FUNDAMENTALS OF MECHANICAL VENTILATION

STATE INSTITUTE OF HEALTH AND FAMILY WELFARE
UTTAR PRADESH

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GUIDANCE

Shri. Partha Sarthi Sen Sharma, *IAS,*
Principal Secretary,
Department of Medical Health and Family Welfare,
Government of Uttar Pradesh

DIRECTION AND LEADERSHIP

Dr. Rajaganapathy R., *IAS,*
Director, SIHFW, Uttar Pradesh &
Director (Administration)
Medical and Health Services, Uttar Pradesh

Lead Author

Dr. Zia Arshad
Professor
Anaesthesiology and Critical Care
King George's Medical University,
Shah Mina Rd, Chowk, Lucknow, Uttar Pradesh 226003

Co-Authors

Dr. Ravi Prakash
Associate Professor
Anaesthesiology and Critical Care
King George's Medical University,
Shah Mina Rd, Chowk, Lucknow,
Uttar Pradesh 226003

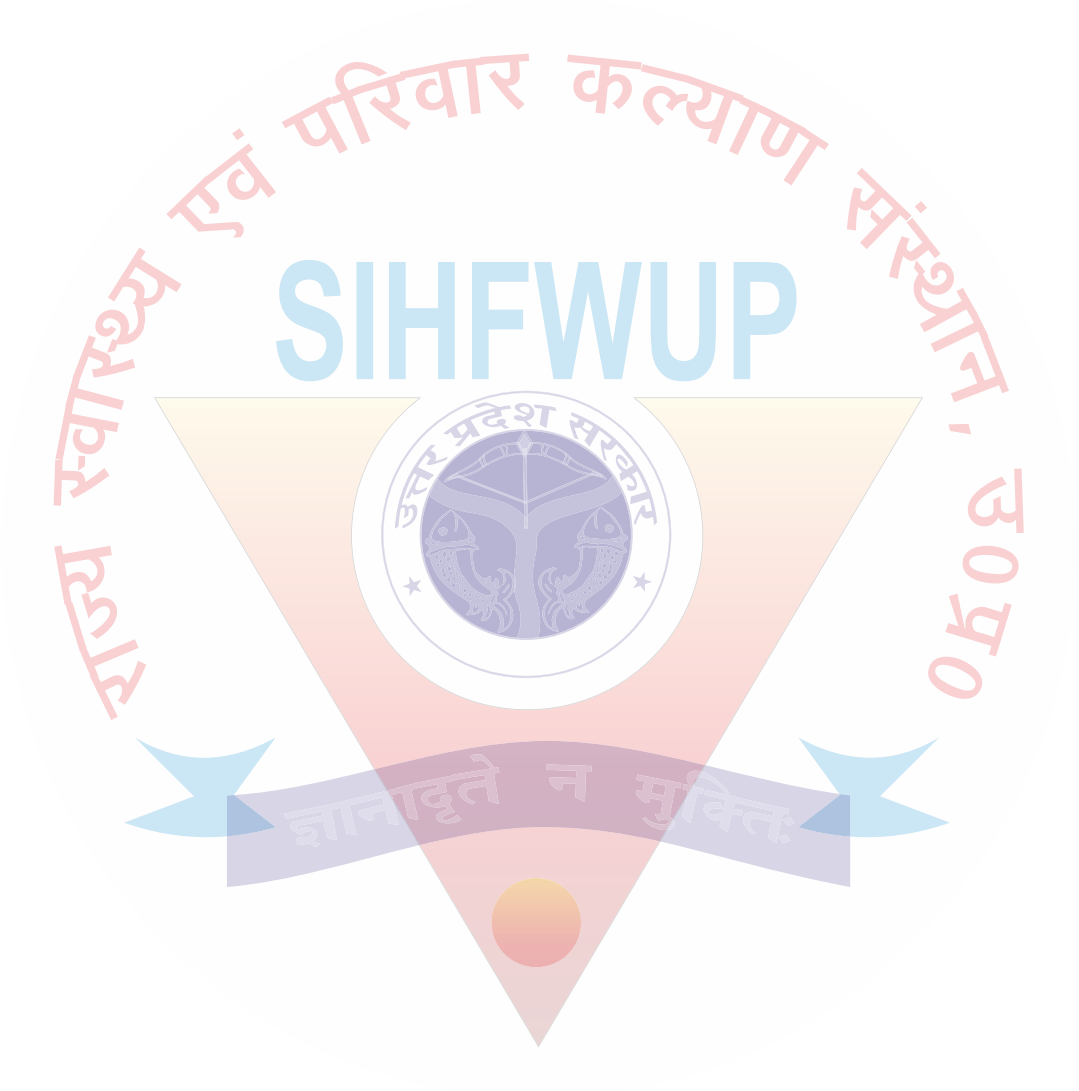
Dr. S. Nabeel Muzaffar
Additional Professor
Critical Care Medicine
King George's Medical University,
Shah Mina Rd, Chowk, Lucknow,
Uttar Pradesh 226003

SIHFW Editorial Board:

Dr. Mahesh Nath Singh
Assistant Professor

Mudasser Ahmed
Assistant Professor

Dr. Diwakar Yadav
Assistant Professor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MESSAGE

