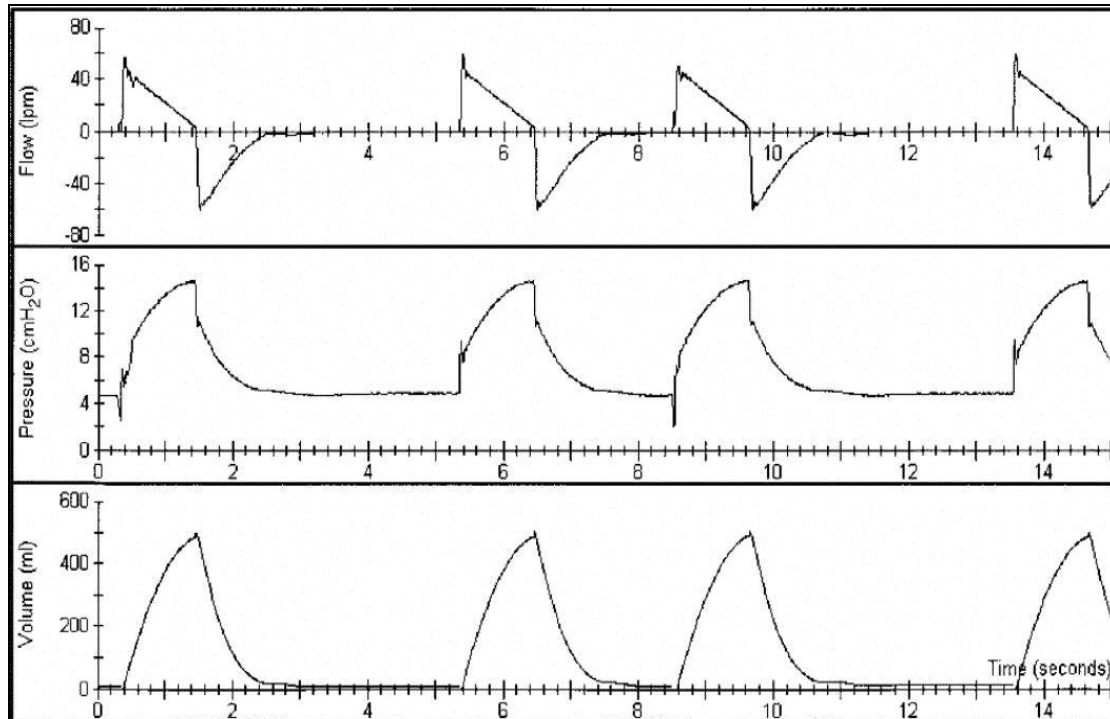
pressure controlled; machine time triggered; volume, pressure, or flow limited; and machine volume, pressure, flow, or time cycled. All breaths are mandatory breaths (*Branson and Campbell, 2009*).



**Fig. (4):** Controlled Mandatory Ventilation, decelerating ramp flow (*Branson and Campbell, 2009*)

### **5- Assist /Control Ventilation (A/C) (Fig. 5):**

It is a mode of ventilator operation in which mandatory breaths are delivered at a set frequency, pressure or volume, and inspiratory flow. Between machine-initiated breaths, the patient can trigger the ventilator and receive an assisted breath at the volume or pressure set on the ventilator. Machine and patient triggered breaths are delivered using the same limit and cycle variables. Breathes would be either time triggered (based on the set rate) or patient triggered (based on patient effort and sensitivity). Thus, A/C ventilation combines mandatory and assisted breaths that can be either volume controlled or pressure controlled. (*Branson and Campbell, 2009*).



**Fig.( 5 ) :** Volume Assist/Control Ventilation, decelerating ramp flow (*Branson and Campbell, 2009*).

### **6-Continuous Positive Airway Pressure (CPAP) -(PEEP) (Fig. 6):**

It is a mode of ventilator in which a clinician set level of pressure is maintained constant while the patient is allowed to breath spontaneously. PEEP and continuous positive airway pressure are identical in their mechanism, but the terms are not interchangeable. The use of one term rather than the other provides a description of the amount of ventilatory support the patient is receiving. Positive pressure applied at the end of expiration may be administered to patients who are either spontaneously breathing or undergoing mechanical ventilation. PEEP is the correct term when patients are receiving positive end expiratory pressure along with any other mechanical ventilatory assistance, such as PS or assist/control ventilation (*Pierce, 2007*).

CPAP is the correct term when positive pressure is being used with the spontaneously breathing patient who is receiving no other ventilatory assistance. CPAP is measured in centimeters of H<sub>2</sub>O pressure and may be

administered through a ventilator or with a CPAP mask. Because CPAP is devoid of mandatory breaths, only the spontaneous breaths need to be considered CPAP is pressure-controlled, patient-triggered, patient-cycled, unsupported spontaneous *breathing (Branson and Campbell, 2009)*.

**Type of PEEP:**

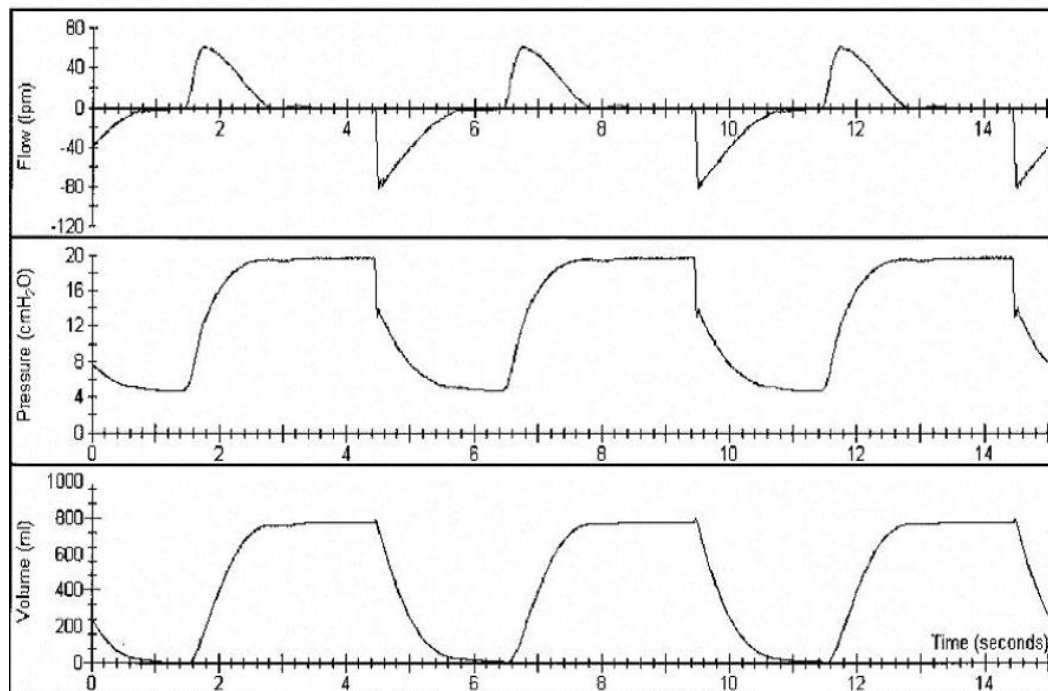
Intrinsic PEEP (auto-PEEP) is the spontaneous development of PEEP as a result of insufficient expiratory time. Extrinsic PEEP is the amount of PEEP that the clinician sets on the ventilator. Physiological positive end-expiratory pressure, The benefits of using a small amount PEEP (3 to 5 cm H<sub>2</sub>O), almost considered physiologic, have been applied to patients who have obstructive airway disease and hyperinflation in an attempt to decrease incomplete exhalation (*Pierce, 2007*).



**Fig. (6) :** Continuous Positive Airway Pressure (*Pierce, 2007*).

**7-Pressure Control Inverse Ratio Ventilation (PC-IRV) (Fig. 7):**

It is a particular version of pressure control-CMV (PC-CMV) in which all breaths are pressure limited and time cycled and the patient can not initiate an inspiration. Additionally, as the name implies, inspiration is longer than expiration (*Branson and Campbell, 2009*).



**Fig.(7) :**Pressure Control Inverse Ratio Ventilation (*Branson and Campbell, 2009*).

**(B) Newer modes of mechanical ventilation:**

**1-Volume support ventilation (VSV):**

Volume support ventilation is a mode of ventilation that pressure supports every breath to a level that guarantees a preset VT. The patient triggers every breath. Initial ventilator settings include a value for the expected spontaneous RR and minimum VT/VE. The ventilator responds to a decrease in the patient's RR that is less than the expected spontaneous rate by calculating a new target VT based on the preset minimum VE and the measured RR. The ventilator uses the new calculated target VT as the reference to regulate inspiratory pressure. VS is suitable for spontaneous breathing patients who do not have sufficient respiratory muscle strength

to consistently guarantee an adequate VT .Volume support differ from volume assured pressure support (*Younes et al., 1992*):

- In volume support, we are trying to adjust pressure so that, within a few breaths, desired TV is reached.
- In VAPS, we are aiming for desired TV tacked on to the end of a breath if a pressure-limited breath is going to fail to achieve TV

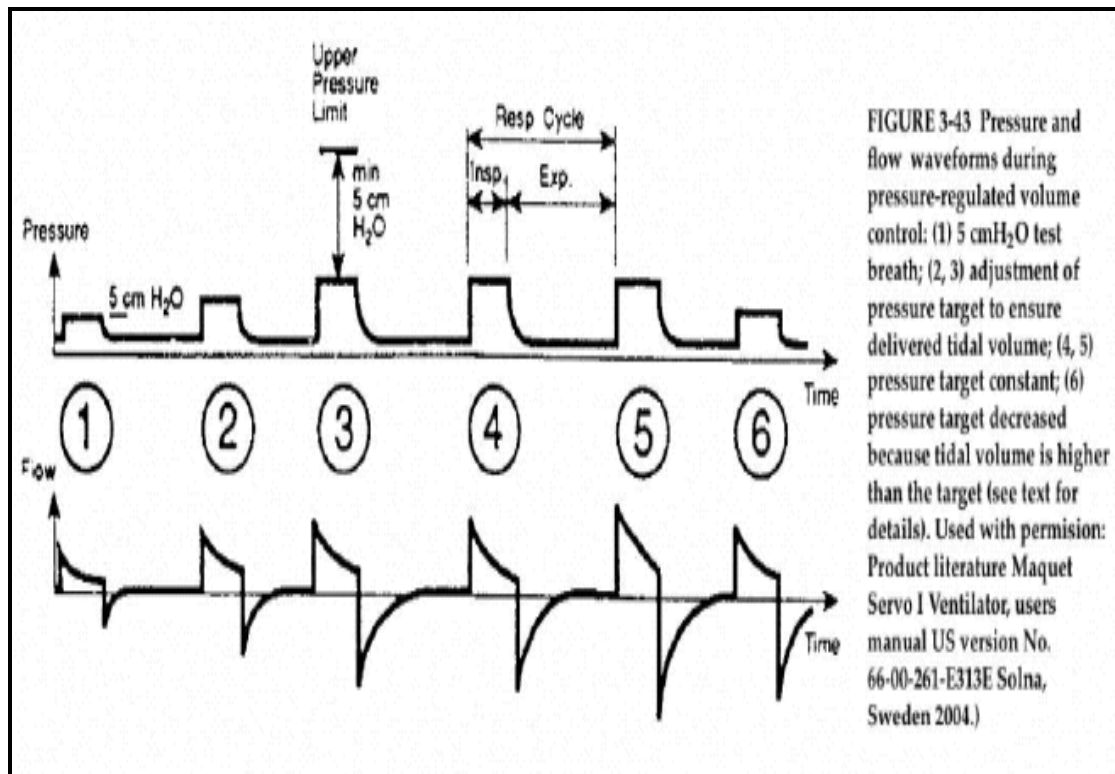
### **2-Proportional assist ventilation (PAV):**

The ventilator generates pressure in proportion to patient-generated flow and volume. The ventilator amplifies patient effort without imposing any ventilatory or pressure targets. Ventilator generated pressure rises as long as inspiratory muscle effort is produced by the patient. The preset parameter is not a target pressure but the proportion between pressure applied by the ventilator and flow and volume generated by the patient inspiratory muscle efforts (*Younes et al., 1992*).

The clinician adjusts the percentage of flow-assisted or volume-assisted ventilation after determining the patient resistance and elastance . In other words, the physician must determine how much to reduce the load imposed by the patient elastance (*Squadrone et al., 2005*).

### **3-Pressure-regulated volume control (PRVC) (Fig. 8):**

PRVC is a control mode of ventilation in which the patient receives a preset number of breaths of a preset VT that is given in the form of a pressure breath. Initial ventilator settings include RR, inspiratory time, and the target VT/VE. The ventilator strives to achieve the target VT using the lowest possible pressure.PRVC is suitable for patients who demonstrate noncompliant lungs caused by disease processes that result in lung units with varying time constants.



**Fig.( 8)** Pressure and flow waveforms during pressure regulated volume control. (1) 5 cmH<sub>2</sub>O test breath. (2,3) Adjustment of pressure target to ensure delivered tidal volume. (4,5) Pressure target constant. (6) Pressure target decreased because tidal volume is higher than target.

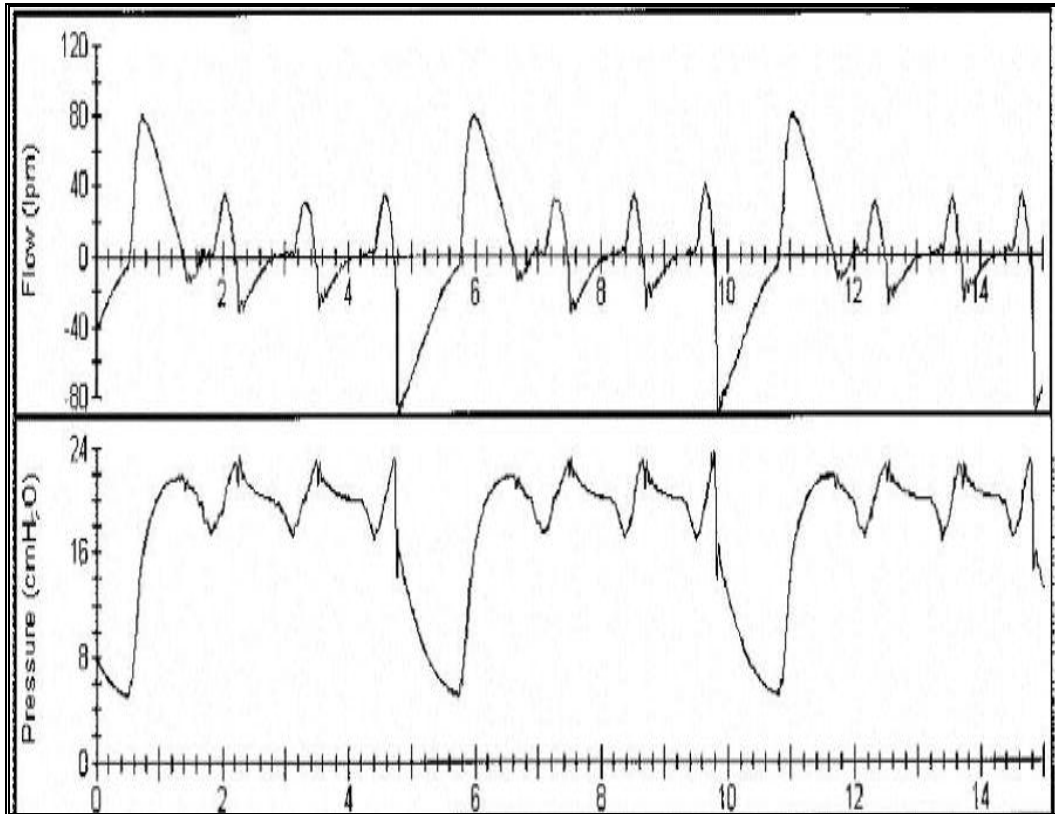
#### 4-Airway pressure release ventilation (APRV)(Fig.2-9):

APRV is a mode of ventilation that entails a continuous positive airway pressure (CPAP) (termed  $P_{high}$ ), with intermittent, time-cycled, transient release of pressure to a lower value ( $P_{low}$ ). Spontaneous ventilation is allowed throughout, independent of ventilator cycle. This mode couples the recruiting effects of CPAP with the superior ventilation/perfusion matching of spontaneous breathing. The intermittent releases act as a supplement for minute ventilation, aiding in CO<sub>2</sub> removal without the threat of overdistension (as with a regular positive pressure breath). Recent studies of APRV have shown favorable results on gas exchange and distribution of ventilation, whether used alone, or coupled with prone positioning (*Wrigge et al., 2005*).



**APRV Benefits (Habashi, 2005).**

- Preservation of spontaneous breathing and comfort with most spontaneous breathing occurring at high CPAP.
- ↓WOB,↓Barotrauma,and ↓Circulatory compromise,
- Better V/Q matching.



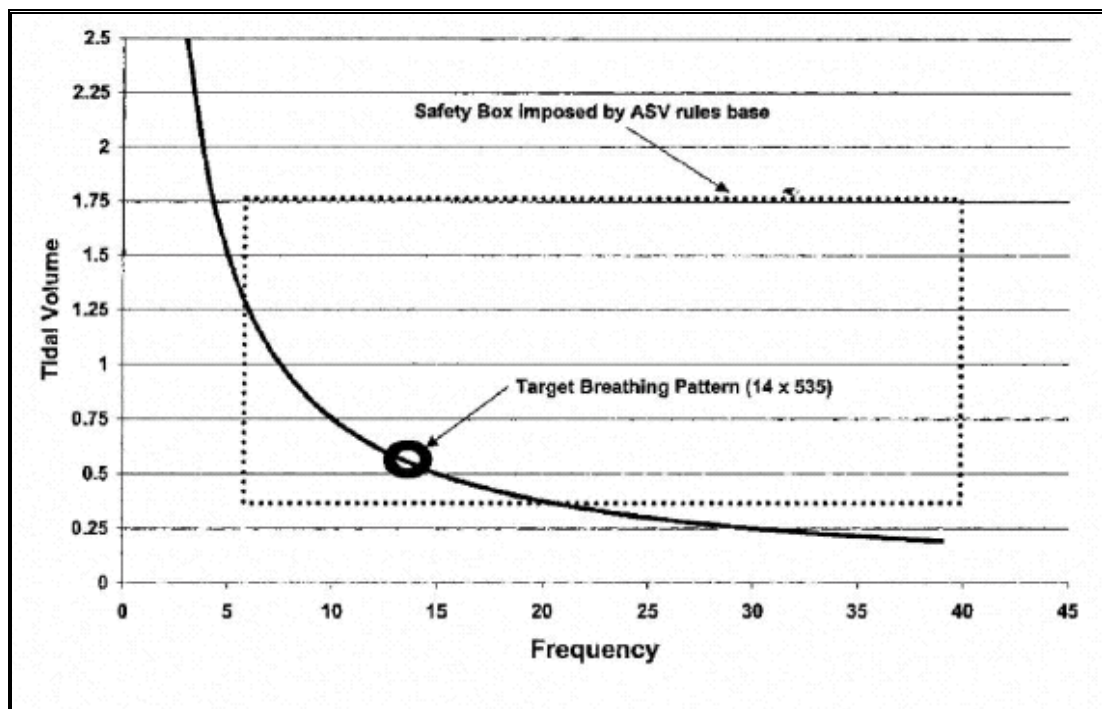
**Fig.( 9): Airway Pressure Release Ventilation (Habashi, 2005)**

**5-Adaptive support ventilation (Fig .10):**

ASV is a mode that combines the dual control breath to breath time-cycled and flow-cycled breaths and allows the ventilator to choose the initial ventilator settings based on the clinician input of ideal body weight and percent minute volume. This is the most sophisticated technique, allowing the ventilator to choose set respiratory frequency, tidal volume, pressure limit of mandatory and spontaneous breaths, inspiratory time of mandatory breaths, and, when spontaneous breathing is absent, I:E ratio. (Petter et al., 2002).

**Indications:**

- Initially designed to reduce episodes of central apnea in CHF: improvement in sleep quality, decreased daytime sleepiness
- Can be used for patients who are at risk for central apnea like those with brain damage. In randomized controlled studies, ASV was able to significantly reduce the weaning time in a population of post-cardiac surgery patients and also reduce the number of nuisance alarms and ventilator manipulations by clinicians, leading to better utilization of resources. ASV automatically selects a breathing pattern that fits the patient’s pathology. This study used patients with COPD and Restrictive lung disease and patients with normal lungs to analyze how ASV selects different breathing patterns(*Petter et al., 2002*).



**Fig.(10):** Graphic depicting target ventilatory pattern during adaptive supportive ventilation (*Petter et al., 2002*).

**6-AutoMode:**

AutoMode combines volume support and PRVC in a single mode. If the patient is paralyzed, the ventilator provides PRVC. All breaths are

mandatory breaths that are time triggered, pressure limited, and time cycled. The pressure limit increases or decreases to maintain the desired tidal volume set by the clinician. If the patient breathes spontaneously for two consecutive breaths, the ventilator switches to volume support. In this case, all breaths are supported breaths that are patient triggered, pressure limited, and flow cycled. During the switch from time-cycled to flow-cycled ventilation, mean airway pressure will decrease. This may result in hypoxemia in the patient with acute lung injury (*Branson and Campbell, 2009*).

### **7-Automatic tube compensation (ATC):**

ATC is pressure controlled, patient triggered, pressure limited, and flow cycled. The pressure delivered is a consequence of the resistive characteristics of the airway and the flow demand of the patient. According to Poiseuille's law, pressure decrease across the endotracheal tube is inversely proportional to the fourth power of the radius and is directly proportional to the length. In 1993, Guttman and associates described a technique for continuously calculating tracheal pressure in intubated, mechanically ventilated patients using the known resistive component of the endotracheal tube and the measurement of flow to calculate tracheal pressure. These authors successfully validated their system in a group of mechanically ventilated patients, finding favorable comparisons between calculated and measured tracheal pressure (*Pierce, 2007*).

This work has led to the introduction of ATC on the Drager Evita4. ATC attempts to compensate for endotracheal tube resistance via calculated tracheal pressure. This system uses the known resistive coefficients of the tracheal tube (tracheostomy or endotracheal) and

measurement of instantaneous flow to apply pressure proportional to resistance throughout the total respiratory cycle. The equation for calculating tracheal pressure is: Tracheal pressure (cm H<sub>2</sub>O) = Proximal airway pressure (cm H<sub>2</sub>O) – Tube coefficient (cmH<sub>2</sub>O/L/s) x flow<sup>2</sup> (L/min). The operator inputs the type of tube, endotracheal or tracheostomy, and the percentage of compensation desired (10-100%). Most of the interest in ATC revolves around eliminating the imposed work of breathing (*Branson and Campbell, 2009*).

### **8-Mandatory Minute Ventilation (MMV):**

MMV is a mode where the patient breathes spontaneously, yet constant minute ventilation is guaranteed. If the patient's spontaneous dose does not match the target minute ventilation the ventilator provides whatever part of the minute ventilation the patient dose did not achieve. In volume mandatory minute ventilation (V-MMV), if the patient's minute ventilation falls below the prescribed level the ventilator responds by delivering mandatory volume breaths. In pressure mandatory minute ventilation (P-MMV) the ventilator increases the level of PS (*Pierce, 2007*).

### **9-High-frequency oscillatory ventilation (HFOV):**

This unique mode of ventilation utilizes rapid respiratory rates, more than four times the normal. At high frequencies, tidal volumes may be less than dead space. The aim is to hold the lung in a state of recruitment, while maintaining ventilation, probably by facilitated diffusion. Precautions must be taken during HFOV; complications may include pneumothorax and acute respiratory acidosis should partial endotracheal tube obstruction occur. Overall, HFOV is a “rescue” mode of ventilation, to be considered in hypoxemic patients refractory to other more conventional ventilation methods. Although most studies on HFOV have been on its use in neonates and children, several studies on adults

have demonstrated beneficial effects on oxygenation and ventilation, as well as its safety as a rescue therapy for patients with severe oxygenation failure (*Mehta et al., 2001*).