Shri Brajesh Pathak

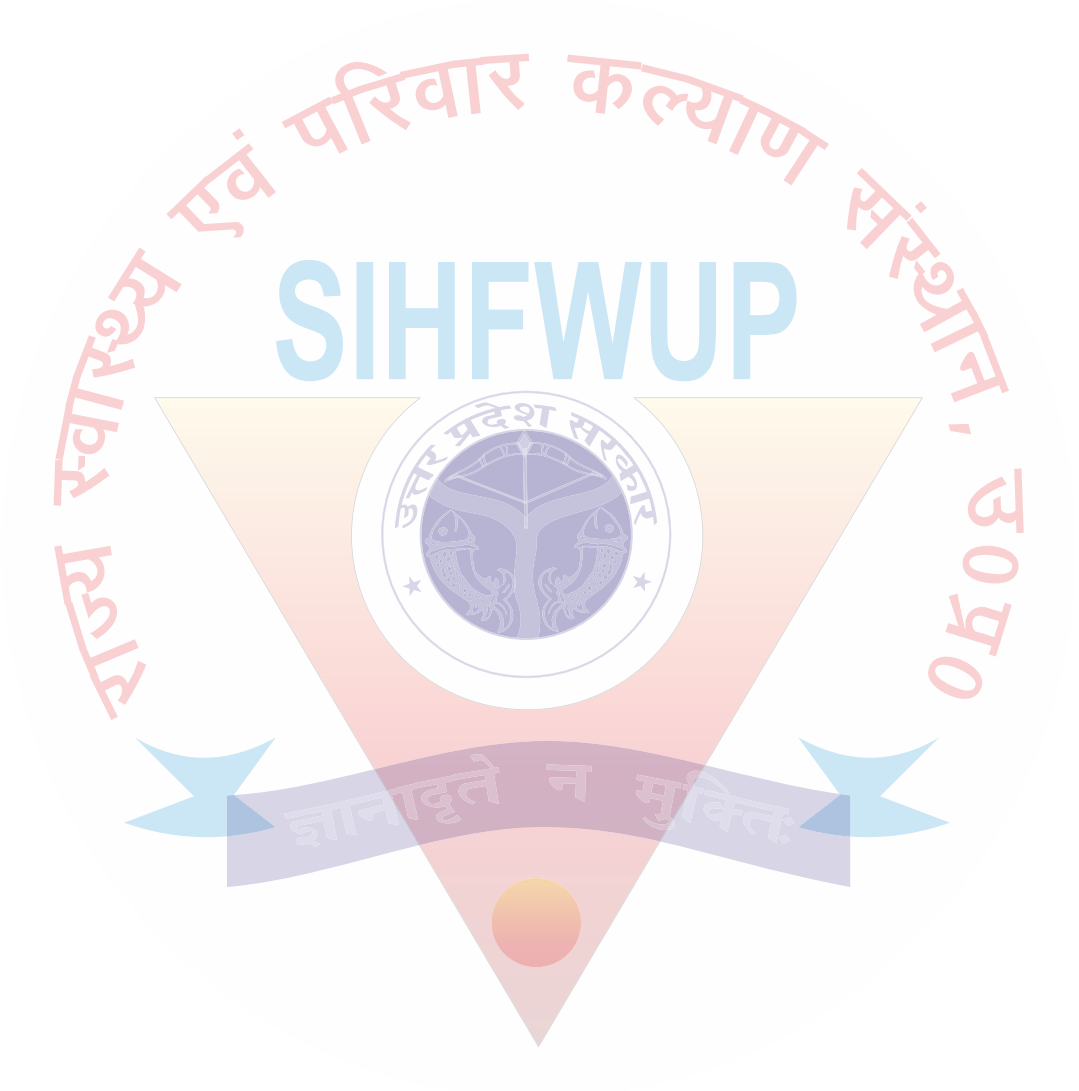
Hon'ble Deputy Chief Minister
Hon'ble Minister of
Medical Health and Family Welfare
Department
Government of Uttar Pradesh

Early recognition of patients who might potentially require ventilator support is a key goal of critical care outreach programs and an important skill for medical professionals. Appropriateness and decisions about invasive ventilation is required to discuss with critical care officials and reciprocate with patients and their families.Therefore, it is desirable that state develops tailored made Continuing Medical Education (CME) modules to caret the medical needs specific to its inhabitants.

Considering the above stated facts, CME on invasive ventilation and non-invasive ventilationis a minimum standard practice to be offered during critical care. Through this, Medical Officers in Provincial Health & Medical Services in Uttar Pradesh, will be exposed to much needed training, thus ensuring that non/invasive ventilation is crucial and this could be achieved through staggered approaches.

I wish the team of State Institute of Health & Family Welfare, Uttar Pradesh and subject matter experts to continue developing such module on CME for the benefit of Medical Officers in Provincial Health & Medical Services in Uttar Pradesh that ultimately benefit their patients too.

(Brajesh Pathak)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MESSAGE

Shri Mayankeshwar Sharan Singh

Hon'ble State Minister
Medical Health and Family Welfare
Department
Government of Uttar Pradesh

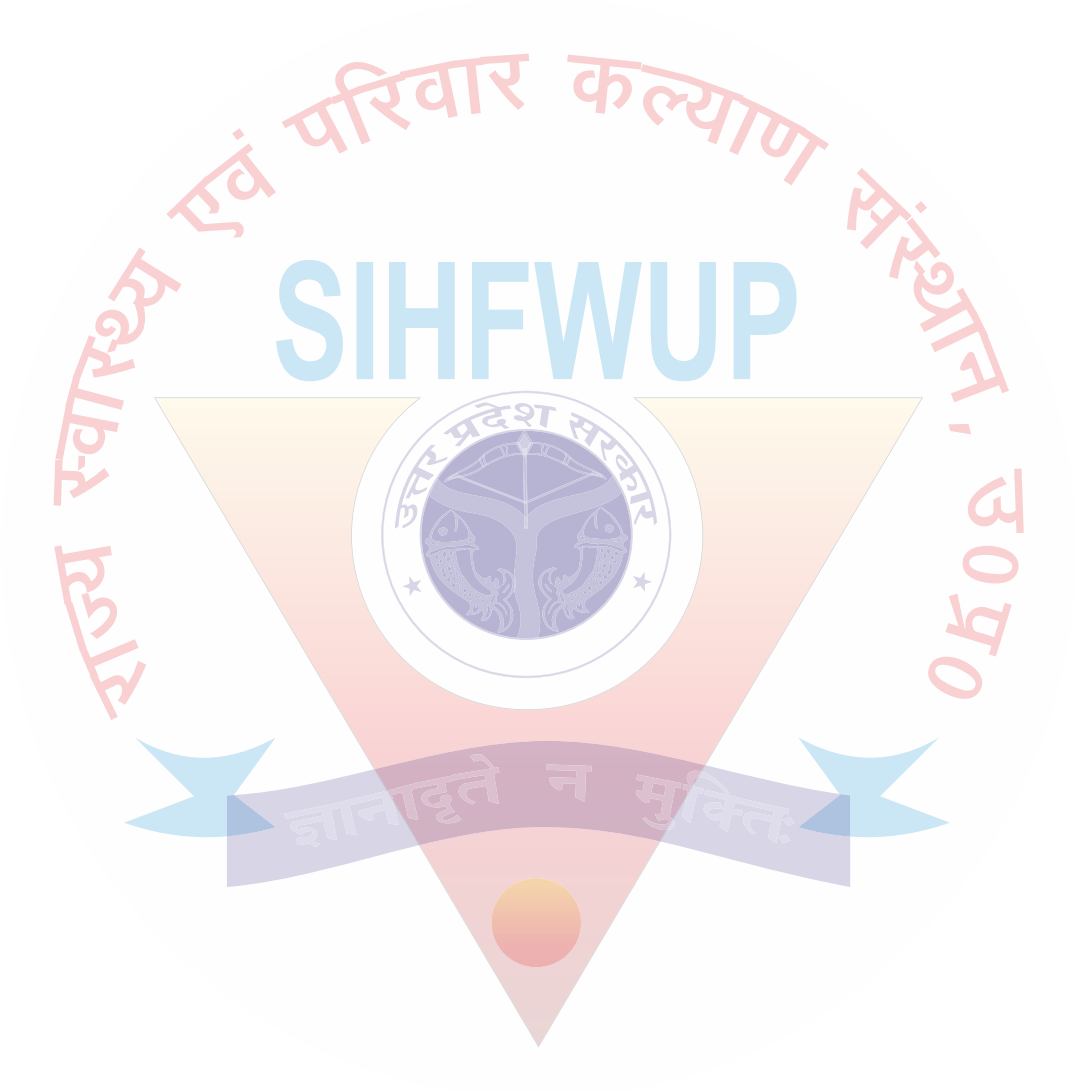
Medical professionals can play a more pivotal role in critical care conditions by knowing the differences between invasive ventilation and non-invasive ventilation.The appropriatetechnique can lead to the right direction, which is an essential part of effective treatment.It's important to choose a professional who are trained in specific techniques.

In order to further strengthen the ventilatory strategies, it helps in understanding a range of common indications for invasive ventilation, Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilation for Medical Officers in Provincial Health & Medical Services in Uttar Pradesh is one of the good intervention in states growth.

I am happy that the team at State Institute of Health & Family Welfare, Uttar Pradesh along with the experts from the field, have come up with such an intensified and detailed CME for Medical Officers in Provincial Health & Medical Services in Uttar Pradesh.

I wish team at SIHFW success in their endeavors of aiding an improved health service interventionthrough such CME oninvasive ventilation and non-invasive ventilation.

(Mayankeshwar Sharan Singh)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FOREWARD

Shri Partha Sarthi Sen Sharma

Principal Secretary
Department of
Medical Health and Family Welfare
Government of Uttar Pradesh

A cost-effective analysis is important in all public health decision-making, and critical in low- and middle-income countries where health care resources are severely limited and rationing decisions are necessary. Although some of the hospitals in the low-income countries have intensive care capabilities, many more do not have these advanced capabilities.

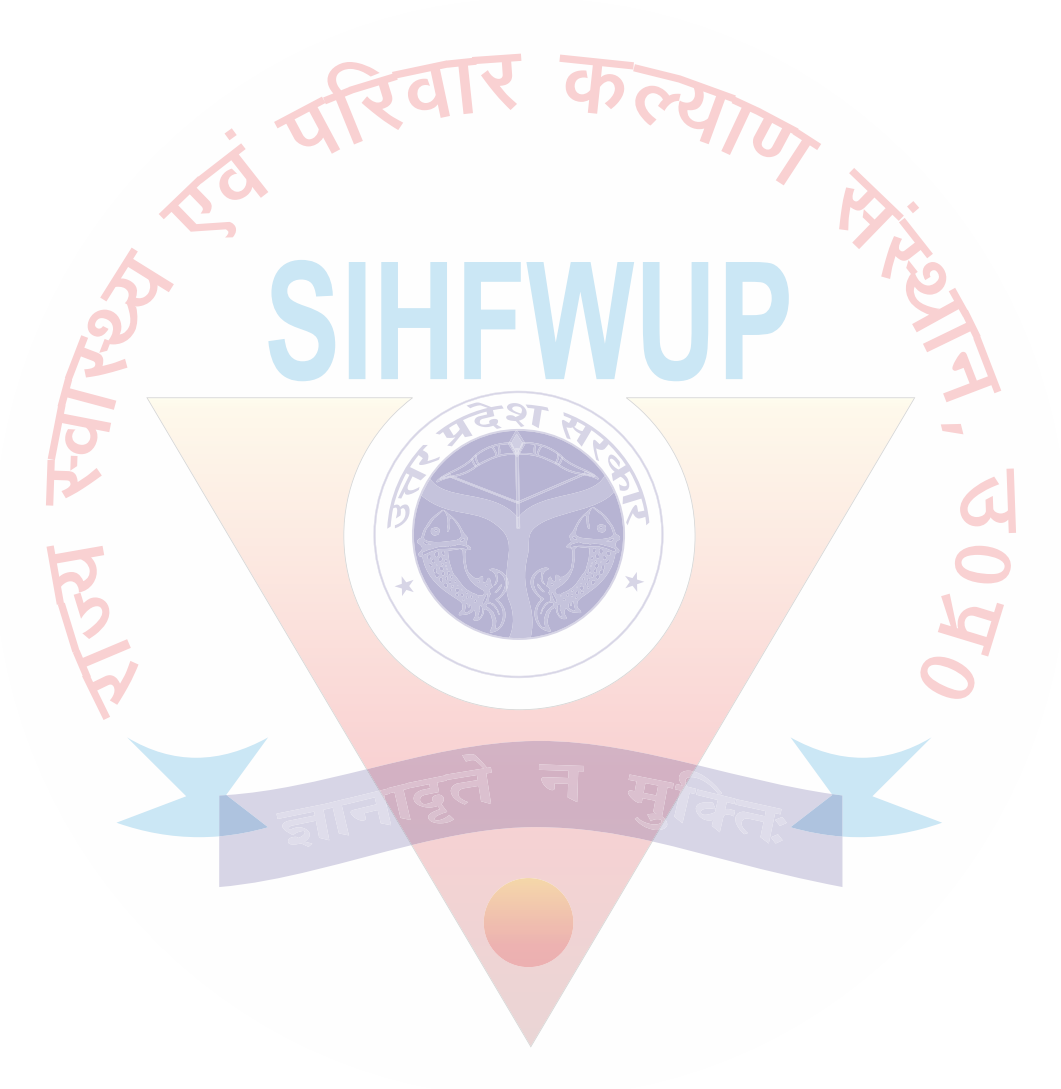
In hospitals without intensive care units, survival of patients with respiratory failure is dismal as no rescue mechanical ventilation is possible. The only option available for these moribund patients is transfer to a hospital with an ICU, if one is even available. As mechanical ventilation is expensive, it may be important for low-income countries to consider less traditional mechanisms to treat respiratory failure patients.

Newer treatments for respiratory failure include non-invasive positive pressure ventilation (NIV) initially followed by mechanical ventilation for NIV failures. This approach has been shown to reduce the need for endotracheal intubation, and is associated with lower mortality, less complications, and reduced length of stay in conditions such as chronic obstructive pulmonary disease (COPD). In this approach, although rescue mechanical ventilation for noninvasive ventilation failures would not be available, it may still offer a survival advantage at a reasonable cost for many patients.