#### **10-Neurally adjusted ventilatory assist (NAVA):**

The ideal method of modifying breath-to-breath ventilator gas delivery would theoretically be based on respiratory centre output. As this is clinically impossible, researchers have strived to reach a feasible alternative. NAVA is a novel system, with a simple yet absolutely intelligent idea, depending on electrodes placed in the lower esophagus that track diaphragmatic activity. This revolutionary system allows ventilatory support to be continually readjusted, according to the varying demands/needs of the patient. Furthermore, it incorporates the breath-to-breath variability that characterizes a natural breathing pattern. This promising invention may provide great changes in the way patients will be ventilated in years to come (*Navalesi and Costa, 2003*).

#### **11-Partial Liquefied Ventilation:**

In use of partial liquid ventilation, the high density of perfluorocarbon causes it to be distributed largely to dependent regions of the lung. To circumvent this problem, *Kandler et al. (2001)* delivered the substance as an aerosol, that is small droplets of perfluorocarbon in the gas phase.

Partial liquid ventilation is usually used in combination with controlled ventilation and neuromuscular blockade. *Franz et al. (2001)* assessed the effect of combining partial liquid ventilation with proportional-assist ventilation, a mode that allows active respiratory efforts. Compared with combining liquid ventilation with controlled ventilation and muscle paralysis, delivering it with proportional-assist ventilation achieved a 13% higher cardiac output and 11% higher oxygen

transport in healthy rabbits, and a 32% higher cardiac output and 36% higher oxygen transport in rabbits with lung injury (secondary to surfactant depletion). The combination of partial liquid ventilation and proportional-assist ventilation achieves a greater improvement in oxygen transport as compared with the combination of partial liquid ventilation and controlled ventilation.

## **(II) Non invasive modes of mechanical ventilation:**

Noninvasive positive-pressure ventilation (NPPV) is the provision of any form of ventilatory support applied without the use of an endotracheal tube (ETT). Use of NPPV ventilation in the intensive care unit (ICU) has increased in recent years as a result of successful application in multiple patient populations and improved equipment. (*Pierce, 2007*).

### **Mechanism of Action:**

1. Improvement in pulmonary mechanics and oxygenation. NPPV augments alveolar ventilation and allows oxygenation without raising the PaCO<sub>2</sub>.
2. Partial unloading of respiratory muscles. NPPV reduces mean-diaphragmatic pressure, pressure time index of respiratory muscles and diaphragmatic electromyographic activity. This leads to an increase in tidal volume, decrease in respiratory rate and increase in minute ventilation. Also overcomes the effect of intrinsic PEEP.
3. Resetting of respiratory centre ventilatory responses to PaCO<sub>2</sub>. In patients with COPD, the ventilator response to raised PaCO<sub>2</sub>, is decreased especially during sleep by maintaining lower nocturnal PaCO<sub>2</sub> during sleep.

By administrating NPPV, it is possible to reset the respiratory control centre to become more responsive to an increased PaCO<sub>2</sub> by

increasing the neural output to the diaphragm and other respiratory muscles. These patients are then able to maintain a more normal PaCO<sub>2</sub> throughout the daylight hours without the need for mechanical ventilation. (*Rajan et al., 2005*).

**Advantages and disadvantages:**

Early intermittent ventilatory support, ease of application and removal, improved patient comfort, reduced sedation requirements, avoidance of complications of intubation, possible ventilation outside hospital setting and, ease to communicate paramedics and nurses. Mask is uncomfortable and claustrophobic, airway is not protected, facial pressure sores and no direct access to bronchial tree for suction if secretions are excessive (*Rajesh, 2002*).

**Requirements for successful non-invasive support:**

A co-operative patient who can control their airway and secretions with an adequate cough reflex. The patient should be able to co-ordinate breathing with the ventilator and breathe unaided for several minutes. Hemodynamically stable. Blood pH > 7.1 and PaCO<sub>2</sub> < 92 mmHg. The patient should ideally show improvement in gas exchange, heart rate and respiratory rate within first two hours (*Pierce, 2007*).

**Selection Criteria (*Liesching et al., 2003*):**

I) Acute Respiratory Failure

- At least two of the following Criteria should be present:
- Respiratory distress with dyspnea
- Use of accessory muscles of respiration
- Abdominal paradox
- Respiratory rate > 25/min.

II) Chronic respiratory failure (obstructive lung disease)

- Fatigue, hypersomnolence, dyspnea
- ABG shows pH <7.35, PaCO<sub>2</sub>>55 mmHg.
- Oxygen saturation <88% for >10% of monitoring time despite O<sub>2</sub> supplementation.

**Contraindications:**

Respiratory arrest/unstable cardiorespiratory status, Uncooperative patients unable to protect airway & impaired swallowing and cough reflex, Facial/esophageal or gastric surgery, Craniofacial trauma/burns, Anatomic lesions of upper airway, Extreme anxiety & Copious secretions. (*Gorini et al ., 2004*).

**Modes of NPPV:**

- 1) CPAP
- 2) BIPAP
- 3) Proportional assist ventilation ( PAV)

**Mask Type:**

Selection of the proper mask interface and assurance of a proper fit is necessary to success. Oronasal (full-face) masks deliver higher ventilation pressures with less leak and may lower carbon dioxide more effectively (providing dead space is not increased); require less patient cooperation; and may benefit mouth breathers. But they may generate feelings of claustrophobia, making patients unable to tolerate NPPV; may be harder to fit and therefore generate leaks; place a barrier to communication; and limit oral intake (*Pierce , 2007*).

**Goals of NIPPV:**

Relieve symptoms, reduce work of breathing, improve or stabilize gas exchange, good patient-ventilator synchrony, optimize patient comfort, avoid intubation, improve sleep duration and quality, maximize quality of life and prolong survival (*Gorini et al ., 2004*).



**Criteria for failure of NIV and need for endotracheal intubation:**

- Inability to improve gas exchange or dyspnea
- Failure to improve mental status within 10 minutes in patients who are lethargic from CO<sub>2</sub> retention or agitated from hypoxemia
- Inability to tolerate the face mask because of discomfort.
- Need for sedation to control the patient's behavior
- Development of conditions requiring intubation to protect the airways (coma or seizure) or to manage copious tracheal secretions
- Hemodynamic or electrocardiographic instability (ischemia or significant ventricular arrhythmias) (*Gorini et al ., 2004*).

**Monitoring:**

Physiologic response. Oximetry, Arterial blood gas (ABG), exhaled tidal volume, respiratory rate, blood pressure, and heart rate. Subjective response. Patient comfort, mental alertness, mask fit & comfort, secretions, skin necrosis, respiratory muscle unloading, and gastric distention (listen for air entry during inspiration) & nausea or vomiting (*Esteban et al ., 2004*).

**Complications and Side effects:**

Air leak, Skin necrosis particularly over bridge of nose CO<sub>2</sub> rebreathing, Retention of secretions, Gastric distension, Failure to ventilate, Sleep fragmentation, Upper airway obstruction (*Pierce, 2007*).

**Clinical utility of ventilator wave forms:**

Ventilator waveforms are the graphical depictions of patient ventilator interactions. Ventilators are technologically limited as generators of volume, pressure, or flow. No ventilator can deliver an ideal breath: the precise waveform desired by the clinician cannot be fashioned by the machine. Because of the multiplicity of ways that the patient can interact with the ventilator, the shapes of these waveforms can be subject

to considerable variation. Waveforms are classified as scalars and loops. *Scalars* are the measurements of volume, pressure, and flow that are graphed against time. *Loops* are the tracings of volume plotted against pressure or of flow against volume (*Hasan ,2010*).

**SCALARS:**

Scalar waveforms are representations of each of pressure, flow, and volume variables plotted against time. Typically, the horizontal, or x, axis depicts time, and the vertical, or y, axis depicts the designated parameter.

**The pressure-time scalar (Fig.11):**

It presents airway pressure (Paw), measured in cm H<sub>2</sub>O, on the y (vertical) axis, and time, measured in seconds, on the x (horizontal) axis.

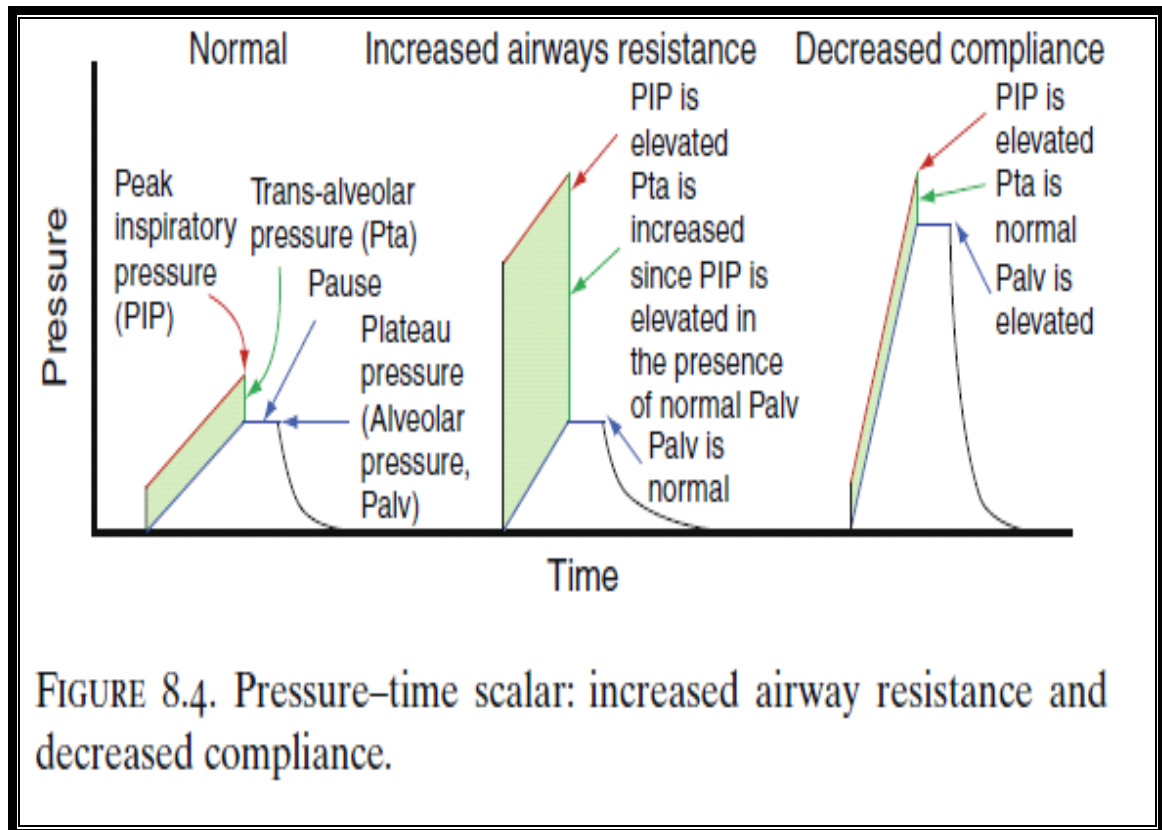
Pressure-time scalars can be used to determine the following:

- Breath type delivered (volume or pressure control).
- Patient versus machine triggering.
- Work required to trigger the breath.
- Breath timing: inspiratory (I) versus expiratory (E).
- Adequacy of inspiratory flow.
- Airway pressure.

Although dynamic lung mechanics can be observed from a Pressure vs. Time curve, the addition of an inspiratory pause or inflation hold provides information to calculate static mechanics (*Pierce, 2007*).

Pressure (P plat) or Alveolar Pressure is detected upon activation of an Inflation Hold or Inspiratory Pause control. The exhalation valve is kept in a closed position and the volume is held in the lungs. For clinical purposes, the plateau pressure is the same as the alveolar pressure. This measurement provides a means of measuring static lung compliance. With inspiratory hold, the clinician can determine the pressure required to

overcome recoiling force (lung compliance). We can calculate static lung compliance by dividing the volume in the lung by the plateau pressure minus PEEP, if present.  $C_s = V_T / (P_{plat} - PEEP)$  (*Pierce, 2007*).



**Fig.( 11):** pressure-time scalar: increased airway resistant and decreased compliance (*Hasan, 2010*)

**Volume vs Time scalar (Fig. 12):**

The volume-time scalar plots volume of gas in milliliters on the vertical axis against time in seconds on the horizontal axis. These curves may be used to detect air trapping or leaks in the patient circuit.

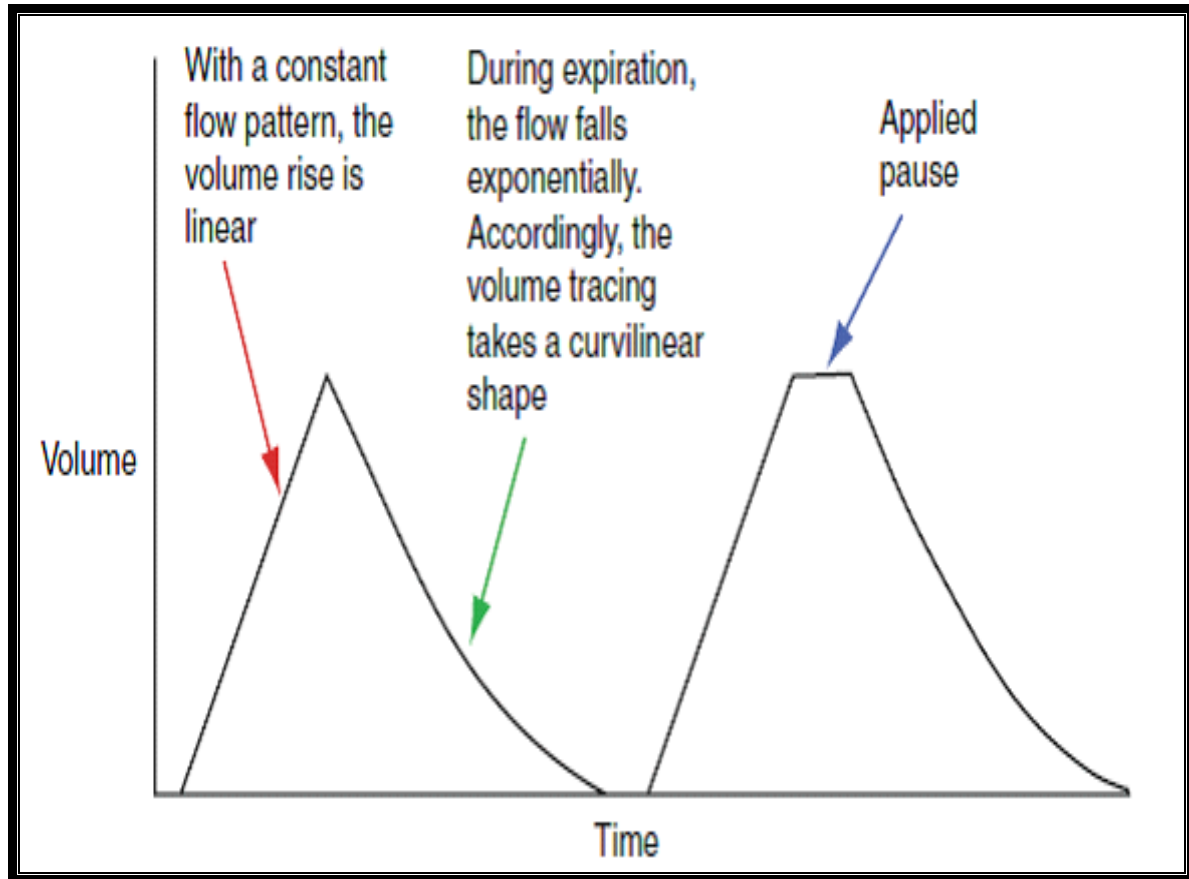


Fig.( 12): Volume-time scalar in constant flow, volume-targeted ventilation (Hasan, 2010)

**The flow-time scalar (Fig.13):**

It shows flow (V), in liters per minute, on the vertical axis, and time, in seconds, on the horizontal axis. Flow depicted above the zero flow line is inspiratory, and flow below the zero flow line is expiratory.

*Flow-time scalars can be used to evaluate the following:*

- Inspiratory and expiratory flow rates
- Type of breath (volume or pressure control)
- Type of inspiratory flow pattern (in volume ventilation)
- Adequacy of inspiratory time (in pressure control [PC] ventilation) Presence of auto-PEEP
- Expiratory resistance and response to bronchodilators
- Presence and degree of continuous air leaks.

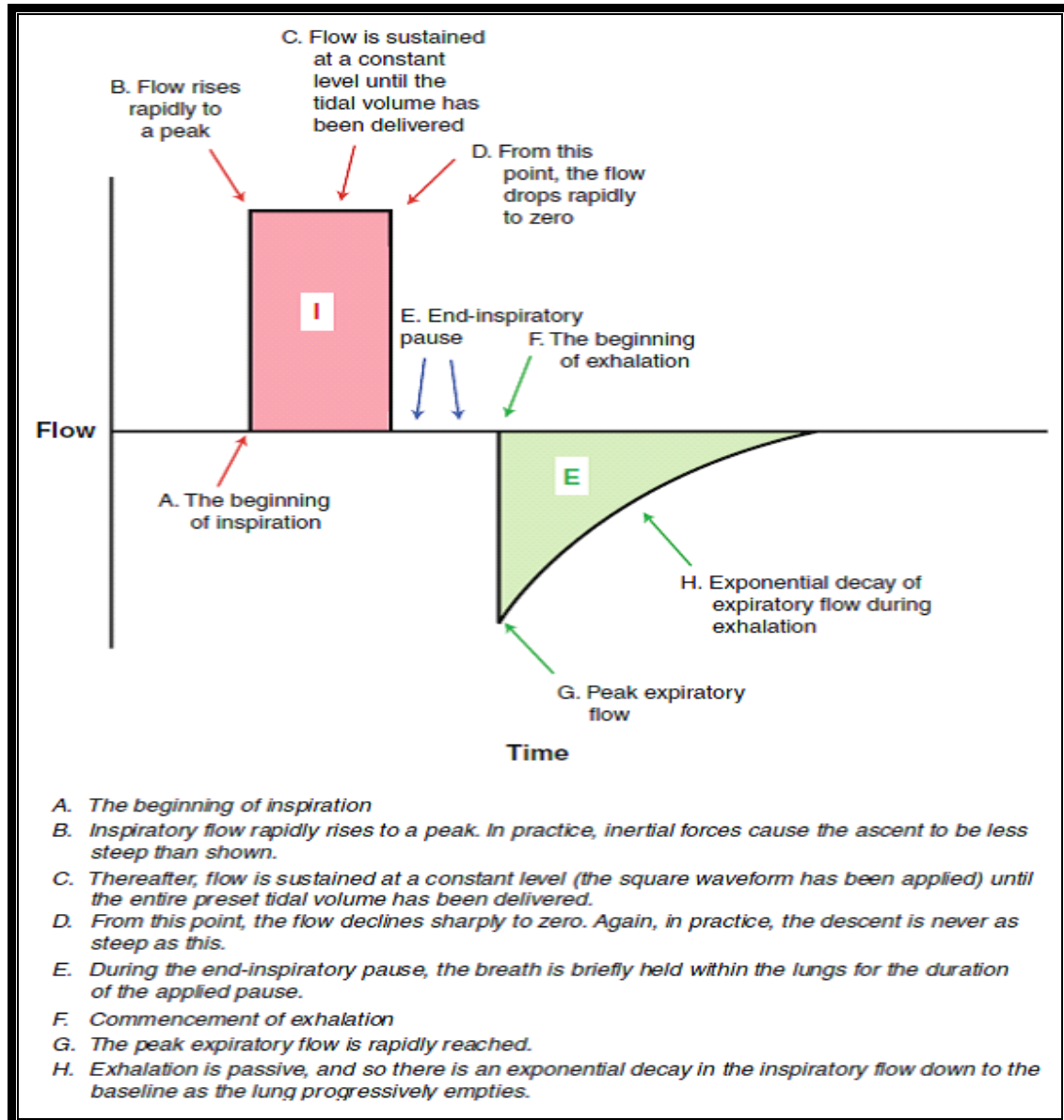


Fig.( 13): Event during aconstant flow breath (Hasan , 2010)

## LOOPS:

Graphic loops display two of the three ventilator variables plotted against one another. A volume-pressure (V-P) loop usually displays pressure on the  $x$  (horizontal) axis and volume on they (vertical) axis. The lower curve of the loop depicts inspiratory pressure and volume; the upper curve depicts expiratory parameters. The slope of the loop is defined by the angle of the inspiratory and expiratory curves. The degree of slope depicts lung and chest wall compliance (Pierce, 2007).

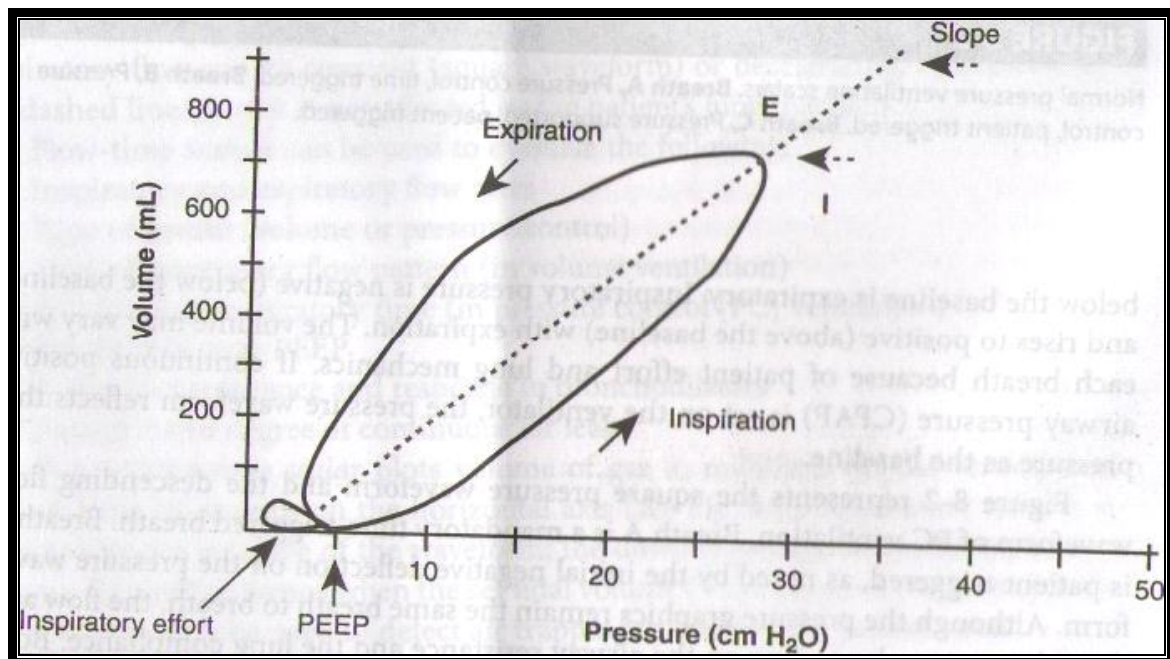
**Pressure – Volume Loop (Fig. 14):**

A Pressure-Volume loop traces changes in pressures and corresponding changes in volume. Inspiration begins from the FRC level and terminates when the preset parameter (volume or pressure) is achieved. The tracing continues during expiration and returns to FRC at end of exhalation. PIP and delivered tidal volume are readily obtained from the Pressure-Volume loop.