Considering the complexity and ever evolving nature of medical intervention, this module on Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilation for Medical Officers in Provincial Health & Medical Services in Uttar Pradesh, is an excellent tool that will assist Medical Officers in managing complex treatment situations.

I congratulate the faculties of State Institute of Health & Family Welfare, Uttar Pradesh and subject matter experts for such a commendable job.

(Partha Sarthi Sen Sharma)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MESSAGE

Dr. Deepa Tyagi

Director General
Medical and Health Services
Uttar Pradesh

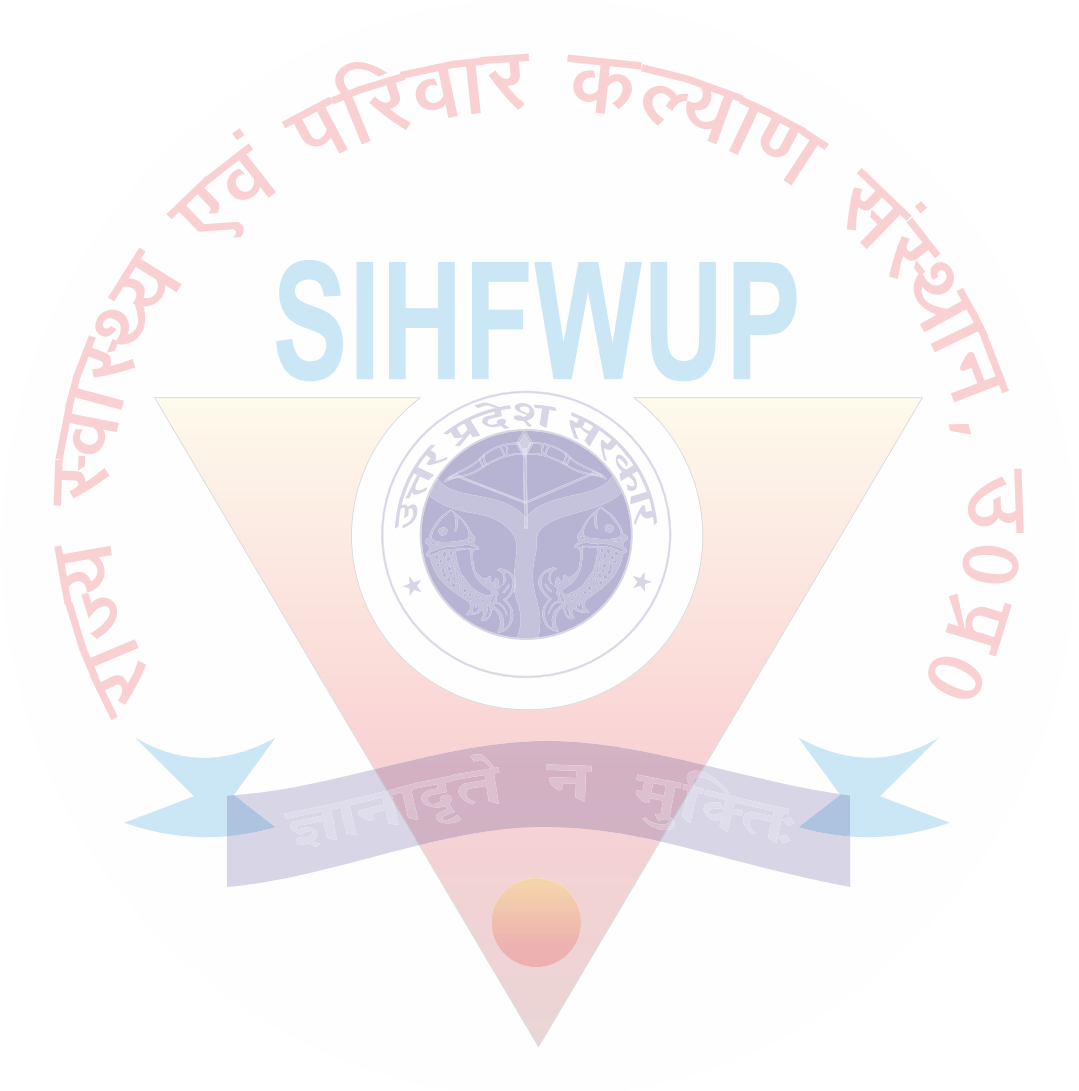
Non-invasive ventilation has now become an integral tool in the management of both acute and chronic respiratory failure, in both the home setting and in the critical care unit. Non-invasive ventilation has assumed its role as a first line ventilation modality in many clinical situations thus avoiding invasive ventilation with all its associated morbidities.

Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilation is an effort to act as a reference for medical professionals, to follow with patients who requires non-invasive ventilation, to guide the safe management of patients requiring non-invasive ventilation, to establish a safe and uniform standard of practice for the application and monitoring of non-invasive ventilation and reduce the need for invasive ventilation.

Considering the above stated facts, this module on Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilationfor Medical Officers in Provincial Health & Medical Services in Uttar Pradesh, State Institute of Health & Family Welfare, Uttar Pradesh with the help of Subject Matter Experts has provided a comprehensive, coherent and insightful module for Medical Officers.

I wish the team of State Institute of Health & Family Welfare, Uttar Pradesh and subject matter experts for such a commendable job.

(Dr. Deepa Tyagi)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MESSAGE

Dr. Brijesh Rathor

Director General
Family Welfare, Uttar Pradesh

The seriously ill patients suffering from COVID-19 needed respiratory support, as their lungs get damaged by the coronavirus leading to breathing difficulties. Ventilators were needed in such cases for supplying adequate oxygen into their lungs and also removing the carbon dioxide, as a lifesaving supportive measure.

The ventilators were one of the most vital medical devices needed to keep these critically ill COVID-19 patients alive. There was a drastic increase in the number of patients struck by COVID-19 pandemic in the hospitals and ICUs worldwide.