**Pressure – Volume Loop are used to assess the following:**

- Changes in resistance and compliance
- Adequacy of peak inspiratory flow rates (in volume ventilation)
- Work required to trigger a breath
- Lung over distention

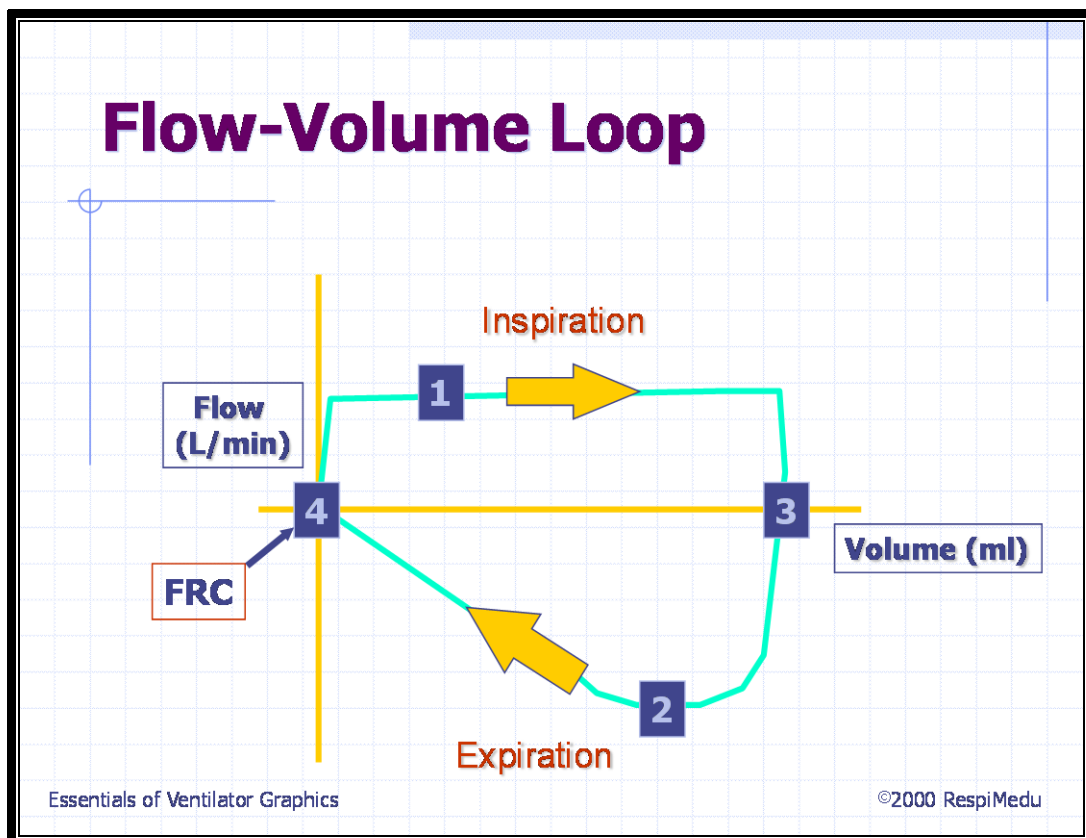
A patient-initiated breath forms a small "trigger-tail" to the left of the vertical axis. The slope of the loop provides information regarding lung compliance. The steeper the slope of the V-P loop, the better the lung compliance.



**Fig(14):** Volume-pressure loop depicting volume-control ventilation. Note the trigger tail, representing degree of patient effort to trigger the breath (*Pruitt, 2002*)

**Flow – Volume loop (Fig. 15):**

A flow-volume loop displays flow on the vertical axis and volume on the horizontal axis. In most cases, inspiratory flow is above the horizontal axis and expiratory flow is below, depending on the configuration of the particular ventilator. The shape of the inspiratory loop is determined by the flow setting on the ventilator (e.g., constant or descending). The shape of the expiratory portion of the flow-volume loop is determined by the patient's lung characteristics. This loop is used primarily to assess the effect of bronchodilator therapy but may also demonstrate other changes in airway resistance. Flow-volume loops may also be used to detect auto-PEEP and volume leaks (*Pierce, 2007*).



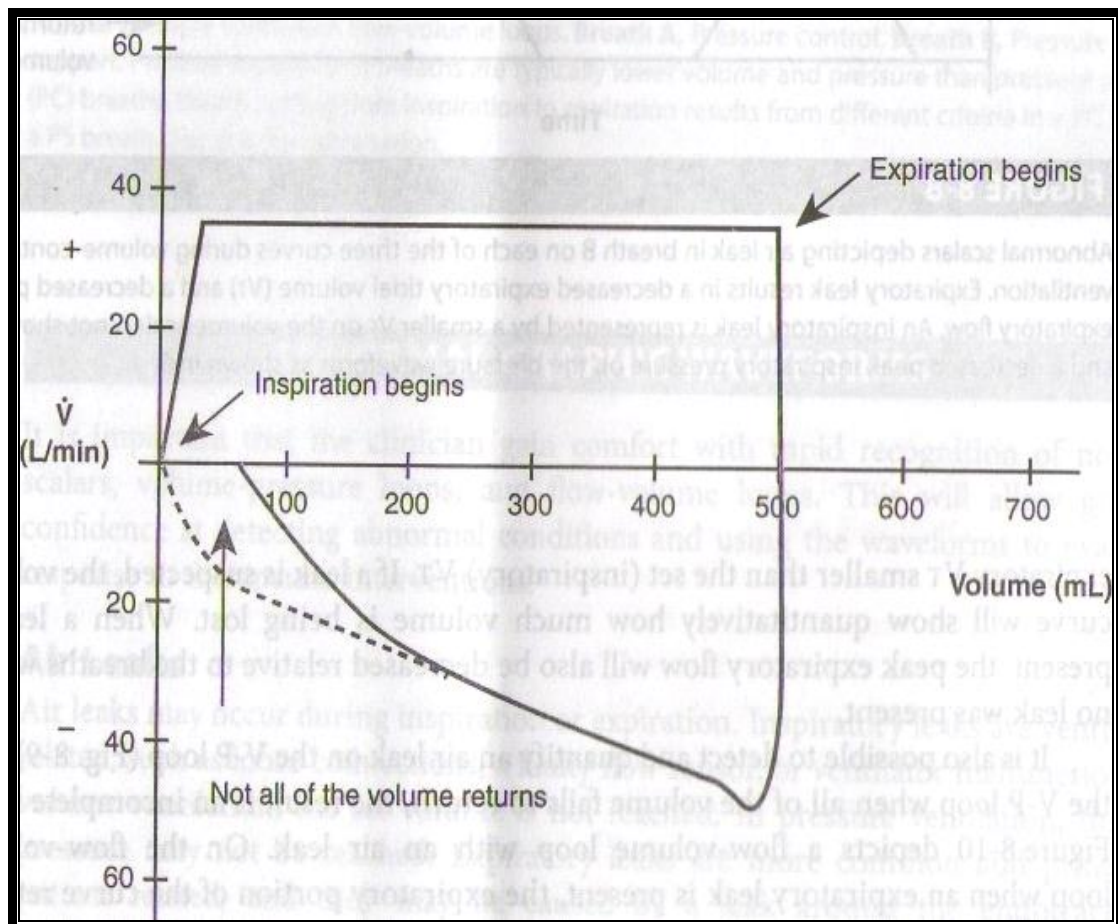
**Fig.(15):** Normal flow-volume loop, volume-control ventilation. Peak inspiratory flow is achieved at the beginning of inspiration and maintained during the entire inspiratory phase, resulting in the square wave pattern. Expiration begins after the set tidal volume is reached and then flow drops to below baseline to a value known as the peak expiratory flow rate. Flow and volume decrease simultaneously until zero flow and zero volume are reached (*Burns, 2004*)



**Abnormal wave forms:**

**I) Air Leaks (Fig. 16,17,18):**

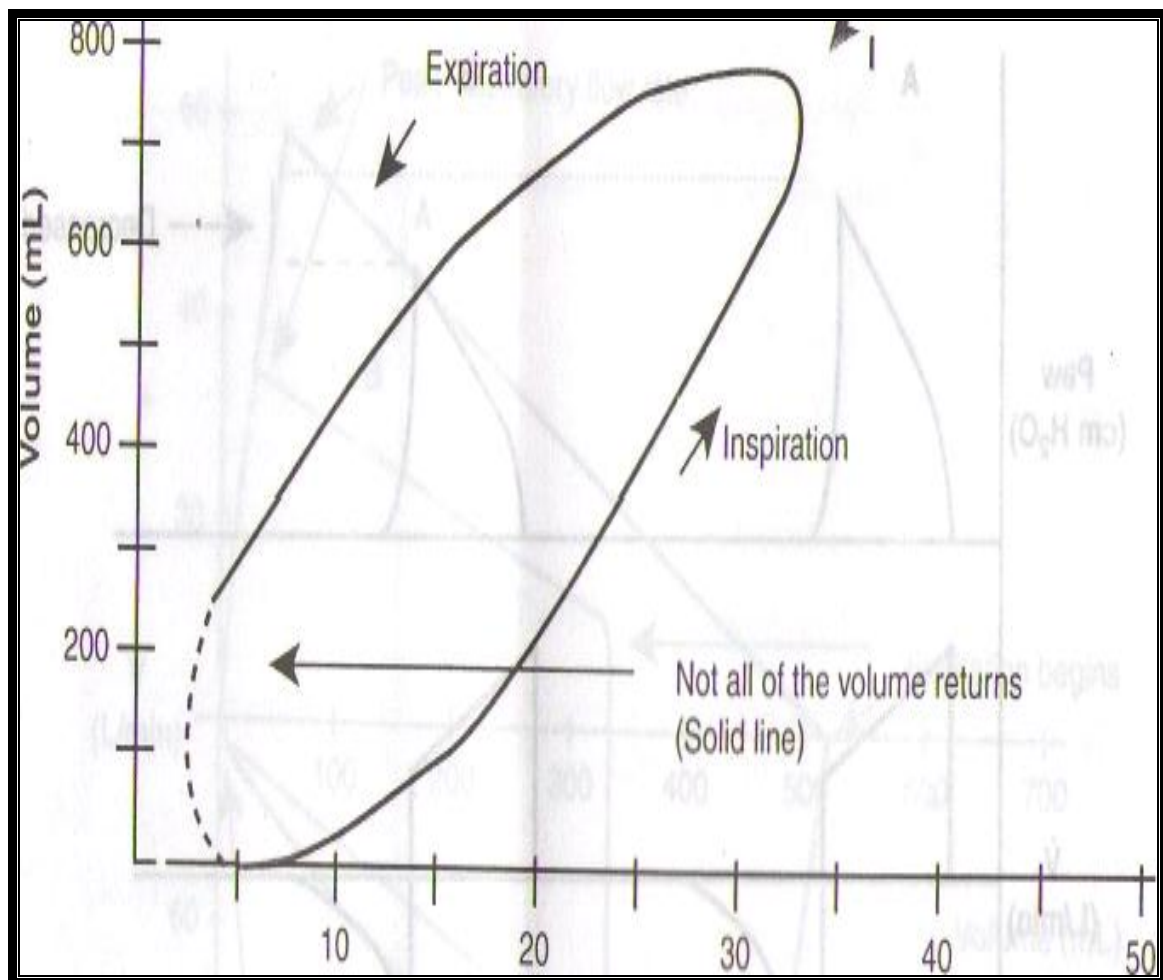
Air leaks may occur during inspiration or expiration. Inspiratory leaks are ventilator related, such as loose connections, a faulty flow sensor, or ventilator malfunction. In volume ventilation, the set volume is not reached. In pressure ventilation, the set pressure may not be reached. Expiratory leaks are more common and primarily patient related, and they may be caused by a leak around the endotracheal/ tracheostomy tube cuff, air loss through a chest tube, or a gastric tube placed inappropriately in the trachea. It is easiest to detect air leaks on ventilator graphics by looking at the waveforms that represent volume.



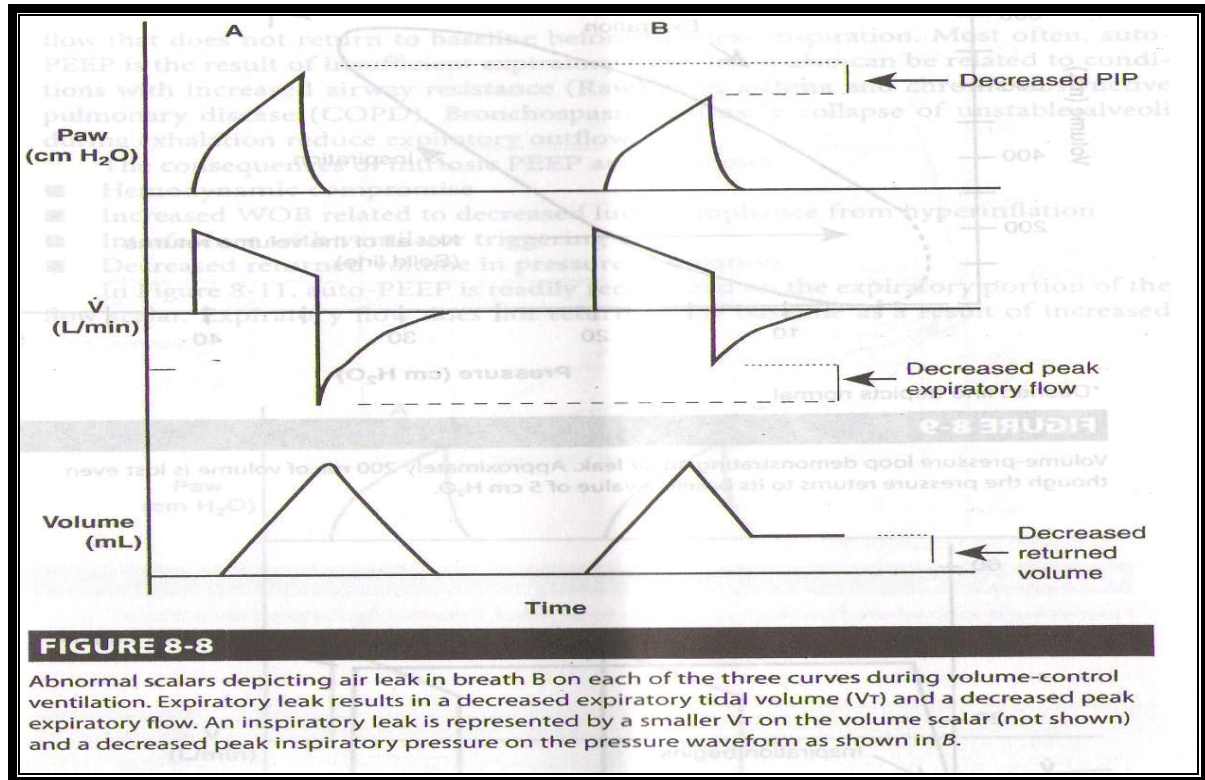
**Fig.( 16) :** Flow-volume loop demonstrating an expiratory air leak. Approximately 75 ml of volume is lost even though the flow returns to its baseline value. Dashed line depicts normal (*Dennison, 2000*)



An inspiratory leak is represented by a smaller VT on the volume scalar and a decreased peak inspiratory pressure on the pressure waveform. Expiratory leaks are demonstrated by an expiratory VT smaller than the set (inspiratory) VT. If a leak is suspected, the volume curve will show quantitatively how much volume is being lost. When a leak is present, the peak expiratory flow will also be decreased relative to the breaths where no leak was present. It is also possible to detect and quantify an air leak on the V-P loop. On the V-P loop when all of the volume fails to return, the result is an incomplete loop. On the flow-volume loop when an expiratory leak is present, the expiratory portion of the curve returns to a value greater than zero (*Dennison, 2000*)



**Fig.( 17):** Volume-pressure loop demonstrating an air leak. Approximately 200 ml of volume is lost even though the pressure returns to its baseline value of 5 cm H<sub>2</sub>O. Dashed line depicts normal (*Pruitt, 2002*)



**Fig.(18):** Abnormal scalar depicting air leak in breath B on each of the three curves .Expiratory leak results in decreased expiratory tidal volume and decreased peak expiratory flow. An inspiratory leak is represented by a decreased peak inspiratory pressure on the pressure waveform as shown in B. (Dennison, 2000)

## II) Increased Airway Resistance (Fig. 19):

### PIP vs Pplat.

Changes in the pressure vs. time curve have notable clinical significance. The figure illustrates four common clinical situations:

- Normal curve: Indicates PIP, Pplat, PTA, and TI.
- High Raw: A significant increase in the PTA is associated with increased in airway resistance.
- High Flow: Notice that the inspiratory time is shorter than normal, indicating a higher inspiratory gas flow rate.
- Decreased Lung Compliance: An increase in the plateau pressure and a corresponding increase in the PIP is consistent with decreased lung compliance.

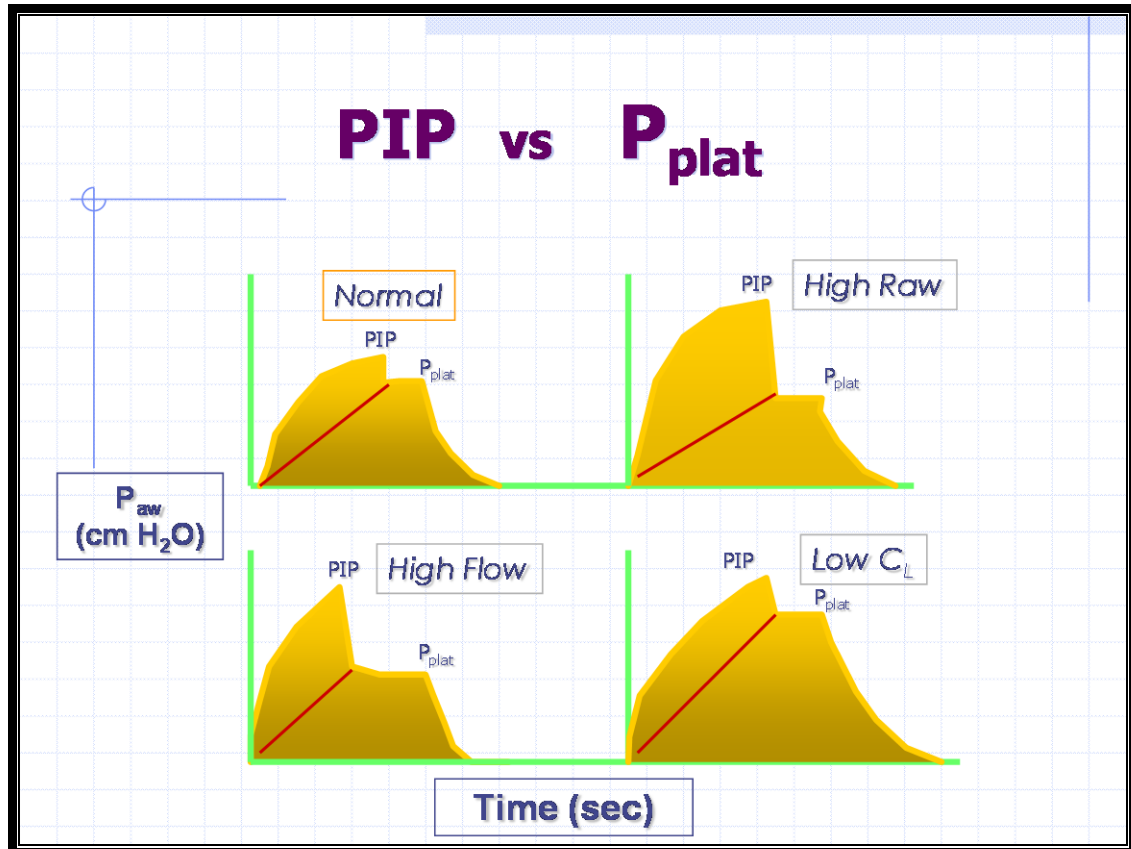


Fig.(19): Increased Airway resistance. PIP vs P<sub>plat</sub>. (MacIntyre et al., 2001)

### III) Alveolar Overdistention (Fig. 20):

Alveolar distension is a common observation made during ventilation of patients with ARDS on a volume-targeted mode. Alveolar overdistension is detrimental to patients (MacIntyre et al., 2001).

### IV) Decreased Lung Compliance (Fig. 21):

A shift of the curve to the right of a Pressure-Volume loop indicates decreased lung compliance. A shift to the left is associated with an increased compliance. Observe the pressure required to deliver the same tidal volume in the three graphs. The classic sign, known as “Beak Effect” or “Duckbill” shows an increase in airway pressure without any appreciable increase in volume. In this situation it is desirable to switch to pressure targeted ventilation at appropriate safe pressure level, or a reduction in VT (Pruitt, 2002).

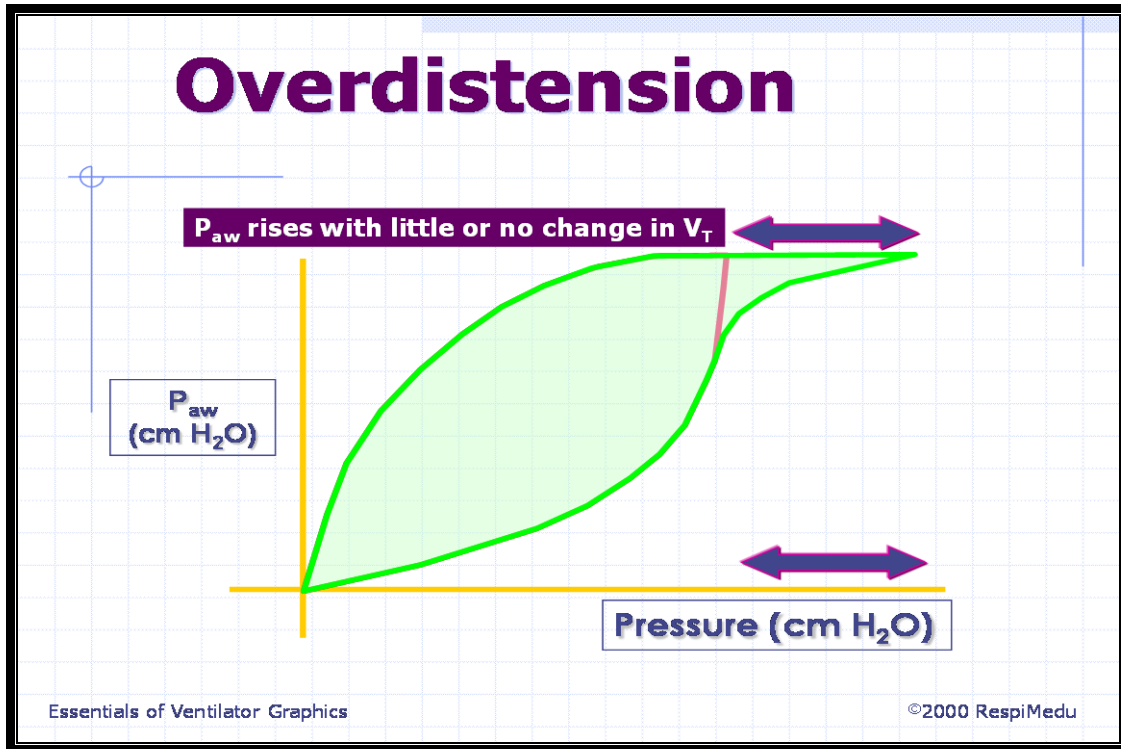


Fig.( 20):Pressure Volume loop representing alveolar overdistention. (MacIntyre et a.,2001).

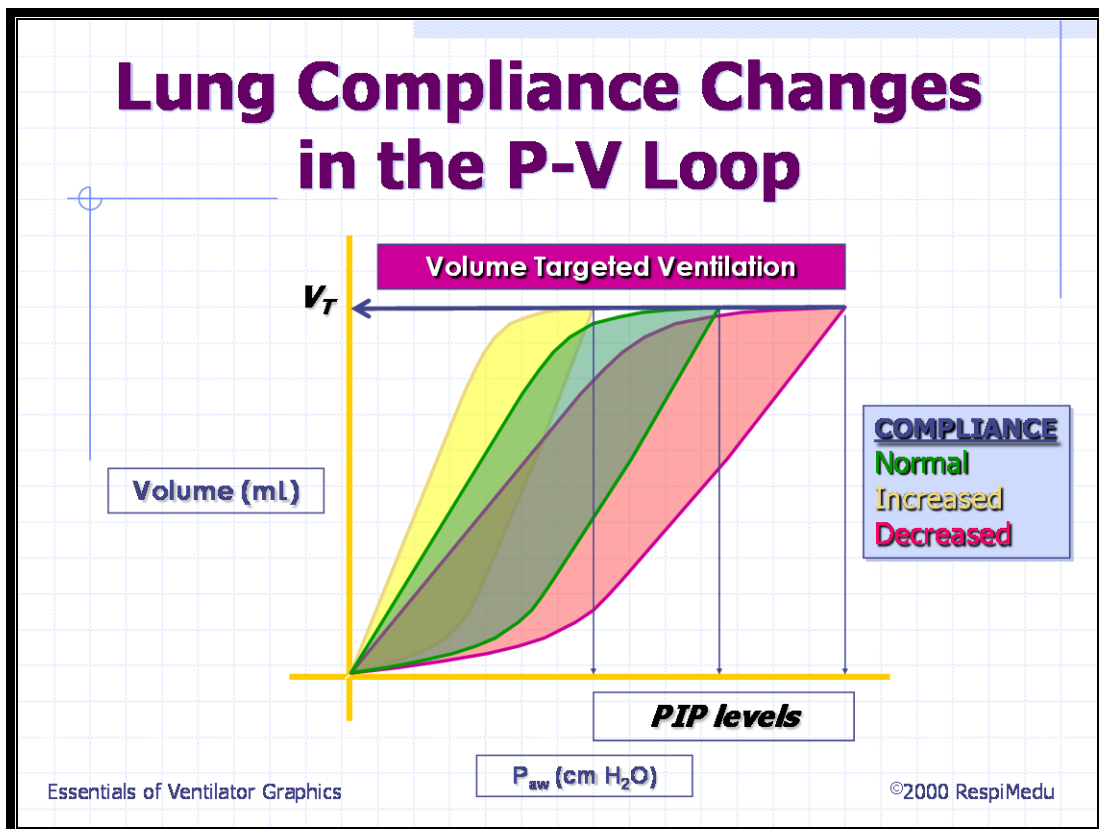


Fig.(21): Pressure Volume loop representing compliance changes (Pruitt, 2002)

## **Weaning from mechanical ventilation**

Weaning from mechanical ventilation could be defined as the gradual process of transferring the respiratory work of breathing from the ventilator to the patient. Physicians often refer to weaning as the moment when any artificial airway is removed, so that the extubation (weaning from the tube) corresponds to the interruption of mechanical ventilation (weaning from the ventilator) (*Volta et al., 2006*).

Several studies demonstrated that mortality increases with increasing duration of mechanical ventilation, in part because of complications of prolonged mechanical ventilation, especially ventilator-associated pneumonia and airway trauma. In the study by *coplin et al. (2000)* mortality was 12% if there was no delay in extubation and 27% when extubation was delayed.

Subjects receiving prolonged mechanical ventilation account for 6% of all ventilated patients but consume 37% of intensive care unit (ICU) resources (*Boles et al ., 2007*).

The incidence of unplanned extubation ranges 0.3–16%. In most cases (83%), the unplanned extubation is initiated by the patient, while 17% are accidental. Almost half of patients with self-extubation during the weaning period do not require reintubation, suggesting that many patients are maintained on mechanical ventilation longer than is necessary. Time spent in the weaning process represents 40–50% of the total duration of mechanical ventilation (*Esteban et al ., 2002*).

Thus, criteria for readiness to begin weaning should be systematically evaluated each day to allow prompt initiation of weaning

as soon as the patient is ready. This will shorten the weaning process and minimize time on mechanical ventilation. This is also an independent predictor of successful extubation and survival. (*Ely et al., 1999*).

**Classification of patients (Table: 1 ):**

A classification of patients into three groups is proposed, according to the difficulty and length of the weaning process (*Brochard, 2005*).

**Table(1):** Classification of patients according to the weaning process (*Brochard, 2005*)

<b>Group/category</b>	<b>Definition</b>
<b>Group(1): Simple weaning</b>	Patients who proceed from initiation of weaning to successful extubation on the first attempt without difficulty
<b>Group(2): Difficult weaning</b>	Patients who fail initial weaning and require up to three spontaneous breath trial SBT or as long as 7 days from the first spontaneous breath trial (SBT) to achieve successful weaning
<b>Group(3): Prolonged weaning</b>	Patients who fail at least three weaning attempts or require 7 days of weaning after the first SBT

**Group 1**, the simple weaning group includes patients who successfully pass the initial SBT and are successfully extubated on the first attempt. This group, represents 69% of weaning patients. Prognosis in this group is good, with an ICU mortality of 5% and an in-hospital mortality of 12%. The remaining patients (31%) represent groups 2 and 3. In this population, ICU mortality is 25%. **Group 2**, difficult weaning, includes patients who require up to three SBT or as long as 7 days from the first SBT to achieve successful weaning. **Group 3**, prolonged

weaning, includes patients who require more than three SBT or 7 days of weaning after the first SBT (*Brochard, 2005*).

**Criteria of weaning:**

**Assessing readiness to wean (Table : 2 ):**

Weaning should be considered as early as possible in the course of mechanical ventilation. The process of initial weaning from the ventilator involves a two-step strategy. It begins with an assessment regarding readiness for weaning, which is then followed by SBT as a diagnostic test to determine the likelihood of successful extubation. In fact, for the majority of patients, the entire weaning process simply involves confirmation that the patient is ready for extubation (*Kress et al ., 2000*).

Patients who meet the criteria reported in table (2) should be considered as being ready to wean from mechanical ventilation. Failing to extubate patients who can in fact be successfully weaned is more injurious than a failed SBT. Since many patients who do not meet all the criteria in table (2) are able to wean successfully from mechanical ventilation, these criteria should be viewed as considerations for probable weaning rather than as strict criteria that must all be met simultaneously. For many patients, discontinuation of sedation is a critical step that can be achieved by either daily interruption of sedation or continuous titration of sedation to a level that allows the patient to be adequately responsive. An spontaneous breath trial (SBT) should be considered as soon as possible once the patient meets the criteria in table (2). An initial assessment of the likelihood of a successful SBT is appropriate in order to avoid trials in patients with a high probability of failure. However, the predictive value of indices that attempt to predict successful SBT may be low in clinical practice. But it must be considered that pre-test probability of successful weaning, upon which predictive value of indices is based, may be very



high because of the late measure of these indices in a majority of patients' course (*Kress et al., 2000*).

**Table (2) :** Considerations for assessing readiness to wean (*Kress et al., 2000*).

<b>Clinical assessment</b>	Adequate cough
	Absence of excessive tracheobronchial secretion
	Resolution of disease acute phase for which the patient was intubated
<b>Objective measurements</b>	Clinical stability Stable cardiovascular status (i.e. HR $\leq$ 140 beats/min, systolic BP 90–160 mmHg, no or minimal vasopressors) Stable metabolic status
	Adequate oxygenation SaO <sub>2</sub> >90% on $\leq$ FIO <sub>2</sub> 0.4 (or PaO <sub>2</sub> /FIO <sub>2</sub> $\geq$ 150 mmHg) PEEP $\leq$ 8cmH <sub>2</sub> O
	Adequate pulmonary function fR $\leq$ 35 breaths/min MIP $\leq$ -20– -25 cmH <sub>2</sub> O VT >5mL/kg VC >10 ml/kg fR/VT <105 breaths/min/L No significant respiratory acidosis
	Adequate mentation No sedation or adequate mentation on sedation (or stable neurologic patient)



**Predictors of successful weaning (Table : 3 ):**

A large spectrum of weaning predictors has been studied, which can be divided into simple weaning indices, simple measures of load and capacity, integrative weaning indices, and complex predictors requiring special equipment. An expert panel sponsored by the American College of Chest Physicians, Society of Critical Care Medicine, and the American Association for Respiratory Care developed evidence-based weaning guidelines and noted that only eight variables had some predictive capacity: minute ventilation (VE), negative inspiratory force, maximum inspiratory pressure, tidal volume (VT), breathing frequency (f), the ratio of breathing frequency to tidal volume (f/VT), P0.1/PImax (ratio of airway occlusion pressure 0.1 sec after the onset of inspiratory effort to maximal inspiratory pressure), and CROP (integrative index of compliance, rate, oxygenation, and pressure) (*MacIntyre et al ., 2001*).

However, another study by Conti and colleagues in 2004 showed that vital capacity, VT, P0.1, VE, f, maximum inspiratory pressure, f/VT, P0.1/PImax and  $P0.1 \times f/VT$  are poor predictors of weaning outcome in a general ICU population (*Conti et al ., 2004*).

These conflicting results have been attributed to many factors, such as the measurement techniques that differ from one study to another, different timing of measurements made by different investigators, and lack of objective criteria to determine tolerance of the trial (*Meade et al., 2001*).

*Martinez et al. (2003)* showed that the time of recovery of VE from the end of a 2-hour spontaneous breathing trial to return to baseline after reinstatement of mechanical ventilation is a good predictor of liberation

from mechanical ventilation. They concluded that short VE recovery times (3-4 minutes) may help in determining respiratory reserve and be valuable in predicting the success of extubation.

**Table (3):** Commonly used clinical parameters that predict successful weaning from mechanical ventilation (*MacIntyre et al., 2001*)

<b>Parameter</b>	<b>Desired value</b>
Respiratory rate	Less than 30-38 breaths/minute
Tidal volume	4-6 ml/kg
Minute ventilation	10-15 L/minute
Negative inspiratory force	-20 to -30 cm H <sub>2</sub> O
Maximal inspiratory pressure	-15 to -30 cm H <sub>2</sub> O
Mouth occlusion pressure 100 msec after the onset of inspiratory effort (P0.1) divided by MIP	0.3
Rapid shallow breathing index (RSBI) (respiratory rate divided by tidal volume)	60-105
Rapid shallow breathing index rate [(RSBI2 – RSBI1)/RSBI1] x 100	Less than 20%
CROP score (an index including compliance, rate, oxygenation and pressure)	13

**Minute ventilation :**

**Maximal inspiratory pressure (P<sub>I</sub>max) :**

P<sub>I</sub>max (also called negative inspiratory force) is commonly used to test respiratory muscle strength and, in particular, the diaphragm. Trwit and Marini described a method for measuring P<sub>I</sub>max that is not dependent on patient cooperation. The proximal end of the endotracheal tube is occluded for 20 to 25 seconds with a one-way valve that allows

the patient to exhale but not to inhale. This procedure leads to increasing inspiratory effort and P<sub>I</sub>max is measured towards the end of the occlusion period (*Trwit and Marini, 1992*).

**Tidal volume:**

Spontaneous tidal volumes greater than 5 ml/kg have been considered as good predictors of weaning outcome. More recent studies have used both qualitative and quantitative non-linear dynamical analysis of the tidal volume pattern for discriminating between outcome success and failure from mechanical ventilation (*MacIntyre et al., 2001*).

*El-Khatib et al. (2001)* showed that approximate entropy of the tidal volume and breathing frequency patterns, a technique that measures the amount of regularity in a series, is a useful indicator of reversibility of respiratory failure. They reported that low approximate entropy that reflects regular tidal volume and respiratory frequency patterns is a good indicator of weaning success.

**Breathing frequency:**

Tachypnea ( $f \geq 30$ -35 breaths/minute) is a sensitive marker of respiratory distress but can prolong intubation when used as an exclusive criterion (*DeHaven et al., 1996*).

*El-Khatib et al. (2001)* have shown that it is the degree of regularity/irregularity in the pattern of the breathing frequency as reflected by approximate entropy rather than the absolute value of the breathing frequency that is important in discriminating between weaning success and failure. They have shown that a highly irregular spontaneous breathing frequency pattern with or without periods of apneas is not a good indicator for liberation from mechanical ventilation outcome.

**The ratio of breathing frequency to tidal volume:**

The most commonly used test is calculation of the RSBI (respiratory frequency (fR)/VT). A value  $< 100$ – $105$  breaths/min/L predicts a successful SBT with a reported sensitivity of 0.97 and specificity of 0.65. In patients in whom the clinical probability of successful weaning is high, the RSBI might be omitted. In general, patients should be considered for an RSBI calculation and subsequent SBT earlier rather than later, since physicians frequently underestimate the ability of patients to be successfully weaned. RSBI has been studied in large numbers of patients and appears to have predictive utility that is superior to other commonly used parameters (*Vassilakopoulos et al., 2006*).

In a non-homogenous group of patients including COPD patients, Tanios and colleagues reported that including the RSBI in a protocol can prolong weaning time from 2 days to 3 days. Nevertheless, an rapid shallow breathing index (RSBI) of  $\leq 105$  breaths/minute/l should prompt a spontaneous breathing trial of 30 to 120 minutes to further assess patient readiness for liberation from mechanical ventilation (*Tanios et al., 2006*).

The RSBI threshold can be influenced by the ventilatory support settings, the experimental conditions, and the patient population. The ratio must be calculated as per Yang and Tobin, otherwise different threshold values for the index might be needed (*Tobin, 2001*).

When measured during trials of pressure support ventilation, the RSBI was of limited value in predicting weaning outcome. *El-Khatib et al. (2008)* showed that the ventilatory support settings can have a significant influence on the RSBI values in the same patient population. They showed that the RSBI significantly decreased during a trial of

pressure support ventilation, during a continuous positive airway pressure (CPAP) trial on 40% oxygen, and during a CPAP trial on room air as compared to a trial of 1 minute spontaneously breathing room air and off the ventilator. They recommended that the predictive value of the RSBI reported by Yang and Tobin should only be adopted if the determination of the index is performed under similar experimental conditions to those applied by Yang and Tobin, where patients were disconnected from the ventilator and spontaneously breathed room air for 1 minute. Furthermore, they recommended that different threshold values for the RSBI should be derived for different ventilatory support levels.

*Krieger et al. (1997)* showed that when adjusting the threshold value of the RSBI to  $\leq 130$  breaths/minute/l, the RSBI measured at 3 hours was very effective in predicting weaning success among patients 70 years and older. These studies support the fact that the RSBI may be one of the better indexes for predicting weaning outcome that can easily be applied at the bedside, and can be readily utilized to identify patients who are candidates for spontaneous breathing trial.

**P0.1/PImax:**

The airway occlusion pressure (P0.1) is the pressure measured at the airway opening 0.1 s after inspiring against an occluded airway. The P0.1 is effort independent and correlates well with central respiratory drive. When combined with PImax, the P0.1/PImax ratio at a value of  $< 0.3$  has been found to be a good early predictor of weaning success and may be more useful than either P0.1 or PImax alone. Previously, the clinical use of P0.1/PImax has been limited by the requirement of special instrumentation at the bedside; however, new and modern ventilators are incorporating respiratory mechanics modules that provide numerical and graphical displays of P0.1 and PImax. (*Kuhlen et al., 1995*).

**Integrative index of compliance, rate, oxygenation, pressure (CROP):**

The CROP index is an integrative index that incorporates several measures of readiness for liberation from mechanical ventilation, such as dynamic respiratory system compliance (Crs), spontaneous breathing frequency (fR), arterial to alveolar oxygenation (partial pressure of arterial oxygen (PaO<sub>2</sub>)/partial pressure of alveolar oxygen (PAO<sub>2</sub>)), and PImax in the following relationship:

$$\text{CROP} = [\text{Crs} \times \text{PImax} \times (\text{PaO}_2/\text{PAO}_2)]/f$$

$$\text{Where: } \text{PAO}_2 = (\text{PB}-47) \times \text{FiO}_2 - \text{PaCO}_2/0.85$$

And PB is barometric pressure.

The CROP index assesses the relationship between the demands placed on the respiratory system and the ability of the respiratory muscles to handle them. *Yang and Tobin(1991)* reported that a CROP value >13 ml/breaths/minute offers a reasonably accurate predictor of weaning mechanical ventilation outcome.

In 81 COPD patients *Alvisi et al. (2000)* showed that a CROP index at a threshold value of > 16 ml/breaths/minute is a good predictor of weaning outcome. However, one disadvantage of the CROP index is that it is somewhat cumbersome to use in the clinical setting as it requires measurements of many variables with the potential risk of errors in the measurement techniques or the measuring device, which can significantly affect the value of the CROP index.

**Lung compliance:**

Pulmonary compliance is volume change per unit of pressure change for the lungs (*Ruppel, 1998*).

The lung tissue elastic forces and surface tension impede the inflation of the lung. This impedance may be expressed as the elastance of the lungs

accordingly, a lung with a high elastance would be harder to inflate than normal, a lung with low elastance would be easier to inflate (*Slonim and Hamilton, 1985*).

Whereas elastance is the tendency of a structure to resist deformation, compliance would represent the relative ease with which a body stretches, or its relative “distinsibility”. Compliance is therefore the reciprocal of elastance (*Altose, 1980*).

Both the lungs and the chest wall have elastic properties. The chest has a tendency to expand outward, while the lungs have a tendency to collapse. Physiologically, this elasticity is defined in terms of compliance, which is defined or calculated as the change in unit volume for a given change in the distending transthoracic pressure(*Murray, 1986*).

$$\text{Compliance (L/cm H}_2\text{O)} = \frac{\Delta \text{ volume}}{\Delta \text{ pressure (cmH}_2\text{O)}}$$

The elastic properties of the lungs and thorax are influenced by the content and character of their tissues, muscle tension, the amount of interstitial lung water or fibrosis, in addition to pulmonary lung volume, state of inflation, and alveolar surface tension. Total respiratory system compliance is inversely related to the overall elasticity of the lungs and thorax. The total compliance of the system is the product of the collapsing forces of the lungs, and the expansive forces of the thorax. This may be expressed by the following equation (*Murray, 1986*):

**Where:**

CT = Total systemic compliance (100 ml/cmH<sub>2</sub>O)

CL = Lung compliance (200 ml/cmH<sub>2</sub>O)

CTh = Thoracic compliance (200 ml/cmH<sub>2</sub>O)

$$\frac{1}{CT} = \frac{1}{CL} + \frac{1}{CTh}$$

Obviously, the total compliance of the respiratory system may be altered by disorders affecting the compliance of the lung, thorax or both simultaneously (*Roussos and Macklem, 1985*).

[

In clinical practice, only total compliance is measured, which can be done dynamically or statistically depending on whether a peak or plateau inspiratory pressure is used for the total compliance calculation. The transthoracic pressure first increases to a peak value and then decreases to a lower plateau value. The peak transthoracic pressure value is due to pressure required to overcome both elastic and air way resistance. The transthoracic pressure decreases to a plateau value following the peak value, because with time, gas redistribution from stiff alveoli (which expand only slightly and therefore have only a short inspiratory period) into more compliant alveoli (which expand a greater deal and therefore have a long inspiratory period. Because the gas redistribution into more compliant alveoli, less pressure is required to contain the same amount of gas, and this explains why the pressure decreases (*Miller, 2000*).

In practical terms, dynamic compliance is the volume change divided by the peak inspiratory transthoracic pressure, and static compliance is the volume change divided by the plateau inspiratory transthoracic pressure. Therefore static compliance is usually greater than dynamic compliance, because the former calculation uses a small denominator (lower pressure) than the latter. However, if the patient is receiving PEEP, this must be first subtracted from the peak or plateau pressure before calculating the compliance.

$$\text{Compliance} = \frac{\text{volume delivered}}{\text{Peak or plateau pressure} - \text{PEEP}}$$



Compliance is represented by the slope of the pressure-volume curve; the curve of a patient with emphysema has a steeper slope, indicating a greater change in volume for a given change in pressure, meaning an increased compliance. This is explained by the loss of elastic fibres occurs in some forms of emphysema, causing increased distensibility of the lungs (*Altose, 1980*).

On the other hand, the curve of a patient with obstructive lung disease has less slope than the normal curve (*Martin, 1987*).

**Normal values of compliance for adult one:**

Static compliance : 50-75 ml/cmH<sub>2</sub>O

Dynamic compliance: 40-65 ml/cmH<sub>2</sub>O

**Airway resistance:**

For air to flow into the lungs, a pressure must also be developed to overcome the non elastic airway resistance of the lungs to airflow. The relationship between the pressure ( $\Delta P$ ) and the rate of airflow ( $V$ ) is known as airway resistance ( $R$ ).

$$R_{aw} \text{ (cmH}_2\text{O/L/S)} = \frac{\Delta P \text{ (cmH}_2\text{O)}}{\Delta V \text{ (L/S)}}$$

The pressure along the airway depends on the caliber of the airway and the rate and pattern of airflow. There are three main patterns of airflow (*Miller, 2000*).

**The spontaneous breathing trial**

There appears to be no difference in either the percentage of patients who pass the SBT or the percentage of patients successfully extubated when a T-tube trial is compared with the use of low levels of pressure support (PS), such as 7 cmH<sub>2</sub>O or 8 cmH<sub>2</sub>O in adults or 10 cmH<sub>2</sub>O in pediatric patients, or the use of CPAP (*Matic and Majeric, 2004*).

The use of automatic tube compensation (ATC), which adjusts for the assumed resistance of the endotracheal tube, is at least as successful as the use of simple T-tube or low-level PS (*Haberthur et al ., 2002*).

PS has been used in previous studies with the purpose of overcoming the resistance of the endotracheal tube. These studies failed to account for the increased resistance of the inflamed natural upper airways following extubation, so that post-extubation work of breathing (WOB) is best approximated without such compensation. Thus, it does not make sense to use PS for the purpose of overcoming the resistance of the endotracheal tube (*Mehta et al ., 2000*).

The same line of reasoning applies to other modes of ventilation that have been proposed for this purpose, such as ATC. In the case of SBT failure because of a particularly narrow endotracheal tube, ATC may be beneficial. Studies demonstrate that patients who fail an SBT do so within the first ~ 20 min, so the success rate for an initial SBT is similar for a 30-min compared with a 120-min trial (*Perren et al., 2002*).

The impact of low levels ( $\leq$  cmH<sub>2</sub>O) of PEEP during an SBT is likely to be small. Due to dynamic hyperinflation, patients with COPD may have improved pulmonary function with CPAP. *Reissmann et al. (2000)* found that patients with COPD were more likely to pass a 30-min SBT when 5–7.5 cmH<sub>2</sub>O CPAP was supplied. The increasing use of NIV following extubation may make extubation more appropriate for such patients. Criteria for passing SBT include respiratory pattern, adequate gas exchange, hemodynamic stability and subject comfort. Recent studies demonstrated that only 13% of patients who successfully passed the SBT and were extubated required reintubation. In patients who do not receive

an SBT and are extubated, the failure rate is 40% (*Zeggwagh et al ., 1999*).

Patients who successfully pass the SBT should be extubated if neurological status, excessive secretions and airway obstruction are not issues. Although depressed mentation is frequently considered a contra-indication to extubation (*Namen et al ., 2001*).

*Coplin et al. (2000)* demonstrated a low reintubation rate (9%) in stable brain-injured patients with a Glasgow coma score  $\leq 4$ . *Koh et al. (1997)* found that Glasgow coma score did not predict extubation failure. *Khamiees et al. (2001)* demonstrated that poor cough strength and excessive endotracheal secretions were more common in patients who failed extubation following a successful SBT.

When upper airway obstruction due to edema is a potential concern, a positive leak test (air leaks around the endotracheal tube after deflation of the cuff) should be adequate before proceeding with extubation (*Jaber et al., 2003*).

When patients fail an initial SBT (the criteria of which are reported in table 4) the clinician should review possible reversible etiologies for failure. The SBT should be repeated frequently (daily) in order to determine the earliest time at which the patient can be successfully extubated. Although respiratory muscle fatigue has been considered to be a major reason for continuing failure to wean from mechanical ventilation, recent data demonstrate that weaning failure is not accompanied by low-frequency fatigue of the diaphragm. Patients who

fail the initial SBT should receive a non fatiguing mode of mechanical ventilation (PSV or generally either assist–control) (*Laghi et al., 2003*).

**Table(4):** Indicators of failure during spontaneous breathing trials (*Laghi et al., 2003*)

<b>Inadequate gas exchange</b>
Arterial oxygenation saturation (SaO <sub>2</sub> ) <85% -90% PaO <sub>2</sub> <50 – 60 mmHg pH < 7.32 Increase in PaCO <sub>2</sub> >10 mmHg
<b>Unstable ventilatory/respiratory pattern</b>
Respiratory rate >30 – 35 breaths/minute Respiratory rate change over 50%
<b>Hemodynamic instability</b>
Heart rate >120 – 140 beats/minute Heart rate change greater than 20% Systolic blood pressure >180 mmHg or <90 mmHg Blood pressure change greater than 20% Vasopressors required
<b>Change in mental status</b>
Coma Agitation Anxiety Somnolence
<b>Signs of increased work of breathing</b>
Nasal flaring Paradoxical breathing movements Use of accessory respiratory muscles
<b>Onset of worsening discomfort ± diaphoresis</b>

**Weaning protocols:**

Weaning protocols may be valuable in standardizing the process of weaning. Physicians often fail to recognize patients who may already be ready for extubation. Studies among patients who are accidentally or self-extubated demonstrate that 23% of patients receiving full mechanical ventilation and 69% of patients who have begun weaning do not require reintubation (*Betbese et al., 1998*).

In fact, 35% of patients who were considered to be unweanable when referred from one facility to another could be extubated without any additional weaning attempts (*Vitacca et al ., 2001*).