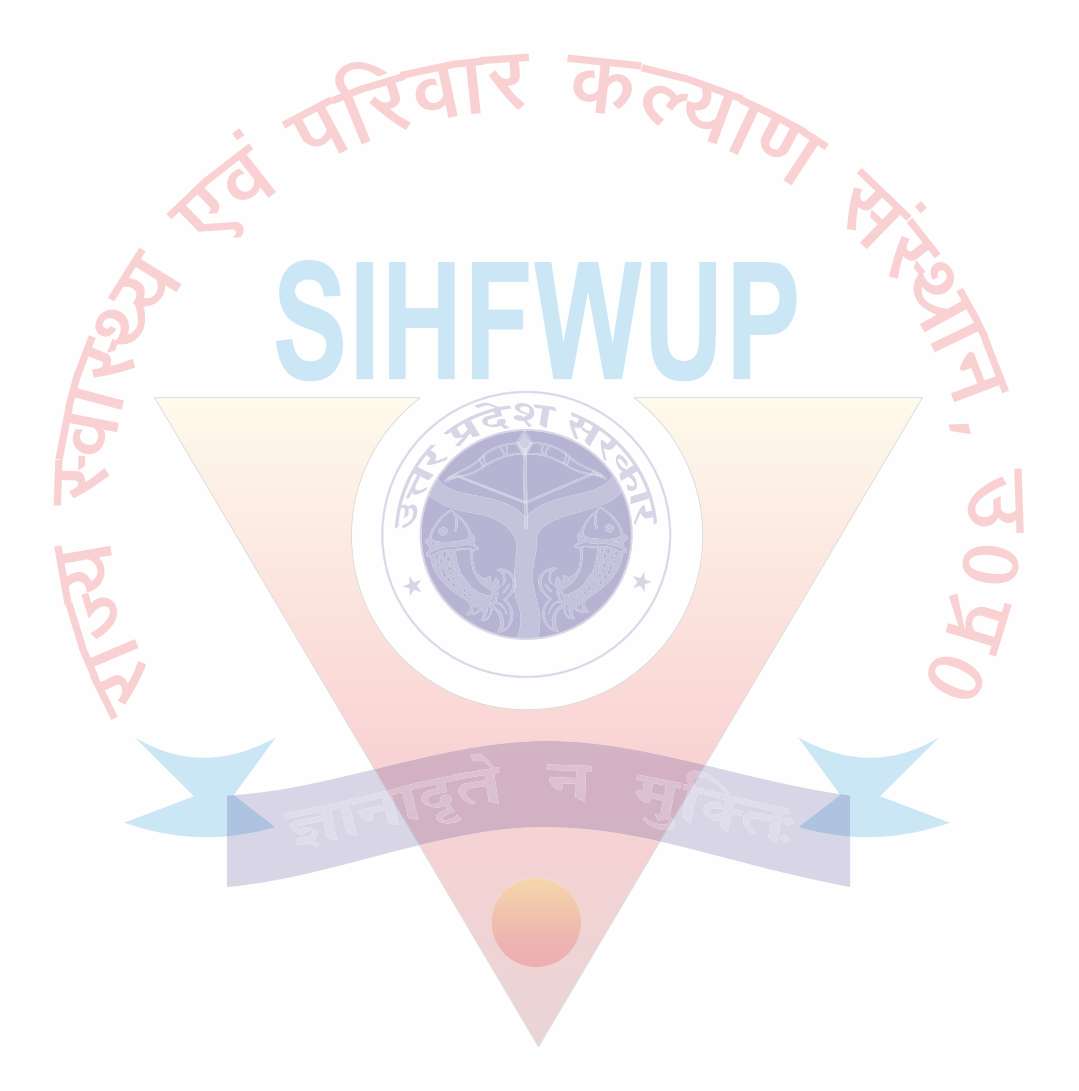
Medical ventilation is basically of two types: a) invasive mechanical ventilation and b) non-invasive ventilation. The invasive mechanical ventilation uses an endotracheal tube which is inserted in to trachea for the flow of oxygen in to the lungs of the patient, whereas the non-invasive ventilation does not employ any internal tube. The non-invasive ventilation devices such as continuous positive airway pressure (CPAP) device and oxygen hoods are also used in the management less severe COVID-19 patients, so as avoid the need of mechanical ventilators which are invasive in nature.

However, mechanical ventilators are most necessarily used in the situations where patients suffer from acute respiratory distress syndrome (ARDS) such as in COVID-19. This helps in normalizing the levels of oxygen in the body. They are primarily used in home care, emergency care, intensive care settings and as one of the parts of general anaesthesia machines.

Considering the above stated facts, this module on Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilation for Medical Officers in Provincial Health & Medical Services in Uttar Pradesh, State Institute of Health & Family Welfare, Uttar Pradesh with the help of Subject Matter Experts has provided a comprehensive, coherent and insightful module for Medical Officers thus equipping them with the required necessary knowledge for managing critical cases.

I wish the team of State Institute of Health & Family Welfare, Uttar Pradesh and subject matter experts for such a commendable job.