The percentage of patients who required weaning decreased from 80 to 10% when physician judgment was replaced by protocol management (*Saura et al ., 1996*).

Weaning protocols are less likely to be effective when the majority of patients are rapidly extubated, when physicians do not extubate patients following a successful SBT, or when the quality of critical care is already high. Weaning protocols incorporating SBT may be particularly effective in helping physicians utilize the most effective techniques (*Ely et al ., 1996*)

**Modes of weaning:**

When initial attempts at spontaneous breathing fail to achieve the goal of liberation from mechanical ventilation, clinicians must choose appropriate mode(s) of ventilatory support which maintain a favorable balance between respiratory system capacity and load, attempt to avoid diaphragm muscle atrophy, and aid in the weaning process.

**Pressure support ventilation (PSV):**

PSV is commonly utilized and is the sole mode of mechanical ventilation used during the weaning process in ~ 21% of patients. PSV can be used during a SBT and as a weaning mode in both groups 2 and 3. PSV used as the sole mode of mechanical ventilation during initial weaning attempts has been tested in two large randomized controlled trials (*Esteban et al., 2002*).

During this protocol PSV was decreased from a mean of 19 cmH<sub>2</sub>O by 2 or 4 cmH<sub>2</sub>O per day. In 130 patients who had failed the initial SBT, *Esteban et al. (1995)* reported that either one daily trial or multiple daily trials of unassisted, spontaneous breathing (T-piece) more substantially reduced the duration of weaning than either SIMV or PSV, the median duration of weaning with each technique being 3, 3, 5 and 4 days, respectively.

### **Noninvasive ventilation (NIV):**

In weaning, NIV has been studied for three different indications:

- Alternative weaning technique for patients who failed conventional weaning.
- Prophylactic measure for patients with a high risk of reintubation.
- Treatment of respiratory insufficiency after extubation (post-extubation failure).

### **1-Alternative weaning technique for patients who failed conventional weaning:**

Physiological studies suggest that similar levels of ventilatory support can be delivered by NIV compared to PSV in stable COPD patients who cannot tolerate spontaneous breathing. It has thus been hypothesized that in this select group of patients NIV might be useful as a bridge to total withdrawal of ventilatory support; and would lower ICU morbidity (*Ferre et al ., 2003*).

In the majority of studied individuals, patients developed hypercapnia during initial attempts at weaning, and most patients had evidence of COPD. Despite failure of the SBTs, the intervention groups were extubated and placed on NIV via face mask with PSV set to a minimum inspiratory pressure of 15 cmH<sub>2</sub>O. The control groups were conventionally weaned with PSV (via standard mechanical ventilation)

and extubated. Based on these trials the use of NIV for weaning shortened the total duration of invasive mechanical ventilation and ICU stay, and substantially reduced the rate of nosocomial infection (*Ferre et al., 2003*).

In two studies, a significantly higher survival rate could also be found in the NIV group. However, two points need emphasis. First, although early extubation can avoid all of the complications of mechanical ventilation, the patients who fail SBTs may be sick with substantial comorbidities and at risk for extubation failure. Thus, although NIV is useful in very selected populations, its use cannot be recommended for all patients failing a SBT. Secondly, patients who are extubated to NIV should not be considered a weaning success until they are completely liberated from NIV as a form of therapy for ARF (*Nava et al., 1998*).

**2-NIV as a prophylactic measure for patients with a high risk for reintubation:**

Prophylactic use of NIV has been studied in two populations of surgical patients. CPAP (5–10 cmH<sub>2</sub>O) was used to prevent reintubation in patients after major abdominal or vascular surgery (*Bohner et al., 2002*)

Compared with a control group (post-operative oxygen insufflation), CPAP (mean 7.5 cmH<sub>2</sub>O) improved oxygenation and reduced the rate of both reintubation and infection. In both studies there was a trend towards a shorter stay in the hospital and a better survival (*Squadrone et al., 2005*).

### **3-NIV for the treatment of respiratory insufficiency after extubation (post-extubation failure):**

Post-extubation failure is defined mainly by clinical criteria ( table 3-4). It has a mean prevalence of 6.3–17.7% and is associated with increased ICU mortality. Two small trials studied organ transplant patients who developed respiratory insufficiency after extubation. NIV improved oxygenation and reduced the fR significantly, compared with oxygen insufflation alone. PSV was also superior to PEEP (*Kilger et al., 1999*).

In the study by *Antonelli et al. (2000)* the reintubation rate and the duration of ICU stay were lower in the control group. In the study by *Esteban et al. (2004)* the NIV group had worse survival compared with the oxygen group. Also, the evidence for use of NIV in COPD patients and those with hypoxic respiratory failure with concomitant hypercapnic respiratory failure is substantially stronger than in other groups. Careful patient selection is imperative for the use of NIV.

In conclusion, NIV cannot generally be recommended for any of the specific topics mentioned previously. However, there is promise that for some subgroups (hypercapnic respiratory insufficiency, especially in COPD patients) NIV may be helpful in expediting the weaning process. Positive effects of a prophylactic CPAP or NIV treatment in patients at risk for reintubation seem likely.

### **Continuous positive airway pressure (CPAP):**

CPAP applied during spontaneous breathing in patients with acute respiratory insufficiency reduces mean intrathoracic pressure, has beneficial effects on right and left ventricular performance improves oxygenation and reduces the WOB (*Jardin et al., 1981*).



In cardiac surgical patients, *Bailey et al.(1995)* randomized patients to receive CPAP or T-piece trials prior to extubation and observed no significant difference in oxygenation or time spent on mechanical ventilation. The use of CPAP during weaning may be helpful to prevent immediate postextubation hypoxemia. *Squadrone et al.(2005)* observed that CPAP compared to oxygen supplementation substantially reduced the reintubation rate.

**Automatic tube compensation (ATC):**

The use of ATC, a ventilatory method aimed at compensating for the nonlinear pressure drop across the endotracheal tube during spontaneous breathing, is at least as successful as the use of simple T-tube or low-level PS for weaning from mechanical ventilation. If an SBT fails because of a particularly narrow endotracheal tube, ATC may be beneficial. For more difficult weaning patients there is a lack of controlled trials to make any meaningful recommendations about the use of ATC (*Haberthur et al., 2002*).

**Proportional assist ventilation (PAV):**

The physiological response to PAV has been studied in ventilator-dependent patients with COPD. In comparison to PSV and CPAP, there was no substantial difference in oxygenation, pressure time product and other physiological variables. Only when CPAP was combined with PAV was a more substantial change in these parameters notable. PAV is available with some respirators but its application is sometimes regarded as difficult and has not been investigated thoroughly in weaning trials. (*Delaere et al., 2003*).

**Servo-controlled ventilation:**

Rapid adaptation of the ventilatory support to the changing situations of a patient is one of the major factors determining the length of the weaning process. However, ICU staff resources are often too limited to allow immediate response. Automatic ventilatory modes provide a tool to achieve optimal ventilatory support and an individual level of PS with the aim of rapid extubation. Two such modes, adaptive support ventilation (ASV) and a knowledge-based expert system (Smartcare1), have been integrated into conventional intensive care ventilators and are available on the market (*Cassina et al., 2003*).

**Adaptive support ventilation (ASV):**

ASV is based on a computer-driven closed-loop regulation system of the ventilator settings which is responsive to changes in both respiratory system mechanics and spontaneous breathing efforts (*Tassaux et al., 2002*).

At the beginning of mechanical ventilation, the clinician enters the patient's body weight and sets the desired percentage of minute ventilation (100% being equal to 100 ml/kg body weight/min in adult patients), as well as the FIO<sub>2</sub>, level of PEEP and maximal inspiratory pressure. Thereafter, mechanical ventilation starts with closed-loop regulation algorithms based on real-time determination of the expiratory time constant. Adjustment of inspiratory pressure, duty cycle and fR (to ensure an fR and minute ventilation within defined limits) may improve patient-ventilator interactions. Any spontaneous breathing efforts trigger either a pressure-controlled breath or a spontaneous breath with inspiratory PS, the level of which is adjusted to meet the target fR/VT combination. ASV can thus manage the spectrum of ventilatory support

ranging from controlled mechanical ventilation to PS, up to the pre-extubation weaning trial (*Lourens et al., 2000*).

Earlier extubation and fewer ventilator adjustments, as well as a reduced need for arterial blood gas measurements and high-pressure alarms have been documented (*Sluzer et al., 2001*).

These results should be interpreted with caution, as ASV was compared with SIMV, which has been shown to be the worst weaning mode (*Esteban et al., 1995*).

### **Knowledge-based expert system**

This system, which is presently integrated in a standard ICU ventilator (Evita XL; Dräger, Lubeck, Germany) under the brand name Smartcare1, has been developed over several years and is based on fuzzy logic algorithms. The system follows two main goals. The first is a real-time adaptation of the level of pressure support to maintain the patient within a “comfort” zone. This is defined as a fR of 15–30 breaths/min (ranging up to 34 breaths/min in patients with neurological disease), a VT above minimum threshold (250 ml if body weight is <55 kg and 300 ml otherwise) and an end-tidal expiratory carbon dioxide below maximum threshold (7.3 kPa (55 mmHg) or 8.6 kPa (65 mmHg) in patients with COPD). To reach these targets, the level of PS is periodically adapted by the system in steps of 2–4 cmH<sub>2</sub>O. Secondly, the device also includes an algorithm of a stepwise decrease of PS with the aim of automatically performing an SBT. The system has been shown to maintain a patient in the comfort zone more successfully than clinician-directed adjustments. (*Dojat et al., 2000*).

**Controlled mechanical ventilation (CMV):**

Older studies have suggested that in patients weaning from mechanical ventilation there is evidence of diaphragm fatigue and possibly injury. This may occur because the load on the respiratory muscles of patients who fail to wean is increased to levels that would predictably produce fatigue in the respiratory muscles if patients were allowed to continue spontaneous breathing without ventilator assistance. Thus, the use of controlled mechanical ventilation (CMV) to rest the fatiguing diaphragm seems reasonable. However, LAGHI et al demonstrated that, despite greater load and diaphragmatic effort, weaning failure patients do not develop low-frequency muscle fatigue, although these patients displayed diaphragmatic weakness (*Laghi et al., 2003*).

Studies have demonstrated that CMV induces diaphragm muscle injury (ventilator-induced diaphragm dysfunction). This phenomenon occurs in animals and is evident after short-term application of CMV. The etiology is unknown but the observed decrease in diaphragm compound action muscle potentials has been attributed to oxidative stress within the muscle and muscle atrophy. Whether the diaphragm damage attributed to controlled ventilation is indeed larger than during assist–control or PSV remains unclear. Therefore, there is no clear advantage of CMV compared with other ventilatory modes in patients with difficult weaning (*Vassilakopoulos et al., 2004*).

## Practice guidelines

A collective task force facilitated by the American college of chest physicians, the American association for respiratory care, and the American college of critical care medicine developed a series of guidelines for weaning and discontinuing ventilatory support (*MacIntyre et al., 2001*) :

1) In patients requiring mechanical ventilation for > 24 hours, a search for all the causes that may be contributing to ventilator dependence should be undertaken. This is particularly true in the patient who has failed attempts at withdrawing the mechanical ventilator. Reversing all possible ventilatory and nonventilatory issues should be an integral part of the ventilator discontinuation process.

2) Patients receiving mechanical ventilation for respiratory failure should undergo a formal assessment of discontinuation potential if the following criteria are satisfied:

- a- Evidence for some reversal of the underlying cause of respiratory failure;
- b- Adequate oxygenation (e.g.,  $\text{PaO}_2/\text{FIO}_2 > 150\text{-}200$ ; requiring positive end-expiratory pressure [PEEP]  $\leq 5\text{-}8$  cm  $\text{H}_2\text{O}$ ;  $\text{FIO}_2 \leq 0.4\text{-}0.5$ ) and pH (e.g.,  $\geq 7.25$ );
- c- Hemodynamic stability as defined by the absence of active myocardial ischemia and the absence of clinically important hypotension (i.e., a condition requiring no vasopressor therapy or therapy with only low-dose vasopressors such as dopamine or dobutamine  $< 5$   $\mu\text{g}/\text{kg}/\text{min}$ ); and
- d- The capability to initiate an inspiratory effort.

The decision to use these criteria must be individualized. Some patients not satisfying all of the above the criteria (e.g., patients with

chronic hypoxemia below the thresholds cited) may be ready for attempts at discontinuation of mechanical ventilation.

3) Formal discontinuation assessments for patients receiving mechanical ventilation for respiratory failure should be done during spontaneous breathing rather than while the patient is still receiving substantial ventilatory support. An initial brief period of spontaneous breathing can be used to assess the capability of continuing onto a formal SBT. The criteria with which to assess patient tolerance during SBTs are the respiratory pattern, adequacy of gas exchange, hemodynamic stability, and subjective comfort. The tolerance of SBTs lasting 30 to 120 minutes should prompt consideration for permanent ventilator discontinuation.

4) The removal of the artificial airway from a patient who has successfully been discontinued from ventilatory support should be based on assessments of airway patency and the ability of the patient to protect the airway.

5) Patients receiving mechanical ventilation for respiratory failure who fail an SBT should have the cause for the failed SBT determined. Once reversible causes for failure are corrected, and if the patient still meets the criteria listed in Table (2), subsequent SBTs should be performed every 24 hours.

6) Patients receiving mechanical ventilation for respiratory failure who fail an SBT should receive a stable, nonfatiguing, comfortable form of ventilatory support.

7) Anesthesia/sedation strategies and ventilator management aimed at early extubation should be used in postsurgical patients.

8) Weaning/discontinuation protocols designed for nonphysician health care professionals (HCPs) should be developed and implemented by ICUs. Protocols aimed at optimizing sedation should also be developed and implemented.

9) Tracheotomy should be considered after an initial period of stabilization on the ventilator when it becomes apparent that the patient will require prolonged ventilator assistance. Tracheotomy should then be performed when the patient appears likely to gain one or more of the benefits ascribed to the procedure. Patients who may derive particular benefit from early tracheotomy are the following:

- a) Those requiring high levels of sedation to tolerate translaryngeal tubes.
- b) Those with marginal respiratory mechanics (often manifested as tachypnea) in whom a tracheostomy tube having lower resistance might reduce the risk of muscle overload.
- c) Those who may derive psychological benefit from the ability to eat orally, communicate by articulated speech, and experience enhanced mobility.
- d) Those in whom enhanced mobility may assist physical therapy efforts.

10) Unless there is evidence for clearly irreversible disease (e.g., high spinal cord injury or advanced amyotrophic lateral sclerosis), a patient requiring prolonged mechanical ventilatory support for respiratory failure should not be considered permanently ventilator dependent until 3 months of weaning attempts have failed.

11) Critical-care practitioners should familiarize themselves with facilities in their communities, or units in hospitals they staff, that specialize in managing patients who require prolonged dependence on mechanical ventilation. Such familiarization should include reviewing published peer-reviewed data from those units, if available. When medically stable for transfer, patients who have failed ventilator discontinuation attempts in the ICU should be transferred to those

facilities that have demonstrated success and safety in accomplishing ventilator discontinuation.

12) Weaning strategy in the PMV patient should be slow-paced and should include gradually lengthening self-breathing trials.



## **Complications of mechanical ventilation**

It is important to realize that complications in ventilated patients are relatively common, and meticulous monitoring is vital for their prevention. Prompt corrective action may be life saving if some of these complications (such as a pneumothorax or sudden blockage of an endotracheal tube) occur. Complications can not only occur at the time of initiating mechanical ventilatory support, but also at any time during the course of ventilatory support. For purposes of discussion, these have been organized into as follows:

- I. Peri-intubation complications
- II. Complications that can occur acutely at any stage during mechanical ventilation
- III. Delayed complications (*Hasan, 2010*).

### **I- Peri-Intubation Complications:**

#### **(1)- Laryngeal Trauma**

Most laryngeal injuries are minor, but vocal cord lacerations, hematomas, and very rarely, arytenoids dislocations can occur. Persistent hoarseness after extubation is a sign of laryngeal injury sustained at the time of intubation (*Hasan , 2010*).

#### **(2)- Pharyngeal Trauma**

Trauma to the posterior pharyngeal wall can introduce infection into the retropharyngeal space with subsequent mediastinitis. Cardiac arrest can occur with injury to the pyriform sinuses, posterior pharyngeal wall, or hypopharynx. Endoscopy may be required for diagnosis and assessment (*Hasan, 2010*).

#### **(3)- Tracheal or Bronchial Rupture**

Though rare, this complication can occur when the membranous posterior part of the trachea is transgressed by the tip of the endotracheal

tube during vigorous or repeated attempts at intubation. A stylet protruding beyond the tip of the endotracheal tube can increase the chances of this, and patients at extremes of age may be especially prone. The occurrence of subcutaneous or mediastinal emphysema or of gastric distension should prompt chest imaging and endoscopy for diagnosis, surgical repair may be necessary (*Fan et al .,2004*).

#### **(4)- Epistaxis**

Epistaxis is more frequently seen with nasal rather than oral intubation. Although usually minor and self-limiting, it can on occasion be significant. Relatively large bleeds can occur if areas on the anterior nasal septum or the posterior Pharyngeal Trauma (*Hasan, 2010*).

#### **(5)- Tooth Trauma**

Most injuries occur during difficult intubations. Because of the shape of the laryngoscope blade, the two left upper incisors and the right central incisor are liable to suffer damage. Dental protection during intubation safeguards to some extent against tooth trauma, but the extra padding narrows the intubation window and can prevent proper visualization of the vocal cords (*Hasan , 2010*).

#### **(6)- Cervical Spine Injury**

Since intubation of the larynx involves manipulation of the head and neck, caution should be exercised when the cervical spine could be unstable, such as after road traffic accidents. In such cases the cervical spine should be assumed to be unstable unless otherwise proven; suitable precautions must be taken and the neck immobilized by a hard collar (*Hasan , 2010*).

#### **(7)- Esophageal intubation**

Poor visualization of the glottis is a common problem during intubation and esophageal intubation is always possible when the vocal cords cannot be properly visualized. Unrecognized placement of the

endotracheal tube into the esophagus can have catastrophic consequences, resulting in cerebral anoxia –if not in mortality (*Laghi et al .,2003*).

**(8)- Esophageal Perforation**

The posterior wall of the esophagus can sometimes be perforated by the tip of the endotracheal tube. Anterior esophageal wall perforation is distinctly unusual: it has not yet been reported (*Epstein,2006*).

**(9)- Right Main Bronchial Intubation**

Ideally, the tip of the endotracheal tube should be located at least 2–2.5 cm above the carina, and yet should be low enough for the cuff of the endotracheal tube to reside below the cricoid cartilage (*Hasan , 2010*).

**(10)- Arrhythmias**

Pharyngeal stimulation during intubation evokes a pressor response. A transient increase in blood pressure and heart rate is common and this response can be exaggerated in hypertensive patients and during nasotracheal intubations. Stimulation of the carina or of other parts of the airway by the endotracheal tube can result in a variety of arrhythmias. Between 0.4–3.1% of patients may suffer fatal cardiac arrest at the time of intubation (*Hasan , 2010*).

**(11)- Aspiration**

Aspiration of gastric contents during intubation may have disastrous consequences. The use of succinylcholine for pharmacological paralysis has been associated with contraction of the gastric smooth muscle, causing vomiting and aspiration (*Hasan , 2010*).

**(12)- Bronchospasm**

Bronchospasm due to irritation of the airways by the endotracheal tube is not uncommon and this may be more pronounced in the setting of hyperreactive airways (*Adnet et al ., 1998*).

### **(13)- Neurologic Complications**

Difficult intubations with delays in securing airway control can result in anoxic neurologic injury. Intracranial pressure has been shown to transiently rise during intubation (*Hasan , 2010*).

## **II-Problems Occurring Acutely at any Stage:**

At any time in mechanical ventilated patients, acute complications are possible. Tube-related complications are common and can occur in as many as two-thirds of all intubated patients (*Hasan , 2010*).

### **(1)- Endotracheal Tube Obstruction**

An obstructed endotracheal tube presents a typical emergency in a mechanical ventilated patient. Endotracheal tube obstruction can occur insidiously, leading to gradually increasing peak inflation pressures. On spontaneous modes of ventilation the patient's breathing may be labored. This can result in patient-exhaustion with failure to wean, or an inability to sustain the desired amount of minute ventilation. If the endotracheal tube cannot be immediately unblocked, it must be replaced with a fresh tube on an emergency basis (*Hasan , 2010*).

### **(2)-Airway Drying**

Normally a thin film of moisture should be visible on the inner surface of the endotracheal tube. Lack of airway hydration leads to inspissations of airway secretions and predisposes to blockage of the endotracheal tube (*Hasan , 2010*).

### **(3)- Upward Migration of the Endotracheal Tube**

The endotracheal tube can also migrate upward. Ventilator circuitry and HME filters exert considerable traction on the endotracheal tube and tend to drag it up and out (*Hasan , 2010*).

#### **(4)- Self-Extubation**

The consequences of unplanned extubation and reintubation are an increased risk for ventilator-associated pneumonia, a protracted ICU stay, a longer time spent on the ventilator and overall a longer hospitalization. Patients who are uncooperative due to disorientation or other factors must be restrained or sedated as appropriate to prevent this dangerous complication. Keeping the patient as comfortable as possible, and matching ventilator settings to the patient's needs, may go a long way toward preventing self-extubation (*Epstein, 2006*)

#### **(5)- Cuff Leak**

The cuff of an endotracheal tube can sometimes leak. Apart from allowing pooled secretions to trickle down into the lower airways (and thereby increasing the risk of ventilator associated pneumonia), a cuff leak can result in sudden loss of airway pressures, especially when PEEP is used, causing autocycling of the ventilator. A cuff leak may manifest itself by the sudden ability of an intubated patient to vocalize (*Hasan , 2010*).

#### **(6)- Dynamic Hyperinflation**

Inspiration during positive pressure breathing is followed by passive exhalation, at the end of which the thorax returns to its resting state. At this point the elastic recoil that tends to collapse the lung is counterbalanced by the forces that tend to pull the thoracic wall outward. The volume of air contained in the lung at this point is termed the functional residual capacity (FRC). Delivery of a premature inspiratory breath before the exhaling lung has reached its FRC results in air trapping. In practice, this occurs if there is delayed lung emptying due to some reason. The failure of the lung to empty to a FRC that is appropriate for the level of set PEEP is termed dynamic hyperinflation (DH). auto-PEEP can only result from DH (*Hasan , 2010*).

### **(7)-Ventilator-Associated Lung Injury (VALI) and Ventilator-Induced Lung Injury (VILI)**

An injured lung is susceptible to further injury. Mechanical ventilation is itself capable of producing or exacerbating acute lung damage. The term VALI is used to describe acute lung injury that develops during the course of mechanical ventilation. VALI is termed VILI if that mechanical ventilation per se can be causally linked to the ALI. Since VILI can be practically impossible to prove at the bedside, the term VALI is the more commonly used. VALI presents in a manner identical to ARDS, with radiologic deterioration and worsening oxygenation (*Hasan , 2010*).

#### **a-Barotrauma:**

A pneumothorax in a patient on a mechanical ventilator must always be presumed to be a tension pneumothorax and prompt action should be taken. If the air from a pneumomediastinum dissects up the subcutaneous tissues of the neck and elsewhere, subcutaneous emphysema occurs. If the air dissects through the fascial planes down to the peritoneum, a pneumoperitoneum is produced. Tension lung cysts and systemic gas embolization are other manifestations of barotrauma. A significant percentage of pneumothoraces seems to be preceded by the development of subpleural air cysts which can be visible on standard bedside films. High airway pressures doubtless engender barotrauma, but contrary to earlier thinking, it is more likely that high plateau (pause) pressures rather than peak airway pressures are predictive of this complication (*Hasan , 2010*)

#### **b- Volutrauma:**

*Dreyfuss et al. (1988)* introduced the term volutrauma in 1988, after demonstrating that lung volume was the major determinant of increased lung water. In this study the consequences of normal tidal

volume ventilation in mechanically ventilated rats at a high airway pressure were compared with those of high tidal volume ventilation at high or low airway pressures. High pressure, low volume-ventilated rat lungs were not different from those of controls.