(Dr. Brijesh Rathor)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MESSAGE

Dr. Shailesh Kumar Srivastava

Director General (Training),
Medical and Family Welfare,
Uttar Pradesh

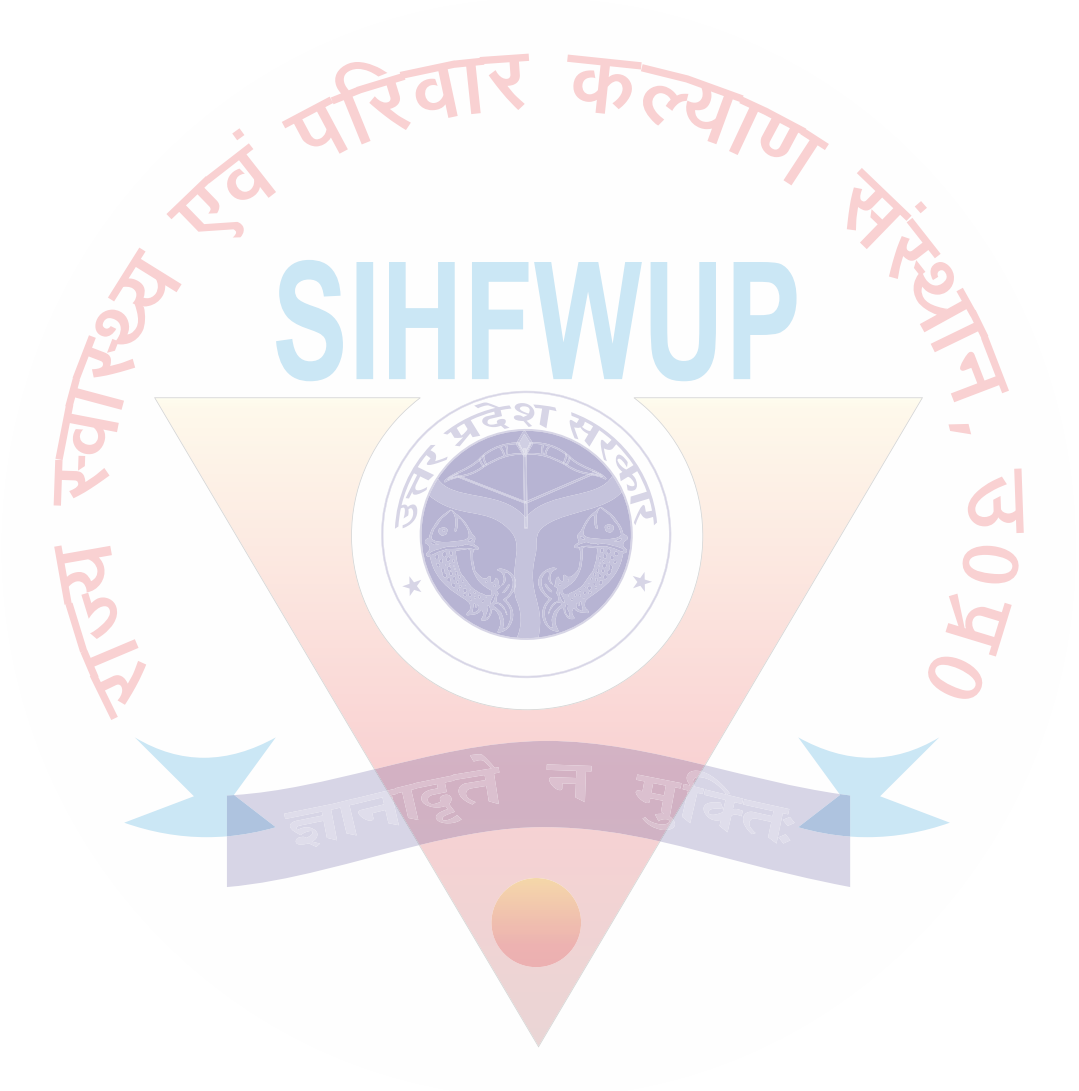
Mechanical ventilation is an established life saving measure in the management of the critically ill. Although it began by simulating the physiology of natural breathing by creation of negative intrathoracic pressure, mechanical ventilation in the present day almost always implies that it is intermittent positive pressure ventilation. The patient's lungs are ventilated with a specified amount of tidal volume at a specified rate to achieve the desired minute volume. The adequacy of which is checked by analysing arterial blood gases, particularly the pH and the carbon dioxide tension ($PaCO_2$).

Traditionally, volume controlled ventilation was used for all patients but pressure controlled modes evolved with increasing recognition of adverse effects of high pressures (barotrauma) on the alveoli. Dual controlled modes are now available where both volume and pressure can be controlled simultaneously. Present generation mechanical ventilators are so sophisticated and versatile that almost any combination of variables such as pressure, volume, time or flow can be chosen and adjusted as necessary with the aid of modern microprocessor systems.

Despite all these, there are issues that remain to be addressed regarding mechanical ventilation. State Institute of Health & Family Welfare, Uttar Pradesh with the help of Subject Matter Experts has developed an extensive and upto date module on Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilation for Medical Officers in Provincial Health & Medical Services in Uttar Pradesh, State Institute of Health & Family Welfare, Uttar Pradesh that deals with all the underlying nuances and provides a comprehensive, coherent and insightful module for Medical Officers.

I congratulate the team of State Institute of Health & Family Welfare, Uttar Pradesh and subject matter experts for such a commendable job.

(Dr. Shailesh Kumar Srivastava)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ACKNOWLEDGEMENT

Dr. Rajaganapathy R.
Director
State institute of
Health & Family Welfare
Government of Uttar Pradesh

In recent years, non-invasive ventilation (NIV), including non-invasive variable positive airway pressure ventilation and continuous positive airway pressure (CPAP) (1), has progressively gained a key role in the therapy of both hypoxemic and hypercapnic acute respiratory failure (ARF).

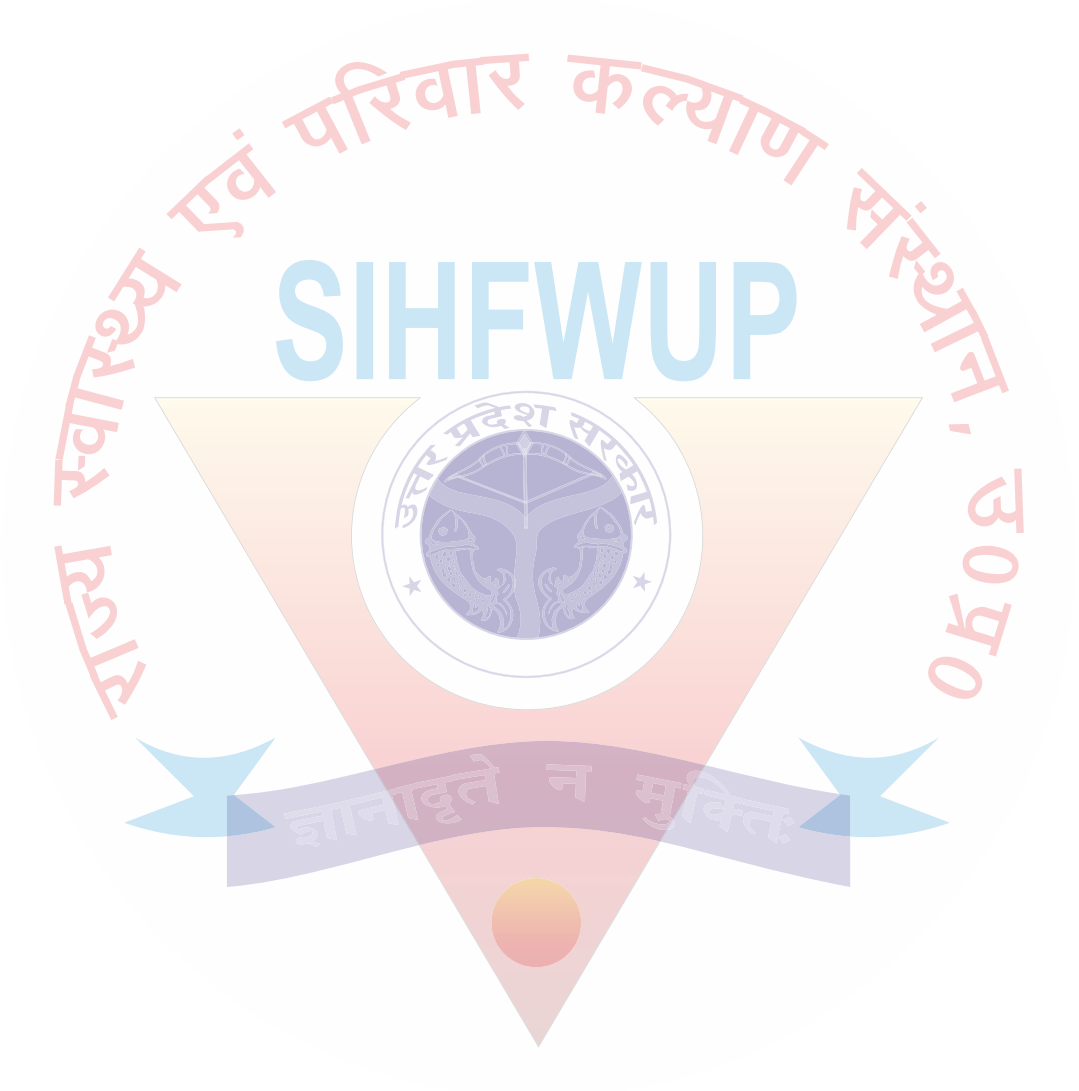
This has been even more true during the massive spread of severe acute respiratory syndrome-related to the novel coronavirus pandemic, when NIV has extensively been used to cope with the massive demand for ventilatory assistance outside the intensive care unit (ICU). In the management of ARF, NIV reduces the recourse to invasive mechanical ventilation (IMV), consequently avoiding the side effects related to endotracheal intubation, and the use of muscle relaxants and sedatives drugs that have been demonstrated to negatively affect clinical outcomes.