By contrast, the lungs from the groups submitted to high volume ventilation had significant permeability type edema. It has now become understood that transpulmonary pressures in the excess of 35 cm H<sub>2</sub>O can cause overdistension injury to the lungs. Moreover, further research has lead investigators to realize that in severe acute respiratory distress syndrome (ARDS), as little as 30% of lung units may remain healthy. The previous practice of using high tidal volumes, although tolerated by normal lungs, are now known to be the cause of much overdistension injury to these “baby lungs” (*Gattinoni et al., 2001*).

**c-Biotrauma:**

In addition to the previously mentioned mechanisms of ventilator-associated lung injury, mechanical ventilation may initiate mediator-related lung damage. *Zhang et al.(2002)* demonstrated that polymorphonuclear leucocytes can be activated by conventional high-volume mechanical ventilation, as manifested by a significant increase in oxidant production, CD18, and CD63 surface expression, and shedding of L-selectin. They further demonstrated that these findings could be avoided by using lung-protective strategies.

**III-Delayed Complication:**

**(1)- Sinusitis**

Sinusitis is a relatively recently recognized complication of endotracheal intubation. Nasotracheal intubation is especially likely to result in sinusitis. Sinusitis can also occur as a consequence of the

mucosal inflammation that nasogastric tubes produce. Bacterial sinusitis may be an important cause of nosocomial pneumonia (*Hasan , 2010*).

### **(2)- Tracheoesophageal Fistula**

Tracheoesophageal fistula occurs in less than 1% patients, but carries with it an extremely high mortality. High endotracheal tube cuff pressure can compromise the capillary perfusion of the tracheal mucosa and lead to ischemic necrosis. Tracheal mucosal injury can be quite insidious and a fistula can go unrecognized until it is quite large. Air leakage around the cuff or a substantial increase in tracheal secretions may be the first sign of development of a tracheoesophageal fistula. Seepage of feeds through the fistula into the trachea can lead to bouts of coughing during feeding and sometimes to the emergence of the food material out of a tracheostomy. Distension of the abdomen due to passage of ventilated air through the fistulous communication into the stomach may also occur. Passage of gastric contents through the fistula into the tracheobronchial tree resulting in pulmonary injury is a recognized complication (*Hasan , 2010*).

### **(3)- Tracheocutaneous Fistula**

This is a rare complication, usually following protracted use of a tracheostomy tube, which causes the tracheostomy stoma to become epithelialized. Dermal inflammation with the chronic discharge is often troublesome; difficulty in phonation may also occur. The patient may show vulnerability to recurrent lower respiratory tract infection (*Lourens et al., 2000*).

### **(4)- Adsorptive Atelectasis**

The partial pressure of oxygen is lower in the alveoli than in the pulmonary capillary blood. As a result, if a portion of the lung parenchyma gets sequestered from its connections with the tracheobronchial tree due to obstruction in the airways (such as a mucus



plug), the oxygen contained within the obstructed segment of the lung is rapidly absorbed into the pulmonary circulation. This results in a loss of volume of the obstructed lung or lobe. Oxygen is absorbed much more rapidly than nitrogen. Therefore, if bronchial obstruction occurs in a patient breathing high fractions of oxygen, absorption is much faster and collapse of the obstructed segment much more rapid (*Vallverdu et al ., 1998*).

#### **(5)- Hyperoxic Hypercarbia**

In normal individuals breathing supplemental oxygen, a slight stimulation of ventilation occurs due to the Haldane effect . Traditional teaching has it that the respiratory center of the COPD patients is accustomed to the relatively high level of PaCO<sub>2</sub> that such patients frequently accumulate; the respiratory drive having been blunted by its constant exposure to the elevated PaCO<sub>2</sub>, the respiratory center relies on a degree of hypoxia to stimulate it. It has been widely advocated that COPD patients be guarded from high levels of supplemental oxygen, which could theoretically abolish the hypoxic drive that is necessary for them to breathe. Although hypercapnia undoubtedly does occur in situations where COPD patients are administered high-flow oxygen, there has been considerable rethinking about the possible underlying mechanisms (*Sternfeld and Wright ,2003*).

#### **(6)- Diffuse Alveolar Damage**

Molecular O<sub>2</sub> by itself is relatively innocuous, but when reduced to reactive oxygen radicals, such as the superoxide anion (O<sub>2</sub><sup>-</sup>), the hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), and the hydroxyl radical (OH<sup>-</sup>), can cause tissue injury . Because of their avidity for electrons, the toxic free radicals tend to rob the nearby enzymes, lipids, and DNA of electrons, thereby inactivating them. In particular, the hydroxyl radical and the peroxy nitrite anion (the

latter is the product of the reaction between H<sub>2</sub>O<sub>2</sub> and NO-) can prove severely damaging (*Hasan , 2010*).

**(7)- Bronchopulmonary Dysplasia**

Described by Northway in 1969, this condition occurs as a result of poorly understood pathologic pathways in premature infants who have received high concentrations of oxygen for several days. Characterized by necrotizing bronchiolitis, squamous metaplasia of the bronchial lining cells, thickening of alveolar walls, and peribronchial and interstitial fibrosis, this entity results in oxygen dependence of the infant for at least a month, but more usually for up to 6 months after birth. Although symptoms generally resolve by the age of 2 years, evidence of pulmonary dysfunction can persist, usually in the form of lung function abnormalities, for several years (*Hasan , 2010*).

**(8)-Ventilator-associated pneumonia (VAP)**

VAP is a life-threatening complication with mortality rates of 33-50%. It is reported to occur in 10-25% of patients given mechanical ventilation. The risk of VAP is highest immediately after intubation. VAP is estimated to occur at a rate of 3% per day for the first 5 days, 2% per day for next 5 days, and 1% per day thereafter. VAP occurs more frequently in trauma, neurosurgical, or burn units than in respiratory units and medical ICUs.

VAP is defined as a new infection of the lung parenchyma that develops within 48 hours after intubation. The diagnosis can be challenging. VAP should be suspected when a new or changing pulmonary infiltrate is seen in conjunction with fever, leukocytosis, and purulent tracheobronchial secretions. However, many diseases can cause this clinical presentation. Examples include aspiration pneumonitis, atelectasis, pulmonary thromboembolism, drug reactions, pulmonary

hemorrhage, and radiation-induced pneumonitis. Qualitative and quantitative cultures of protected brush and bronchoalveolar lavage specimens may help with the diagnosis, but the utility of these techniques is still debated (*Byrd and Roy, 2008*).

Microorganisms implicated in VAP that occurs in the first 48 hours after intubation are flora of the upper airway, including *Haemophilus influenzae* and *Streptococcus pneumoniae*. After this early period, gram-negative bacilli such as *Pseudomonas aeruginosa*; *Escherichia coli*; and *Acinetobacter*, *Proteus*, and *Klebsiella* species predominate. *Staphylococcus aureus*, especially Multi-Resistant *Staph aureus* (MRSA), typically becomes a major infective agent after 7 days of intubation and mechanical ventilation. Most of the medical literature recommends initial therapy with broad-spectrum antibiotics that cover pathogens resistant to multiple drugs until the sensitivities of the causative organism are identified. Knowledge of organisms that cause VAP in the individual ICU and the pattern of antibiotic resistance is imperative. Choices of antibiotics should be tailored to the microorganisms and the antimicrobial resistance observed in each ICU (*Byrd and Roy, 2008*).

### **Lung-protective ventilatory strategies**

A lung-protective strategy aims to avoid the aforementioned mechanisms of ventilator-associated lung injury. This may be achieved by using low tidal volumes to avoid overdistension (6–8mL/kg), enough PEEP to avoid atelectasis and atelectrauma, permissive hypercapnia, and (more recently) the implementation of lung recruitment maneuvers to maintain an “open lung” (*Mancini et al., 2001*).

Studies have suggested that PEEP could be better targeted according to the slope of deflation-limb compliance, because this measure may

more accurately reflect global alveolar closing pressures. That is, setting PEEP levels according to the deflation curve may be a method that points out the pressure below which the lung units start to close. This is as opposed to the inflation curve in which the lower inflection point rather denotes the pressure at which the lungs start to open (*Kallet, 2003*).

Another subsequent study assessed the effects of a lung-protective ventilation strategy that combined both volume- and pressure-limited and open-lung approaches. Patients were randomized to either a conventional study group receiving tidal volumes of approximately 12 ml/kg of measured body weight and mean PEEP of approximately 8 cm H<sub>2</sub>O during the first 7 days, or to a lung-protective ventilation group receiving initial tidal volumes of approximately 6 ml/kg of measured body weight. Tidal volumes were decreased further in the lung protective group if inspiratory airway pressures exceeded 40 cm H<sub>2</sub>O. The mean PEEP level in the lung-protective ventilation group was 16.4 cm H<sub>2</sub>O during the first 36 h. Recruitment maneuvers that sustained increases in airway pressure at 35–40 cm H<sub>2</sub>O were used in the lung-protective ventilation group to reverse atelectasis of some lung units. Survival, rate of weaning from mechanical ventilation, and frequency of barotrauma events were improved in the lung-protective ventilation group (*Amato et al., 1998*).

Recruitment maneuvers attempting to “open” the lung and keep it open have been described in a multitude of forms 32–34 and may provide a basis for a readily available and low-cost modality of treatment for patients with ARDS and acute lung injury. The basic idea behind the various designs of these maneuvers is to inflate the atelectatic lung to a volume that ensures opening of most lung units, and avoiding its return to atelectasis (*Frank et al., 2005*).

## **Difficult Weaning**

Prolonged mechanical ventilation (Ventilator dependence) is defined as the need for continual assistance from a mechanical ventilator for at least 6 h/d for at least 21 days. There are numerous factors that may contribute to ventilator dependency in patients intubated for acute respiratory failure.

### **A) Systemic Factors**

patients with prolonged mechanical ventilation have persistently high severity illness and frequently have important comorbid conditions (e.g., COPD) that likely contribute to persistent weaning failure (*Chan et al., 1999*).

### **B) Mechanical Factors**

These factors include abnormalities in respiratory drive, increased work of breathing (resistive, elastic, intrinsic PEEP), decreased respiratory muscle capacity, cardiovascular factors (ischemia, pulmonary edema), and psychological factors (*Jubran et al., 1997*).

### **C) Iatrogenic Factors**

abnormalities of the upper airway resulting from complications of the artificial airway can contribute to ventilator dependence. Ten percent of patients with prolonged mechanical ventilation will develop tracheal injury despite the use of artificial airways with low-pressure, high-volume cuffs. Tracheal injury at or above the level of the tracheal tube is typically clinically silent until the time of extubation or decannulation (*Rumbak et al., 1997*).

### **D) Process of Care Factors**

Data from several studies suggest that the ability of a center to liberate patients from mechanical ventilation is related to the caregivers' skills with patients on prolonged mechanical ventilation. Absence of a

structured approach to weaning (a weaning protocol) may increase the number of patients requiring prolonged mechanical ventilation (*Bagley and Cooney , 1997; Rothenhausler et al., 2000*).

**Table(5):Mechanisms Associated With Ventilator Dependence**  
*(MacIntyer et al., 2005)*

<b>Systemic factors</b>
-Chronic comorbid conditions (e.g malignancy, COPD) -Overall severity of illness -Nonpulmonary organ failure -Poor nutritional status
<b>Mechanical factors</b>
-Increased work of breathing -Reduced respiratory muscle capacity -Critical illness polyneuropathy -Steroid myopathy &Disuse myopathy -Isolated phrenic nerve/diaphragmatic injury. -Imbalance between increased work of breathing and respiratory muscle capacity -Upper airway obstruction (e.g tracheal stenosis) preventing decannulation
<b>Iatrogenic factors</b>
-Failure to recognize withdrawal potential -Inappropriate ventilator settings leading to excessive loads/discomfort -Imposed work of breathing from tracheotomy tubes -Medical errors
<b>Complications of long-term hospital care</b>
-Recurrent aspiration -Infection (e.g., pneumonia, sepsis) -Stress ulcers -Deep venous thrombosis -Other medical problems developing in the PMV care venue
<b>Psychological factors</b>
Sedation -Delirium -Depression -Anxiety -Sleep deprivation
<b>Process of care factors</b>
-Absence of weaning (and sedation) protocols -Inadequate nursing staffing -Insufficient physician experience

In most studies, weaning failure is defined as either the failure of SBT or the need for reintubation within 48 h following extubation (*Vallverdu et al., 1998*).

**Failure of SBT is defined by:**

- 1) Objective indices of failure, such as tachypnea, tachycardia, hypertension, hypotension, hypoxemia or acidosis, arrhythmia.
- 2) Subjective indices, such as agitation or distress, depressed mental status, diaphoresis and evidence of increasing effort (*Ely et al., 1996*).

Failure of a SBT is often related to cardiovascular dysfunction or inability of the respiratory pump to support the load of breathing. Extubation failure may be related to the same causes, in addition to upper airway obstruction or excessive secretions (*Epstein, 2002*).

Failure of extubation is associated with high mortality rate, either by selecting for high-risk patients or by inducing deleterious effects such as aspiration, atelectasis and pneumonia. Interestingly, mortality is not especially increased when failure of extubation is related to upper airway obstruction (one out of nine patients; 11%) but is markedly increased in the other cases (19 out of 52 patients; 36%) (*Esteban et al., 1995*).

Predictors of extubation failure have been reported such as excess secretions, arterial carbon dioxide tension ( $\text{PaCO}_2$ ) > 45 mmHg, duration of mechanical ventilation >72 h upper airway disorders and a prior failed weaning attempt. Weaning success is defined as extubation and the absence of ventilatory support 48 h following the extubation. Weaning failure is defined as one of the following: Failed SBT, reintubation and/or resumption of ventilatory support following successful extubation and death within 48 h following extubation (*Carlucci et al., 2001*).

**Table(6):** Common pathophysiologies and their incidence, which may impact on the ability to wean a patient from mechanical ventilation (*MacIntyer et al., 2005*)

<b>Pathophysiology</b>	<b>Consider</b>
<i>Respiratory load</i>	Increased work of breathing: inappropriate ventilator settings
	Reduced compliance: pneumonia (ventilator-acquired); cardiogenic or noncardiogenic edema; pulmonary
	fibrosis; pulmonary hemorrhage; diffuse pulmonary infiltrates
	Airway bronchoconstriction
	Increased resistive load
<i>Cardiac load</i> <i>Neuromuscular</i>	During SBT: endotracheal tube
	Post-extubation: glottic edema; increased airway secretions; sputum retention
	Cardiac dysfunction prior to critical illness
	Increased cardiac workload leading to myocardial dysfunction: dynamic hyperinflation; increased metabolic
	demand; unresolved sepsis
	Depressed central drive: metabolic alkalosis; mechanical ventilation; sedative/hypnotic medications
	Central ventilatory command: failure of the neuromuscular respiratory system
<i>Neuropsychological</i>	Peripheral dysfunction: primary causes of neuromuscular weakness; CINMA
	Delirium
	Anxiety, depression
<i>Metabolic</i>	Metabolic disturbances
	Role of corticosteroids
	Hyperglycemia
<i>Nutrition</i>	Overweight
	Malnutrition
	Ventilator-induced diaphragm dysfunction
	Anemia



## **Patients and Methods**

The study was conducted on 60 patients and divides randomly into 3 group according to weaning method. It included 19 patients suffering from ARDs, 14 patients suffering from pneumonia, 8 patients suffering from cardiogenic pulmonary oedema ,7 patients suffering from post blood transfusion hypoxia, 7 patients suffering from acute lung injury, 5 patients suffering from post operative hypoxemia.

### **Patients:**

Our study included 60 patients suffering from acute Hypoxemic respiratory failure.

### **Inclusion criteria:**

- Males and females admitted with hypoxic respiratory failure such as “ARDS, pneumonia, acute lung injury, postoperative hypoxemia and cardiogenic pulmonary oedema” and requiring ventilatory support as determined by the clinical condition and blood gases.
- Patients with no more than two systems failure.

### **Exclusion criteria:**

- Extremes of age (below 15 or above 70).
- More than two system failure.
- Moribound terminal irreversible condition in the respiratory system e.g. bronchogenic carcinoma.
- Patients suffering from obstructive lung diseases and patients with hypercapnic respiratory failure such as COPD.
- Patients requiring intubation and ventilation for non respiratory reasons e.g. cardiac arrest or hyperventilation in neurosurgical patients.

- Patients with exclusion criteria for measurement of respiratory mechanics (presence of chest tube with air leak, open or flail chest).
- Unconscious or uncooperative patients.

## **Methods:**

All patients included in the study were subjected to:

- Detailed medical history (from patients if possible or relatives)
- Full general and local examination.
- Twelve lead electrocardiogram.
- Monitoring the patients by continuous ECG monitoring, non invasive blood pressure pulse oximetry.
- Central venous line inserted through the internal jugular or subclavian vein.
- Arterial cannulation through the radial or dorsalis pedis artery for sampling.
- Arterial blood gas sampling at least twice daily.
- Full laboratory investigations. Complete blood count, random blood sugar, liver function tests, kidney function tests, electrolyte levels Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>++</sup>, Ca<sup>++</sup>, Phos) as needed.
- Daily chest x-ray.
- All patients intubated with appropriate sized endotracheal tubes using a sedative dose of propofol and the patients subjected to endotracheal suctioning at least once hourly.
- Patients were ventilated using Puritan-Bennett 840 and Dräger Evita 4 ventilators .

**patients were put on the initial ventilator settings :**

- Tidal volume : 5 ml /kg.
- Respiratory rate : 12-15 breath/min.
- I : E ratio , 1: 2.
- Fio2: 100% .
- Inspiratory flow rate: 60 L/min.
- Inspiratory flow profile: declerating ramp.
- PEEP 5 cm H2O
- Trigger sensitivity: pressure trigger: 1 cm H2O.
- Modes of ventilation: ASV.

After fullfiled criteria of weaning according to Physiological parameters that suggest weaning is possible (table 4-1) the patients then were divided into three equal groups each consists of 20 patients put on one of the three weaning modes Pressure support ventilation (PSV) , Synchronized intermittent mandatory ventilation (SIMV) and Biphasic Positive Airway Pressure (BIPAP).

**1)Group I (n=20 patients) Weaning by PSV:**

This method of weaning is probably the method of choice for most patients. It involve turning the patient to PSV mode with a level insuring adequate VT and respiratory rate of less than 30 followed by gradual decrease of the level of inspiratory pressure support until the patient is breathing spontaneously with virtually no assist .Gradually deacreate the PS level by 2-3 cm H2O.When a PS level of<5-8 cm H2O is reached,the patient can extubated.It can be combined with SIMV (*Fiaastro et al.,1988*).

**2)Group II (n=20 patients) Weaning by SIMV:**

This is a method of weaning that was extremely popular in the 1980s, but seems to have fallen out of popularity towards the turn of the century. This method entails gradual decreasing of the rate of mandatory breaths during SIMV ventilation until the patient is spontaneously breathing. The disadvantage of this method is mainly that it forces the patient to breath through ademand valve, which can impose a great amount of additional work of breathing (*Christopher et al.,1985*).

**3)Group III (n=20 patients) Weaning by BIPAP:**

It is pressure controlled ventilation. Two pressure level (PH&PL),inspiratory time at PH & expiratory time at PL or TH/TL ratio.weaning is done bydecreasing the ventilation pressure until the difference between the( P high & P low) is 5 cm H2O (*Marini, 1998*).

**Table (7):Physiological parameters that suggest weaning is possible**  
(*Marini, 1998*)

<b>Tests of mechanical abilities:</b>	
Maximal inspiratory pressure	>-20 cmH2O
Vital capacity	>15 ml/kg
FEV1	>10 ml/kg
Resting VE	<10 L/min
Compliance on ventilator	>30 ml/cmH2O
MVV	Twice spontaneous VE
Spontaneous VT	>5 ml/kg
Spontaneous respiratory	<30 breaths /min and >6
Rate	breaths/min
Rate: VT ratio	<100
<b>Tests for gas exchange</b>	

PaO <sub>2</sub> on ≤ 40%FiO <sub>2</sub>	≥ 60 mmHg
PaCO <sub>2</sub>	<50 mmHg in absence of metabolic alkalosis
PaO <sub>2</sub> /FiO <sub>2</sub>	>200
PaO <sub>2</sub> /PAO <sub>2</sub>	>0.20
QS/QT	<0.15
VD/VT	<0.60

Indicators that a patient should be returned to mechanical ventilation during weaning reported in the following table.

**Table (8):** Indicators that a patient should return to mechanical ventilation during weaning (*Hess, 1997*)

<b>Indicator</b>	<b>Magnitude</b>
Blood pressure	Change >20 mmHg systolic or 10mmHg diastolic
Pulse	Heart rate increase >20 beats/min
Respiratory rate	Increase of 10 breaths/min or rate >30/min
Tidal volume	<250 ml
Rate to tidal volume ratio	>100
MIP	A drop indicates respiratory muscle fatigue
Breathing pattern	Dyscoordinate breathing indicates respiratory muscle fatigue
PaO <sub>2</sub>	<60 mmHg
PaCO <sub>2</sub>	Increase greater than 10mmHg from baseline

PH	Decrease greater than 0.10 from baseline
Significant ECG changes	Increased ectopy

In practical terms, dynamic compliance is the volume change divided by the peak inspiratory transthoracic pressure, and static compliance is the volume change divided by the plateau inspiratory transthoracic pressure.

Therefore static compliance is usually greater than dynamic compliance, because the former calculation uses a small denominator (lower pressure) than the latter. However, if the patient is receiving PEEP, this must be first subtracted from the peak or plateau pressure before calculating the compliance.

$$\text{Compliance} = \frac{\text{volume delivered}}{\text{Peak or plateau pressure} - \text{PEEP}}$$

When peak pressure is reached, immediately close off the exhalation side of ventilator circuit. Turn inspiratory pause up until measured static compliance is read on graphic screen. Immediately turn down to expiratory pause until measured static compliance disappears. Record positive end expiratory pressure (PEEP) from end expiratory pressure display.

Calculate dynamic and static compliance using the following formulas:

- Dynamic compliance =

$$\frac{\text{exhaled tidal volume}}{\text{cm H}_2\text{O peak inspiratory pressure} - \text{PEEP}}$$

- Static compliance =

$$\frac{\text{exhaled tidal volume}}{\text{cm H}_2\text{O plateau pressure} - \text{PEEP}}$$

## **Results of the study**

This study was carried on sixty patients suffering from acute hypoxemic respiratory failure. The patients' age was ranged from 15 to 70 years. All patients admitted as hypoxic respiratory failure “ such as ARDS, pneumonia, acute lung injury, postoperative hypoxemia and cardiogenic pulmonary oedema”, requiring ventilatory support as determined by the clinical condition and blood gases and with no more than two systems failure.

### **Patients were put on the initial ventilator settings :**

- Tidal volume : 5 ml /kg.
- Respiratory rate : 12-15 breath/min.
- Inspiratory: Expiratory ratio; 1:2.
- O<sub>2</sub> concentration: 100%.
- Inspiratory flow rate: 60 L/min.
- Inspiratory flow profile: declerating ramp.
- Trigger sensitivity: pressure trigger: 1 cm H<sub>2</sub>O.
- Modes of ventilation: ASV.

After fullfilled criteria of weaning according to Physiological parameters that suggest weaning is possible (table 5-1) the patients then were divided into three equal groups each consists of 20 patients and were put on one of the three weaning modes (PSV, BIPAP and SIMV).

- 1) Group I (no=20 patients) Weaning by PSV.
- 2) Group II (no=20 patients) Weaning by BIPAP.
- 3) Group III (no=20 patients) Weaning by SIMV.



**Table (9):** Physiological parameters that suggest weaning is possible

<b>Tests of mechanical abilities:</b>	
Maximal inspiratory pressure	>-20 cmH <sub>2</sub> O
Vital capacity	>15 ml/kg
FEV1	>10 ml/kg
Resting VE	<10 L/min
Compliance on ventilator	>30 ml/cmH <sub>2</sub> O
MVV	Twice spontaneous VE
Spontaneous VT	>5 ml/kg
Spontaneous respiratory Rate	<30 breaths /min and >6 breaths/min
Rate: VT ratio	<100
<b>Tests for gas exchange</b>	
PaO <sub>2</sub> on ≤ 40%FiO <sub>2</sub>	≥ 60 mmHg
PaCO <sub>2</sub>	<50 mmHg in absence of metabolic alkalosis
PaO <sub>2</sub> /FiO <sub>2</sub>	>200
PaO <sub>2</sub> /PAO <sub>2</sub>	>0.20
QS/QT	<0.15
VD/VT	<0.60

The clinical data were recorded on a report form. These data were tabulated and analyzed using the computer program SPSS (Statistical package for social science) version 16 to obtain:

### **Descriptive data**

Descriptive statistics were calculated for the data in the form of:

1. Mean and standard deviation ( $\pm SD$ ) for quantitative data.
2. Frequency and distribution for qualitative data.

**Analytical statistics**

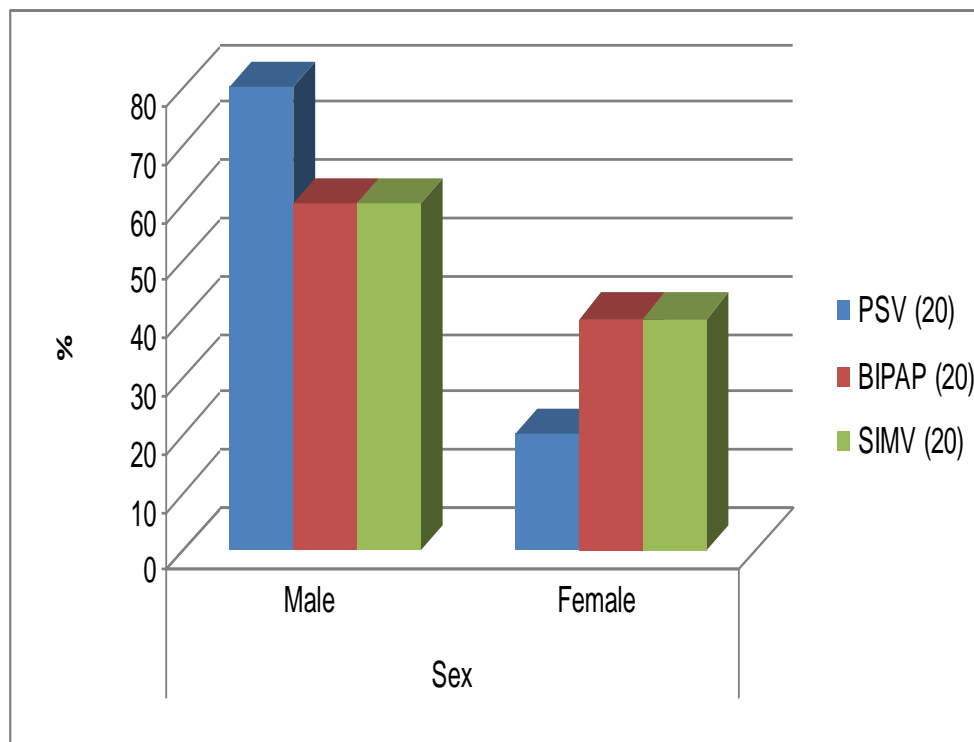
In the statistical comparison between the different groups, the significance of difference was tested using one of the following tests:

- 1- F test (Test of ANOVA):- Used to compare mean of more than two groups of quantitative data.
- 2- Inter-group comparison of categorical data was performed by using fisher exact test (FET).

**N.B.** A *P* value <0.05 was considered statistically significant (S) ,while >0.05 statistically insignificant and *P* value <0.001 was considered highly significant (HS) in all analyses.

**Evaluation of demography and its relationship to final outcome:**

According to results of this study there were no significant differences (*P* value >0.05) between PSV, BIPAP and SIMV as regards Sex (Fig.22) , Age and Height (Fig.23).



**Fig. (22 ):**Sex ratio among groups

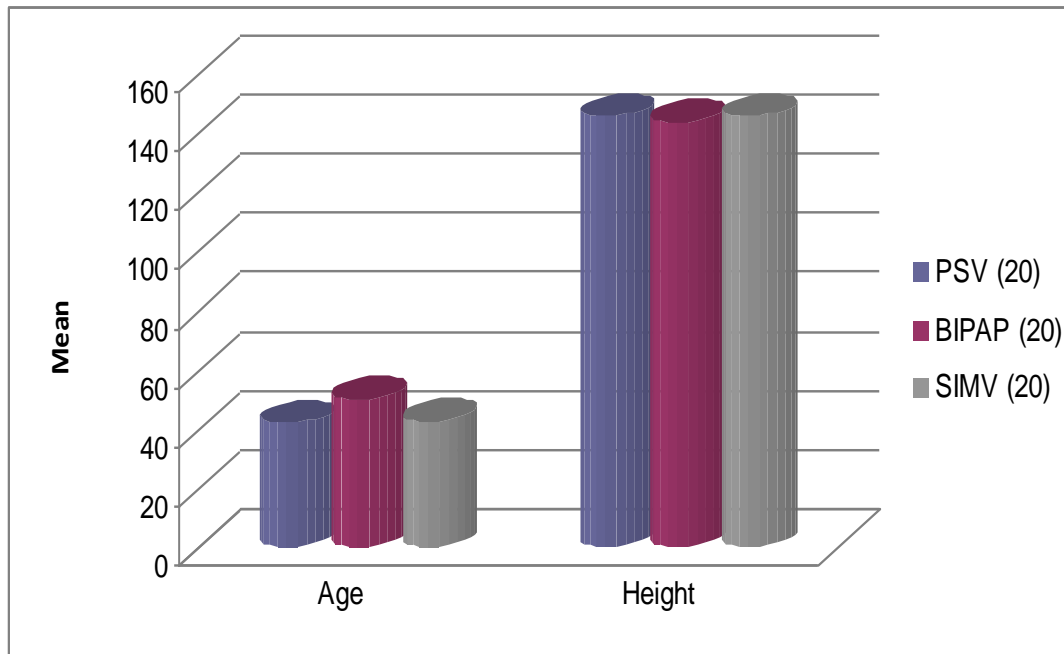


Fig. ( 23 ) :Age and Height ratio among groups

**Evaluation of associated diseases and its relationship to final outcome:**

There were no significant differences (P value > 0.05) between PSV, BIPAP and SIMV as regards smoking, DM, hypertension and IHD. Fig. (24).

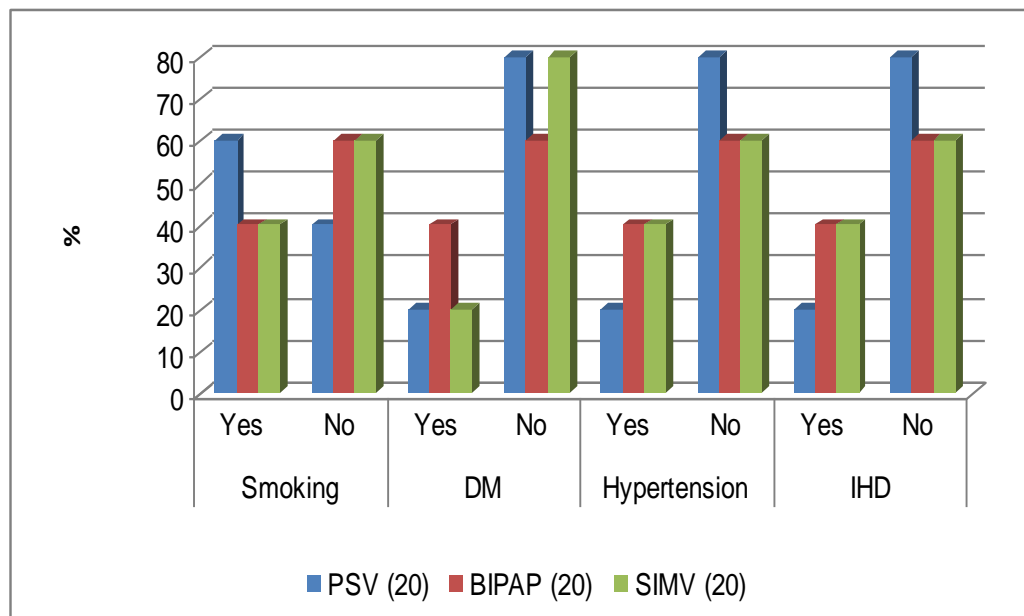


Fig. ( 24 ): Associated diseases ratio among groups

**Evaluation of blood gases and its relation to final outcome:**

According to results of this study there were no statistically significant differences (P value > 0.05) between PSV, BIPAP and SIMV as regards PH, PO<sub>2</sub>, O<sub>2</sub> saturation and Pao<sub>2</sub>/ Fio<sub>2</sub> and PCO<sub>2</sub> due to case selection type 1 respiratory failure (table:10).

**Table (10):** ABG Parameters of the successfully weaned patients in relation to the mode of ventilation

	<b>PSV</b> (Mean ±SD)	<b>BIPAP</b> (Mean ±SD)	<b>SIMV</b> (Mean± SD)	<b>F</b> <b>test</b>	<b>P</b> <b>value</b>	<b>P1</b> <b>(PSV&amp;</b> <b>BIPAP)</b>	<b>P2</b> <b>(PSV&amp;</b> <b>SIMV)</b>	<b>P3</b> <b>(BIPAP&amp;</b> <b>SIMV)</b>
<b>PH</b>	7.35± 0.046	7.37± 0.041	7.35± 0.047	1.66	0.198 NS	0.154 NS	0.786 NS	0.092 NS
<b>PO<sub>2</sub>(m</b> <b>mHg)</b>	75.0± 16.04	70.0±1 0.69	65.0± 4.08	0.89 8	0.426 Ns	0.258 NS	0.397 NS	0.475 NS
<b>O<sub>2</sub></b> <b>saturati</b> <b>on %</b>	95.0± 3.5	92.5± 2.97	92.2± 4.02	3.13	0.053 Ns	0.057 NS	0.055 NS	0.805 NS
<b>Pao<sub>2</sub>/Fi</b> <b>O<sub>2</sub>%</b>	375.0± 4.08	351.67 ±71.39	339.0± 66.84	0.54 7	0.584 NS	0.534 NS	0.302 NS	0.616 NS
<b>PCO<sub>2</sub>(</b> <b>mmHg)</b>	41.5± 0.89	40.0± 3.65	40.0± 5.62	0.75 2	0.477 Ns	0.121 NS	0.299 NS	1.0 NS

**Evaluation of respiratory mechanics and its relation to final outcome**

According to results of this study there were no statistically significant differences (P value > 0.05) between PSV, BIPAP and SIMV as regards tidal volume , RR/ TV and negative inspiratory pressure (NIP). Table ( 11).

**Table (11):** Respiratory mechanics of the successfully weaned patients in relation to the mode of ventilation

	<b>PSV</b> (Mean ±SD)	<b>BIPAP</b> (Mean±SD)	<b>SIMV</b> (Mean±SD)	<b>F test</b>	<b>P value</b>	<b>P1</b> (PSV& BIPAP)	<b>P2</b> (PSV& SIMV)	<b>P3</b> (BIPAP & SIMV)
<b>Tidal volume/ml</b>	460.0±41.68	450.0±79.47	441.0±40.77	2.53	0.088 NS	0.621 NS	0.105 NS	0.155 NS
<b>RR (cycle/min)</b>	14.0±0.816	16.67±1.78	19.8±6.53	3.74	0.034 S	0.096 NS	0.041 S	0.096 NS
<b>RR/TV</b>	37.0±0.816	45.67±16.1	52.0±8.55	1.91	0.174 NS	0.057 NS	0.311 NS	0.323 NS
<b>NIP(mmHg)</b>	23.75±2.24	22.5±2.67	20.4±5.76	2.77	0.074 NS	0.239 NS	0.336 NS	0.135 NS
<b>Static compliance</b>	63.75±2.24	57.5±5.77	48.0±2.51	155.01	0.031 S	0.021 S	0.031 S	0.061 NS
<b>Dynamic compliance</b>	55.62±3.59	51.25±7.64	40.0±5.62	34.88	0.03 S	0.047 S	0.021 S	0.055 NS
<b>Resistance</b>	14.75±3.96	17.5±4.47	19.0±2.05	6.46	0.03 S	0.051 NS	0.019 S	0.063 NS

From table (11) as regards respiratory rate there were significant differences between PSV/ SIMV (P value =0.041) but there were no significant differences between PSV/ BIPAP (P value=0.096) nor BIPAP/ SIMV (P value =0.096).

As regards static compliance there were statistical significant differences between PSV/ BIPAP (P value =0.021) and PSV/ SIMV (P value=0.031) but there were no significant differences between BIPAP/ SIMV (P value =0.061). Table(11), Fig.(25).

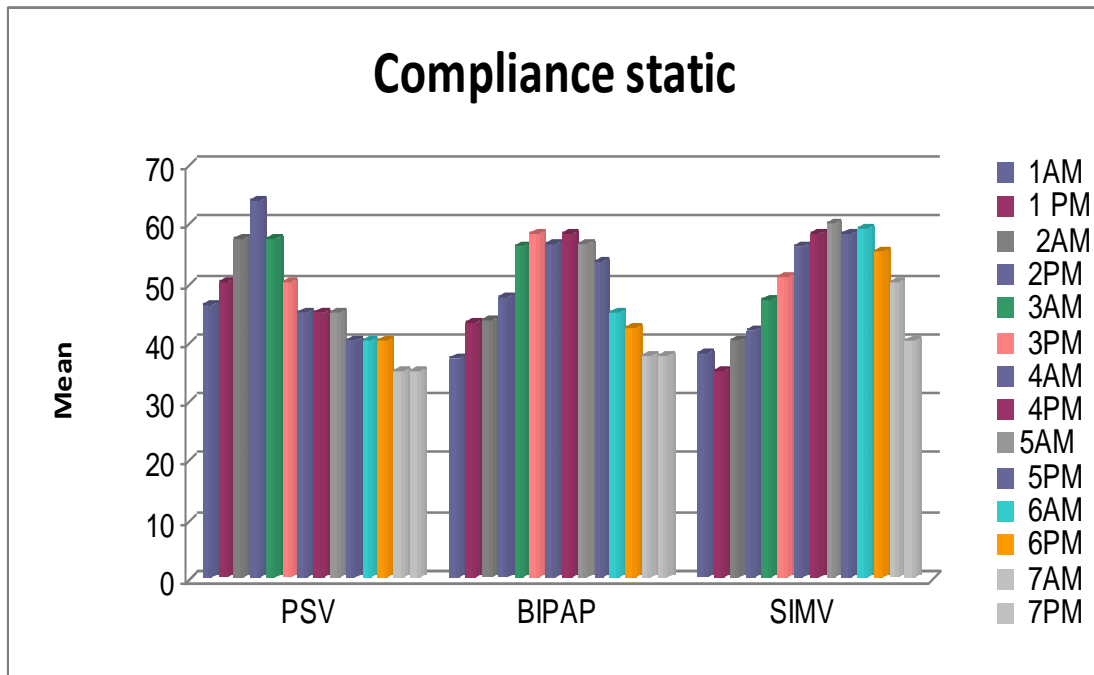


Fig. (25) Static compliance values among groups

As regards dynamic compliance there were statistical significant differences between PSV/ BIPAP (P value =0.047) and PSV/ SIMV (P value=0.021) but there were no significant differences between BIPAP/ SIMV (P value =0.055). Table(11), Fig.(26).

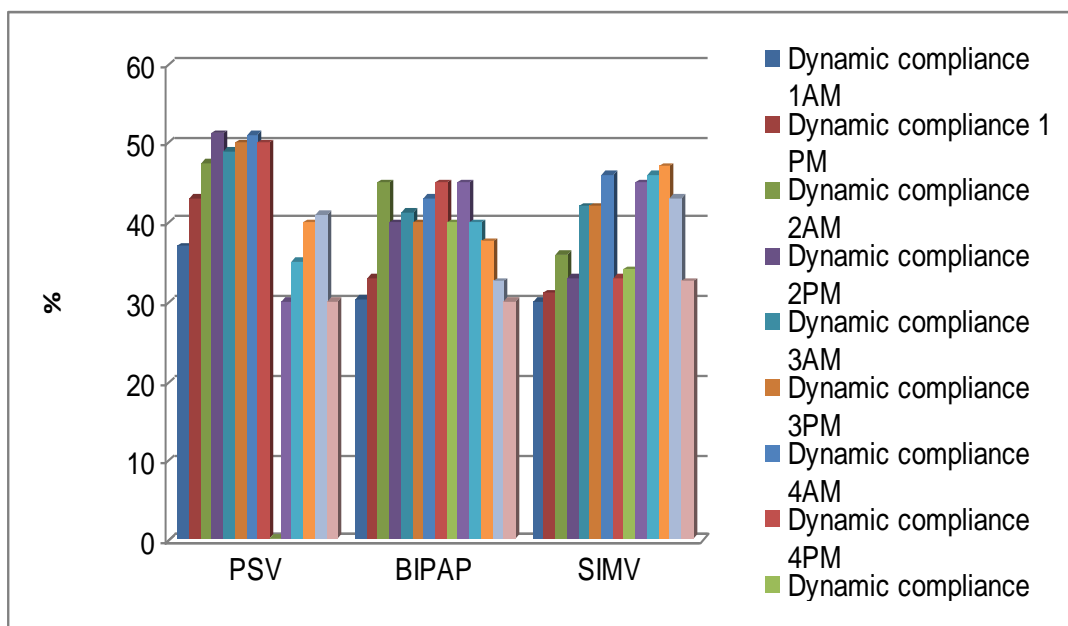
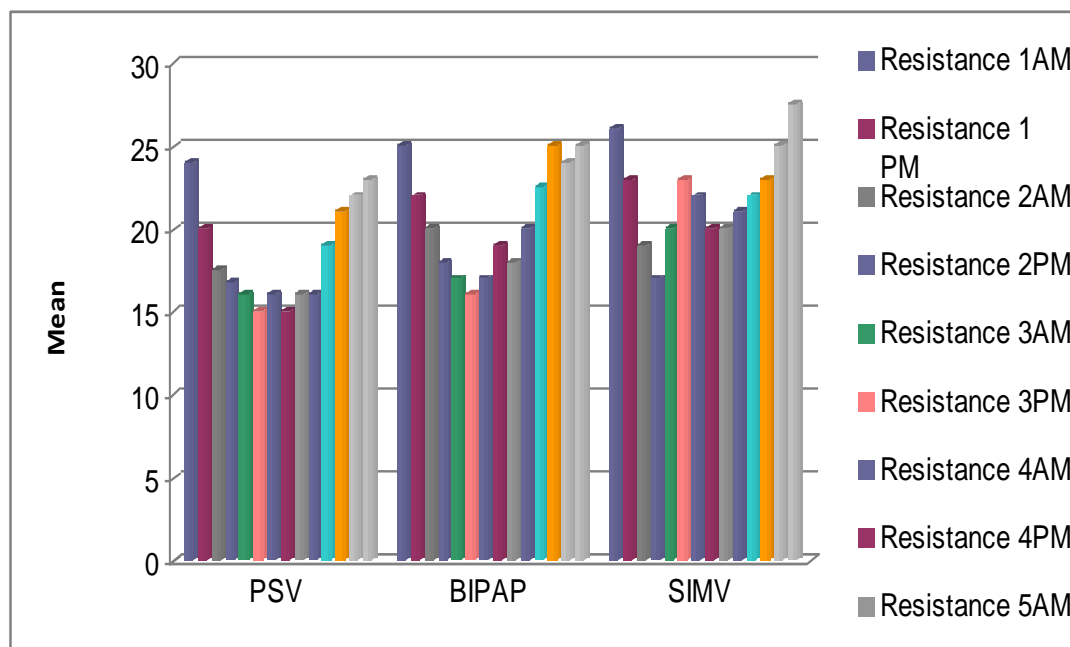


Fig. (26) Dynamic compliance values among groups

As regard resistance there were no statistical significant differences between PSV/ BIPAP (P value =0.051) and BIPAP/ SIMV (P value=0.063) but there were significant differences between PSV/ SIMV (P value =0.019). Table (11), Fig.(27).



**Fig. (27)** Resistance values among groups

**Evaluation of haemodynamics and its relation to final outcome:**

According to this study there were no statistically significant differences (P value > 0.05) between PSV, BIPAP and SIMV as regard mean arterial blood pressure (MAB) and heart rate (table :12).

**Table (12):** Haemodynamic Parameters of the successfully weaned patients in relation to the mode of ventilation

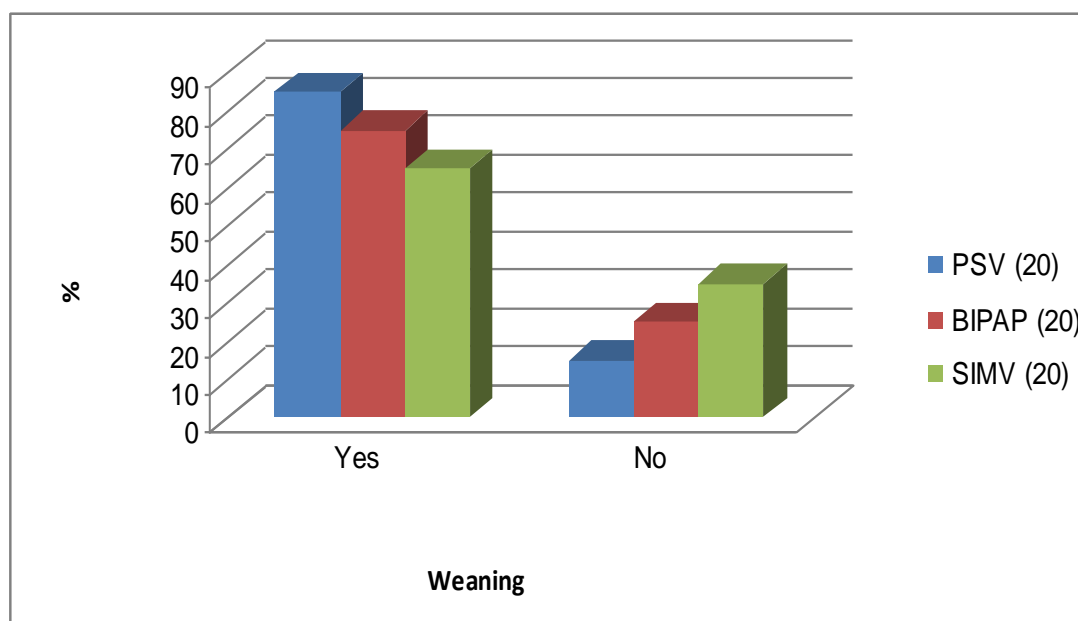
	PSV (Mean ±SD)	BIPAP (Mean± SD)	SIMV (Mean ±SD)	F test	P value	P1 (PSV& BIPAP)	P2 (PSV& SIMV)	P3 (BIPAP& SIMV)
<b>MAB (mm Hg)</b>	75.0± 4.08	80.0± 5.98	82.0± 11.18	0.92 3	0.413 NS	0.167 NS	0.25 NS	0.65 NS
<b>HR(b eat/m in)</b>	100.0± 9.13	100.06.4 9	93.33± 9.85	2.77	0.077 NS	0.254 NS	1.0 NS	0.058 NS

**Evaluation according to failure Evaluation according to failure rate :**

Results of this study showed that successfully weaned patients 75% occurred within a period  $\leq$  one week and 25% failed to be weaned. Number of successfully weaned patients in PSV 17 cases (17/20) 85% and weaning failure cases 3 cases (3/20) 15%. In BIPAP number of successfully weaned patients 15 cases (15/20) 75% and weaning failure 5 cases(5/20) 25%. In SIMV successfully weaned patients were 13 cases (13/20) 65% and failed patients 7 cases (7/20) 35% .Table (13),Fig.(28).

**Table (13) :**Comparison among groups as regard weaning success and failure

Weaning	PSV (20)		BIPAP (20)		SIMV (20)		Total	
	No	%	No	%	No	%	No	%
Yes	17	85.0	15	75.0	13	65.0	45	75.0
No	3	15.0	5	25.0	7	35.0	15	25.0
Total	20	100	20	100	20	100	60	100



**Fig.( 28) :**Comparison among groups as regard failure rate.



**Evaluation according to duration of weaning and number of patients weaned per day:**

As regard duration of weaning results of the study showed that patients on PSV weaned within (3.1±0.91) days, BIPAP(5.0±1.03) days and SIMV (6.0± 0.97) days. There were statistical significant differences as regard PSV/BIPAP (p value=0.011), PSV/SIMV (P value=0.021) and BIPAP/SIMV(P value=0.023) .Table (14), Fig (29).