Non-invasive ventilation has been shown to be effective in preventing intubation and improving survival of patients with ARF when compared to conventional oxygen therapy. Accordingly, NIV has been progressively employed outside the emergency department, in both clinical and surgical wards in the early treatment of ARF.

However, this widespread diffusion of NIV has in turn allowed to discover out the limits of its application. In this regard, NIV failure, defined as the need for endotracheal intubation, is the main issue while dealing with patients with NIV.

In the light of these above stated facts, this module on Continuing Medical Education (CME) on invasive ventilation and non-invasive ventilation for Medical Officers in Provincial Health & Medical Services in Uttar Pradesh, covers all the aspect in details. I acknowledge the sincere efforts made by the faculties of State Institute of Health & Family Welfare, Uttar Pradesh and by Professor Zia Arshad, Additional Professor Dr. S. Nabeel and Associate Professor Dr. Ravi Prakash of King George Medical University in developing such a comprehensive, coherent and insightful module for Medical Officers.

(Dr. Rajaganapathy. R)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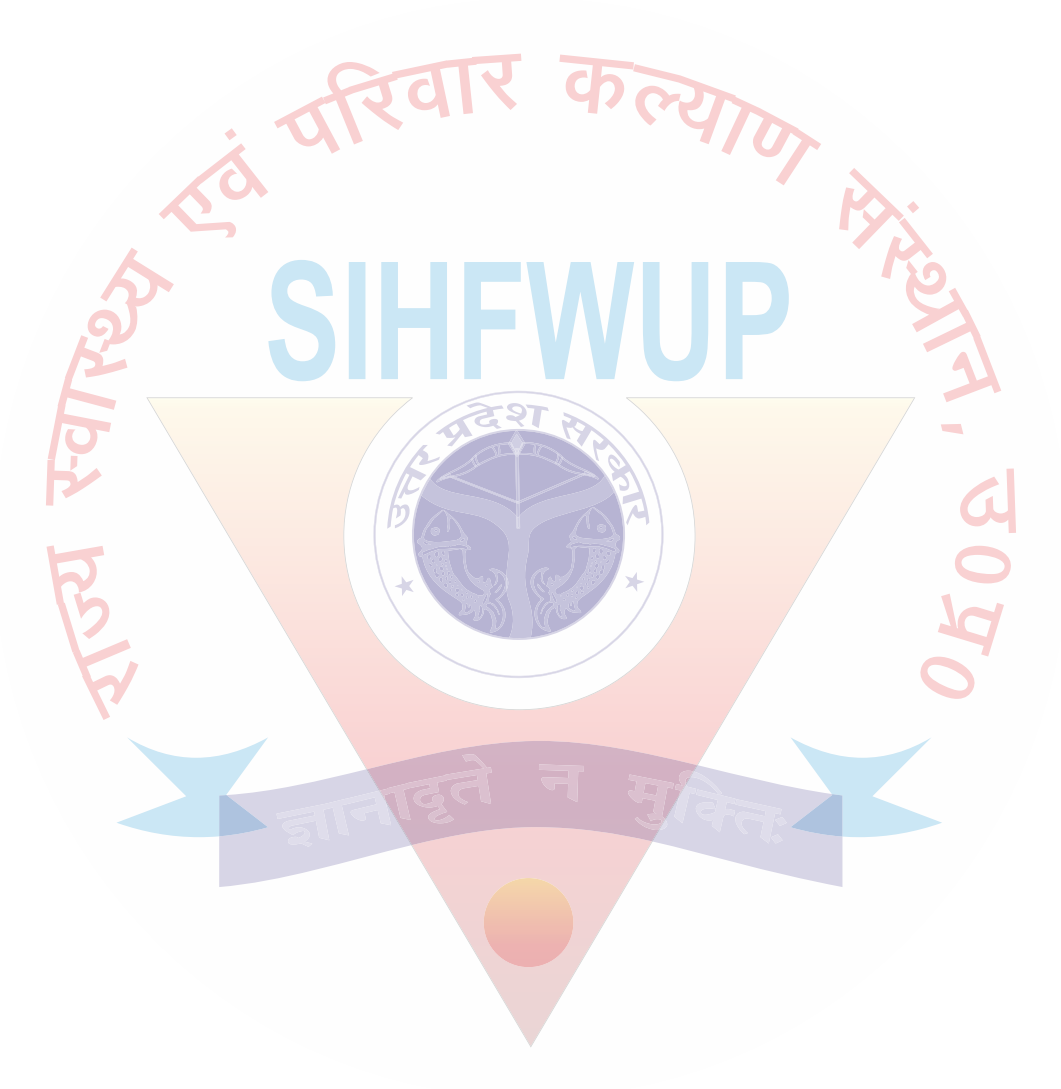
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Mechanical Ventilation

History of mechanical ventilation:

In 16th century, Andreas Vesalius used a reed pipe to intubate the trachea of an animal and blow air into its lungs giving the first description of an endotracheal intubation. Thereafter, in 1929, the first mechanical ventilator was successfully used in medical practice, known as the "iron lung". It was a negative pressure ventilator in which patient's body was enclosed in an iron tank and air moved into the lungs along a pressure-gradient generated by creating a negative pressure around patient's body. However, this process of negative pressure ventilation was quite cumbersome.