**Table (14):** Duration of weaning

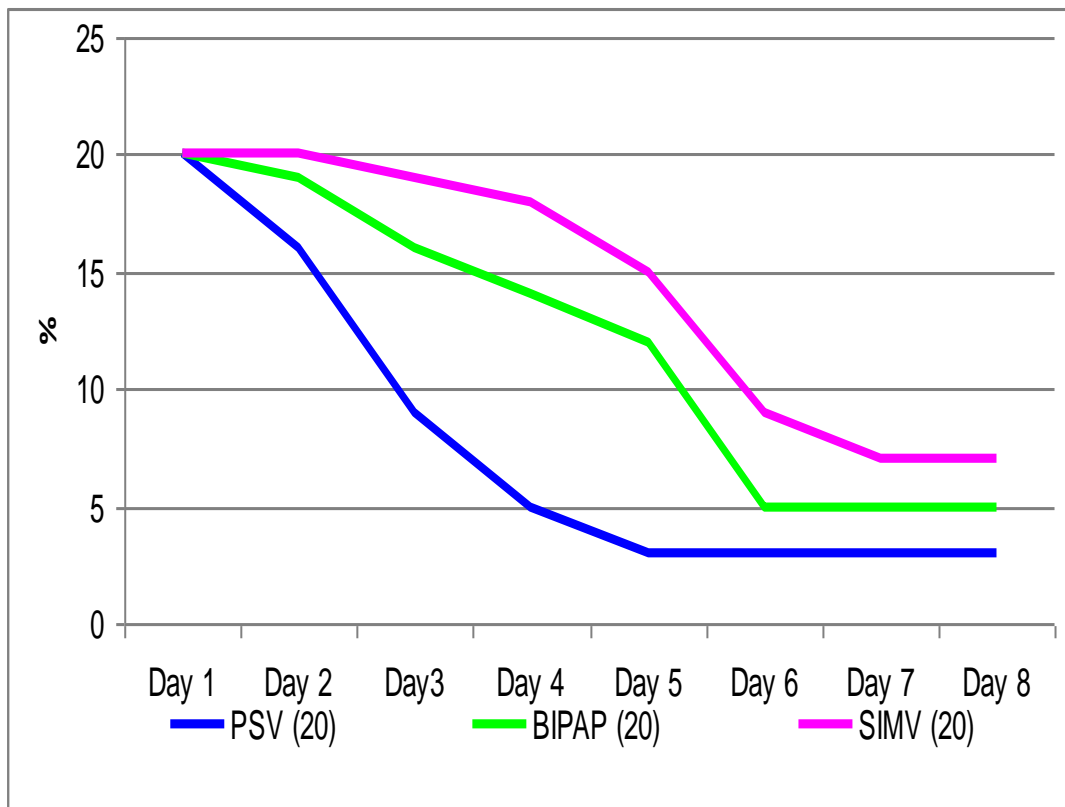
	<b>PSV</b> (Mean ±SD)	<b>BIPAP</b> (Mean ±SD)	<b>SIMV</b> (Mean ±SD)	<b>F</b> <b>test</b>	<b>P</b> <b>value</b>	<b>P1</b> (PSV& BIPAP)	<b>P2</b> (PSV& SIMV)	<b>P3</b> (BIPAP& SIMV)
Duration of weaning	3.1± 0.91	5.0± 1.03	6.0± 0.97	45. 98	0.021 S	0.011 S	0.021 S	0.023 S

**Fig. (29):** Duration of weaning

As regard number of patients weaned per day with PSV,BIPAP and SIMV weaning mode is shown in (table :15, Fig. 30).

**Table (15 ):** Number of patients weaned per day

	<b>PSV</b>	<b>BIPAP</b>	<b>SIMV</b>
<b>Day 1</b>	20	20	20
<b>Day 2</b>	16	19	20
<b>Day 3</b>	9	16	19
<b>Day 4</b>	5	14	18
<b>Day 5</b>	3	12	15
<b>Day 6</b>	3	5	9
<b>Day 7</b>	3	5	7
<b>Day 8</b>	3	5	7



**Fig.(30) :**Comparison between groups as regard number of patients weaned per day

## Discussion

Mechanical ventilatory support is one of the most common therapeutic interventions in the intensive care settings. Mechanical ventilation is used for patients with all types of respiratory difficulties who are unable to maintain adequate ventilation or oxygenation. The need for mechanical ventilation is usually the result of an imbalance between the ventilatory demand and the patients ability to meet the demands.

Prolonged mechanical ventilation is expensive and is associated with multiple complications. Thus it is advantageous to reduce support (wean) and extubate patients as soon as they are able to support their own respiratory requirement.

Determining when mechanical ventilation can be discontinued, and the patient extubated, is often a very difficult decision, which even the best clinician can not always correctly make. Regardless of the criteria used to make this decision, some patients will inevitably be misclassified, i.e. patients who can not sustained breathing on their own are extubated and require reintubation and patients who could have been successfully extubated are returned to mechanical ventilation. When patients are prematurely extubated and require reintubation, the clinician receive immediate feedback that their decision was incorrect, and the feedback may influence their subsequent decision-making.

Several criteria have been proposed to predict the outcome of weaning thus identifying the appropriate time to start weaning and avoid exposing patients who are not ready for weaning to unnecessary stress.

This study was carried on 60 patients suffering from acute hypoxaemic respiratory failure with an age range from 15 to 70 years. Out of 60 patients ,40 patients were males, 20 patients were females. Their body weights ranged from 45 to 90 kg and there were no statistically significant differences between the studied groups as regard demographic data and associated diseases.

Out of 60 patients 19 patients were suffering from ARDs they represent (32%) Of cases,14 patients were suffering from pneumonia they represent (23%)of cases, 8 patients were suffering from cardiogenic pulmonary oedema they represent (13%) of cases,7 patients were suffering from post blood transfusion hypoxia they represent (12%)of cases, 7 patients were suffering from acute lung injury they represent (12%) of cases and 5 patients were suffering from post operative hypoxemia they represent (8%) of cases.

This level of agreement is similar to that recorded by *Kelly and Mathay (2003)* they showed that 51% of the patients who need mechanical ventilation presented with pulmonary disease, 32% presented with neurological dysfunction and minority of cases diagnosed as cardiogenic pulmonary oedema 9%, and chest wall disease & surgical condition found in 8% of patients.

*Cockcroff and Dosman (1996)* also reported that most of the ICU patients needing mechanical ventilation presented with acute exacerbation of COPD and the minority presented with different etiology e.g. pulmonary edema, bronchial asthma, pulmonary fibrosis and neurological dysfunction.

This study showed that successfully weaned patients were 75% who were weaned within a period  $\leq$  one week and 25% of patients were failed to be weaned. Number of successfully weaned patients in PSV 17 cases (17/20) 85% and failed to be weaned cases were 3 cases (3/20) 15%. In BIPAP the number of successfully weaned patients 15 cases (15/20) 75% failed to be weaned cases were 5 cases (5/20) 25%. In SIMV successfully weaned patients were 13 cases (13/20) 65% and failed patients were 7 cases (7/20) they represent 35%.

**Menzies and Gibbons (2001)** reported 42.1% of 95 patients with acute respiratory failure due to different causes were successfully weaned in less than 14 days and 34.7% after 14 days.

**Kelly and Mathway (2003)** reported that when mortality rate were analyzed for time, the low rate was found in the patients with a neurological diseases who where requiring mechanical ventilation at 48 hours and this rate increased to 44% for those patients who required mechanical ventilation after one week.

As regard duration of weaning results of the study showed that PSV were (3.1 $\pm$ 0.91) days, BIPAP (5.0 $\pm$ 1.03) days and SIMV (6.0 $\pm$  0.97) days. There were statistical significant differences as regard PSV/BIPAP (p value=0.011), PSV/SIMV (P value=0.021) and BIPAP/SIMV(P value=0.023) .

This level of agreement is similar to that was reported by **Esteban et al.(1995)** who showed that the duration of weaning was significantly shorter with PSV (5.7 $\pm$ 3.7 days) than with SIMV (9.9 $\pm$ 8.2

days) or trials of spontaneous breathing ( $8.5 \pm 8.3$  days). *Brochard et al.(2005)* have also shown that SIMV weaning is inferior to weaning with PSV.

Analysis performed to search for factors explaining weaning duration to be significant showed that aetiology of the disease followed by mode of weaning employed the main finding reported. *Esteban et al.(1995)* reported that the probability of remaining on mechanical ventilation over time was significantly lower with pressure support ventilation than with the other two modalities SIMV and BIPAP.

Patients who successfully weaned from mechanical ventilation shows a significant improvement in the form of increase of both dynamic and static compliance and reduction in airway resistance. Our results showed there were statistically significant differences between the initial values and final values of both dynamic, static compliance and resistance in successfully weaned patients with (P-value <0.05).

This study showed that there were significant differences as regard static compliance between PSV /BIPAP (p value=0.021) and PSV/SIMV (P value=0.031) but there were no significant differences between BIPAP and SIMV (P value=0.061). As regard dynamic compliance there were significant differences between PSV /BIPAP (p value=0.047) and PSV/SIMV (P value=0.021) but there were no significant differences between BIPAP and SIMV (P value=0.055).

*Shemeda (2000)* used dynamic compliance as monitoring tool for weaning and found that a value of 20-30 ml/cmH<sub>2</sub>O could successfully separate survivors from non survivors in ARDS patients.

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As regard resistance this study showed that there were no significant differences between PSV /BIPAP (p value=0.051) nor BIPAP /SIMV (P value=0.063) but there were significant differences between PSV and SIMV (P value=0.019).

As regard respiratory rate there were significant differences between PSV/ SIMV (P value =0.041) but there were no significant differences between PSV/ BIPAP (P value=0.096) nor BIPAP/ SIMV (P value =0.096).

This level of agreement is similar to that was reported by *Tokioka et al.(1999)* that PSV allows patients to retain nearly complete control over respiratory rate and timing, inspiratory flow rate and tidal volume. Also they have reported that patients breath more slowly and comfortably with PSV than with SIMV.

On the other hand *Knebel et al.(1994)* found that dyspnea and anxiety are not significantly different when comparing similar levels of partial support provided by either mode.

This study showed that there were no significant differences (P value>0.05 ) between PSV, BIPAP and SIMV as regard PH, PaO<sub>2</sub> ,PaCO<sub>2</sub>, Pao<sub>2</sub>/Fio<sub>2</sub> ,O<sub>2</sub> saturation, tidal volume, RR/TV ,negative inspiratory pressure ,MAB and heart rate.

This level of agreement is similar to that was recorded by *Fedullo et al. (1997)* who found that ABGS for survival who where presenting with parenchymal lung disease before mechanical ventilation and after weaning were non significant.

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PSV, a recent mode of ventilation that has been evaluated mainly in physiological or short-term studies, efficiently reduces the workload imposed on the respiratory muscles. The level of assistance can be gradually decreased until it only compensates for the additional work imposed by the endotracheal tube and the demand valve of the ventilator, at which time tracheal extubation can be performed (*Brochard et al.,2005*).

PSV might therefore be an optimal support for patients who have difficulties being weaned from the ventilator and offers several potential advantages compared with other modes, although few comparative data are available (*Tokioka et al.,1999*).

If one technique has any superiority over the other, improvement in weaning outcome is more likely to be expected in the subgroup of mechanically ventilated patients who do not tolerate prolonged discontinuation from mechanical ventilation when weaning is attempted. Therefore, we designed a prospective randomized trial to evaluate the efficacy of these three techniques of gradual withdrawal from mechanical ventilation in patients having difficulties tolerating discontinuation of mechanical ventilation. (*Tokioka et al.,1999*)



## Summary

The aim of this study is to Comparison between Pressure support ventilation (PSV) ,Synchronized intermittent mandatory ventilation (SIMV) and Biphasic Positive Airway Pressure (BIPAP) as three weaning modes of mechanical ventilation in Type I Respiratory failure.

This study was conducted on 60 patients and divides randomly into 3 group according to weaning method. It included 19 patients suffering from ARDs, 14 patients suffering from pneumonia, 8 patients suffering from cardiogenic pulmonary oedema ,7 patients suffering from post blood transfusion hypoxia, 7 patients suffering from acute lung injury, 5 patients suffering from post operative hypoxemia.

The patients were divided into three equal groups each consists of 20 patients put on one of the three weaning modes Pressure support ventilation (PSV) , Synchronized intermittent mandatory ventilation (SIMV) and Biphasic Positive Airway Pressure (BIPAP).

As regards respiratory rate there were significant differences between PSV/ SIMV (P value =0.041) but there were no significant differences between PSV/ BIPAP (P value=0.096) nor BIPAP/ SIMV (P value =0.096).

As regards static compliance there were statistical significant differences between PSV/ BIPAP (P value =0.021) and PSV/ SIMV (P value=0.031) but there were no significant differences between BIPAP/ SIMV (P value =0.061).

As regards dynamic compliance there were statistical significant differences between PSV/ BIPAP (P value =0.047) and PSV/ SIMV (P value=0.021) but there were no significant differences between BIPAP/ SIMV (P value =0.055).

As regard resistance there were no statistical significant differences between PSV/ BIPAP (P value =0.051) and BIPAP/ SIMV (P value=0.063) but there were significant differences between PSV/ SIMV (P value =0.019).

**We can summarize the data studied as follows:**

- **First** There were no statistically significant difference as regards demographic data , associated diseases and MAB, heart rate and ECG findings.
- **Second** their were no statistical significant differences between PSV,BIPAP and SIMV modes in PH and PaCo<sub>2</sub> , Pao<sub>2</sub>,O<sub>2</sub> saturation and Pao<sub>2</sub>/ Fio<sub>2</sub> values.
- **Third** There were significant differences between PSV,BIPAP and SIMV as regard respiratory rate .
- **Fourth** there were statistically significant difference between the initial values and final values of both dynamic & static compliance and reduction in airway resistance in PSV mode **followed by BIPAP followed by SIMV .**
- **Fifth** the least failure rate of weaning with PSV followed by BIPAP followed by SIMV .
- **Sixth** the least duration of weaning with PSV followed by BIPAP followed by SIMV .

## Conclusion

From the study, it was concluded that PSV improves patient-ventilator synchrony and patient comfort because the patient has control over the process of ventilation, the patient determines when to initiate a breath, the timing of inspiration and expiration, and the ventilator pattern. Therefore, the patient also maintains greater control over the PaCo<sub>2</sub> and acid-base balance.

We found that a strategy of progressive reduction of PSV until a threshold level was reached offered a benefit over more conventional approaches during gradual withdrawal from mechanical ventilation

## **Recommendation**

**The following is to be recommended:**

- Every effort should be made to wean the patient as soon as possible before complications of prolonged mechanical ventilation occur.
- Pressure support ventilation is recommended as a weaning mode PSV allows patients to retain nearly complete control over respiratory rate and timing, inspiratory flow rate and tidal volume
- The cornerstone in weaning is to decide when to start weaning so as not to expose the patient to a task he is not yet fit for the patient should fulfill the minimum criteria for weaning.
- Many predictive indices have been proposed to predict outcome of weaning including, traditional weaning criteria, measurement of dynamic compliance, static compliance, work of breathing cardiac output Hb% and oxygen delivery.
- The work of breathing is considered an accurate index for predicting weaning from mechanical ventilation.
- The ability to predict weanability from mechanical ventilatory support can take a variety of forms. Some use purely clinical judgement and observe the patient's respiratory efforts and look for the "Twinkle in the eye", others rely on more objective data. The debate as to whether weaning is an art or a science continues to range on our suggests that weaning is probably much of both; science flavored by art.

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## المخلص العربي

يعتبر التنفس الصناعى واحداً من أصعب المهام التى تواجه الأطباء فى وحدة الرعاية المركزة. تعرف عملية الفطام بأنها عملية تدريجية لنقل عمل الجهاز التنفسى من جهاز التنفس الصناعى إلى المريض . وهى عملية من السهل الحصول عليها فى حوالى ٧٠-٨٠ % من المرضى ، لكن ٢٠-٣٠ % منهم يواجهون صعوبة فى الفطام .

ينقسم الجهاز التنفسى إلى أعضاء للتنفس (الممرات الهوائية العلوية و السفلية) و الحويصلات الهوائية. بالنسبة للتكوين الداخلى للرئة، تنقسم الشعبات الهوائية إلى شعبيات نهائية و التى تؤدى إلى قناتين حويصليتين التى تؤدى إلى الأكياس الحويصلية، التى تحتوى على الحويصلات الهوائية، و التى يحدث فيها تبادل الغازات.

يتم تنظيم عملية التنفس عن طريق مركز التنفس فى جرع المخ . تستشعر المستقبلات الكيميائية نسبة الأكسجين فى الدم الشريانى، نسبة ثانى أكسيد الكربون فى الدم الشريانى، و درجة الحموضة فى الدم. تستجيب الأجسام الأورطية و الجسم السباتى لإنخفاض نسبة الأكسجين فى الدم الشريانى. تستجيب المستقبلات الكيميائية المركزية لإرتفاع نسبة ثانى أكسيد الكربون و إنخفاض درجة الحموضة فى الدم. القوة المحركة لعملية تبادل الغازات بين الحويصلات الهوائية و الهواء المحيط هى إختلافات الضغط .

الأهداف الرئيسية للتنفس الصناعى هى : علاج نقص نسبة الأكسجين فى الدم ، علاج الحموضة التنفسية الحاده وذلك لتخفيف حدة إرتفاع نسبة الحموضة فى الدم المهدده للحياة لا معادلة نسبة ثانى أكسيد الكربون فى الدم، و أيضاً لتخفيف الضيق فى التنفس وزيادة عمل الجهاز التنفسى .

تشمل مضاعفات التنفس الصناعى المضاعفات الناتجة عن إستخدام الأنبوبة الحنجرية ، إصابة الرئة الناتجة عن التنفس الصناعى ، الألتهاب الرئوى المرتبط بالتنفس الصناعى ، التسمم الناتج عن الأكسجين ، و إحتباس الهواء بالحويصلات الهوائية .

تبدأ عملية الفطام بتقييم إستعداد المريض للفطام يتبعها محاولة التنفس الطبيعى . بالنسبة لكثير من المرضى يعتبر إيقاف التخدير خطوة حاسمة . قرار إزالة مجرى الهواء الصناعى فى المرضى الذين يجتازون محاولة التنفس الطبيعى بنجاح يحتاج لمزيد من التقييم لقدرة المريض على مجرى الهواء .

**بعض المعايير الموضوعية للتنبؤ بنجاح عملية الفطام تشمل ما يلى :**

- نسبة الأكسجين فى الدم الشريانى إلى نسبة الأكسجين المستنشق أكثر من ١٥٠-٢٠٠ .
- مستوى الضغط الموجب فى آخر الزفير بين ٥-٨ سم مائى .
- نسبة الأكسجين المستنشق أقل من ٥٠ % .

- (د) نسبة الحموضة في الدم أكثر من ٧.٢٥ .  
 (هـ) القدرة على بدء التنفس الطبيعي .  
**بعض المعايير الذاتية تشمل ما يلي :**  
 (أ) إستقرار الدورة الدموية .  
 (ب) عدم وجود قصور في الدورة الدموية لعضلة القلب .  
 (ج) عدم وجود هبوط في الدورة الدموية يحتاج إلى أدوية رافعة للضغط أو يؤثر إكلينيكيًا على حالة المريض .  
 (د) نتيجة فحص الجهاز العصبي تكون مناسبة .  
 (هـ) صورة الأشعة السينية للصدر تكون طبيعية أو تتحسن .  
 (و) قوة العضلات تكون كافية للسماح ببدء أو مواصلة الجهد التنفسي .

### تتضمن المبادئ التوجيهية لعملية الفطام ما يلي :

- ١- تصنيف المرضى إلى ثلاث مجموعات على أساس صعوبة و مدة عملية الفطام.
- ٢- يجب البدء في عملية الفطام في أقرب وقت ممكن .
- ٣- محاوله التنفس الطبيعي هي الأختبار التشخيصي الرئيسي لتحديد مدى إمكانية نجاح عملية الفطام .
- ٤- المحاوله الأولى تستمر لمدة ٣٠ دقيقة و تكون إما عن طريق أنبوبة حرف T أو مستويات منخفضة من دعم الضغط .
- ٥- يفضل إستخدام دعم الضغط أو التحكم المساعد في المرضى الذين يفشلون في المحاولات الأولية .
- ٦- ينبغي إستخدام تقنيات التنفس الصناعي الغير تدخلية في حالات مختارة من المرضى لتقليل مدة إستخدام الأنبوبة الحنجرية ، لكن لا ينبغي أن تستخدم بشكل روتيني كأداة في حالات فشل عملية الفطام .

تنتج صعوبة الفطام عن الإختلال بين الجهد المفروض على الجهاز التنفسي و قدرة عضلات الجهاز التنفسي على أداء هذا العمل الزائد . العوامل التي تحد من عملية الفطام تشمل عدم القدرة على توصيل الأكسجين ، الجهد المفروض على الجهاز التنفسي ، و قدرة عضلات الجهاز التنفسي على تحمل هذا العبء ، أداء القلب و الأوعية الدموية ، و العوامل النفسية .

يعرف التنفس الصناعي لفترات طويلة بأنه الإحتياج إلى المساعدة المستمرة من جهاز التنفس الصناعي لأكثر من ٦ ساعات يومياً لمدة لا تقل عن ٢١ يوم . إستراتيجية الفطام في حالات إستخدام التنفس الصناعي لفترات طويلة ينبغي أن تكون على وتيرة بطيئة و ينبغي أن تشمل إطالة محاولات التنفس الطبيعي تدريجياً .

أصبح إستخدام الشق الحنجري عملية شائعة في وحدات الرعاية المركزة مع إدخال تقنية الشق الحنجري عن طريق الجلد و التي يؤديها طبيب الرعاية المركزة داخل الرعاية . إعادة

التأهيل هي عملية إسترجاع الحياه الطبيعية أو الصحة عن طريق التدريب و العلاج بعد المرض

تقدم وحدات الفطام المتخصصة فرقة متخصصة (مثل: التمريض ، المتخصصين فى علم وظائف الأعضاء ، معالجين الجهاز التنفسى ، و أخصائى التغذية ..... إلخ ) و بيئة مناسبة كمرحلة إنتقالية للمنزل لمثل هؤلاء المرضى و أسرهم (مثل: الخصوصية ، الأنشطة خلال النهار ، مدة أطول للزيارة ، و النوم غير المتقطع ) كما أنها تخفف الضغط على أسرة الرعاية المركزة الشحيحة .

بعد اجراء دراسه على ٦٠ مريض و تقسيمهم الى ثلاث مجموعات متساويه وهم PSV , BIPAP, SIMV وبعد استيفاء كافة الشروط اللازمه لفصل المريض من جهاز التنفس الصناعى وجد ان افضل طريقه لفصل المريض من جهاز التنفس الصناعى هو PSV وذلك لأنه افضل طريقه لتحسين معدل وطريقة التنفس وتحسين مرونة واستيعاب الرئتين قدره اكبر على التنفس الطبيعى ويقلل من حالة القلق والتوتر التى تنتاب المريض على جهاز التنفس الصناعى ويقلل ايضا المده اللازمه للفصل ووجد ايضا انه يقلل من نسبة الفشل فى معدلات الفصل من جهاز التنفس الصناعى ولذلك ننصح باستخدام PSV كأفضل طريقه للفصل من از التنفس الصناعى بالمقارنه بالطريقتين السابقتينز

# دراسة مقارنة بين ثلاثة من طرق الفطام من جهاز

## التنفس الصناعي

دراسه

توطئة للحصول على درجة الدكتوراه فى التخدير والعنايه المركزه

مقدمه من

الطبيب/ سمير حسنى حسن

ماجستير التخدير والعنايه المركزه

تحت اشراف

الأستاذ الدكتور / محمود عبد الرحمن الشربيني

استاذ التخدير والعنايه المركزه

كلية الطب - جامعة بنها

الأستاذ الدكتور / محمد يسري سري

استاذ التخدير والعنايه المركزه

كلية الطب - جامعة بنها

الدكتور / محمد أحمد الربيعي

استاذ مساعدالتخدير والعنايه المركزه

كلية الطب- جامعة بنها

كلية الطب

جامعة بنها

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