Finally in 1950s, during the epidemic of paralytic polio myelitis, Bjørn Ibsen, an anaesthetist from Denmark, introduced the concept of positive pressure ventilation (similar to the concept described by Andreas Vesalius). In this period, 1500 medical students provided mechanical ventilation manually by pressing rubber bags attached to tracheostomy tubes of patients for around 1,65,00 hours, resulting in reduction in overnight mortality from 87% to 40%. This is known as the "golden era of mechanical ventilation" during which the first intensive care unit (ICU) also got set up in medical history in Copenhagen, Denmark. Since then, the field of mechanical ventilation is progressively evolving.

Indications for mechanical ventilation

The common indications of mechanical ventilation include acute hypoxemic respiratory failure (eg ARDS), exacerbation of COPD, coma and neuromuscular respiratory failure.

Basic terms and concepts of mechanical ventilation

Patient-ventilator interaction:

Patient-ventilator interaction can be viewed as a mechanical or electrical analog system comprising a resistive element (resistor; endotracheal tube and airways) and elastic element (capacitor; lungs and chest wall) in series. It is based on linear model principles. The pressure or flow program implemented by ventilator determines the forcing function of this model. For air flow through a tube, pressure at one end should be higher than the pressure at other end. Air flow occurs from high to low pressure points (pressure gradient). Expiration is usually passively driven by the elastic recoil of respiratory system, which is influenced by the time constant of respiratory system.

Transrespiratory pressure (P_{TR}) is the pressure gradient between airway opening and body surface pressures which is the total pressure required to generate inspiration. It has two components; transairway (Pta) and transthoracic pressures (Pw). The pressure gauge on ventilators displays P_{TR}.

1. Transairway pressure (Pta): Pressure gradient between airway opening pressure and alveolar pressure which generates flow through airways.
2. Transthoracic pressure (Pw): Pressure gradient between alveolar and body surface pressures. which expands the elastic chamber. Transpulmonary pressure (Ptp) is the pressure di erence between Palv and pleural space pressures.

Figure 1 shows the equation of motion model for respiratory system along with the various pressures important to understand the patient-ventilator interaction.

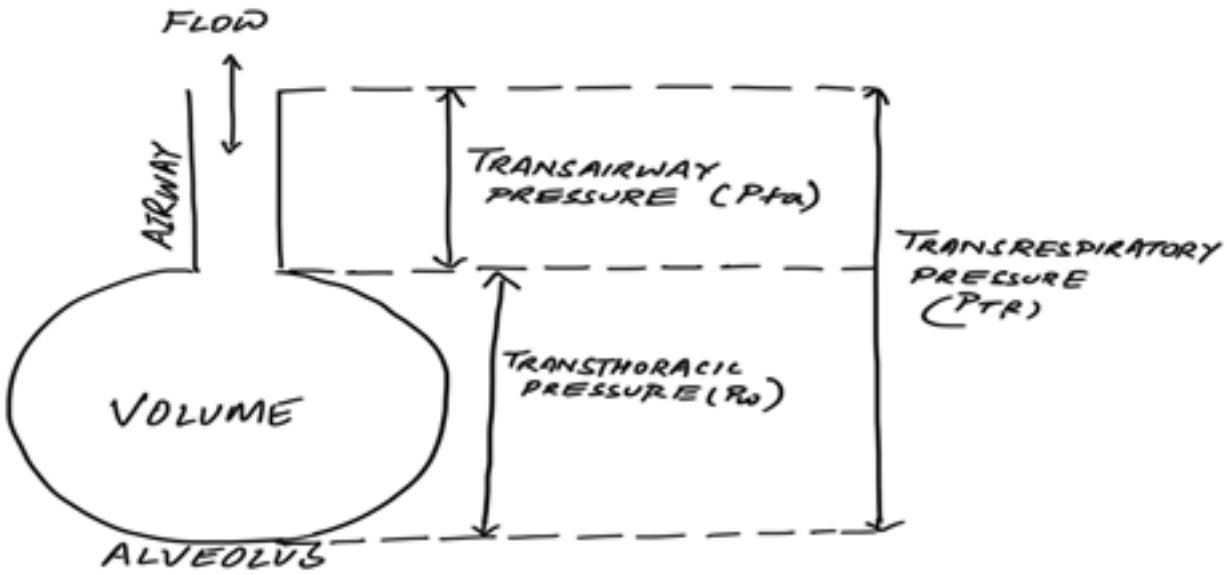


Figure 1: Equation of motion model for respiratory system in which respiratory system can be seen as a conductive tube attached to an elastic compartment (From Tobin MJ, editor. Principles and Practice of mechanical ventilation. Ed- 3, McGraw Hill, 2013)

Equation of motion:

To understand patient-ventilator interaction, it is necessary to recapitulate the equation of motion. When applied to respiratory system, this mathematical model can be modified as, Tranrespiratory pressure (P_{TR})= Pressure caused by elastic recoil (P_E)+Pressure caused by flow resistance (P_R). P_{TR}has two components, one generated by the ventilator (Pvent) and the other generated by patient's respiratory muscles (Pmus). Elastic recoil pressure is the product of elastance and volume and resistive pressure is the product of resistance and flow.

So, **Pvent+ Pmus= (elastance×volume) + (resistance×flow).** Pressure, volume and flow are functions of time and are called variables whereas elastance and resistance are assumed to be constant and are called as parameters. Thus, the combined ventilator and muscle pressures cause flow and volume to be delivered to the patient. It follows from this equation that any ventilator can control only one variable at a time; pressure (left hand side of equation) or flow/volume (right hand side of equation). Therefore, only pressure and volume are considered as control variables.

Factors controlled and measured by ventilator to deliver a breath

The primary variable that ventilator adjusts to achieve inspiration is called control variable.

Control variables:

As discussed earlier, the ventilator can control only one variable at a time. The two commonly used control variables are volume and pressure.

Volume control (VC): in volume preset mode, each breath is delivered with the same pre-defined inspiratory flow-time profile. The resulting pressure profile (peak inspiratory pressure, plateau pressure) depends upon respiratory mechanics.eg Volume control-continuous mandatory ventilation (VC-CMV)

Pressure control (PC): in pressure-preset mode, a predefined pressure target is applied by the ventilator during inspiration. The resulting tidal volume and inspiratory flow profile depends upon respiratory

mechanics. eg pressure controlled-continuous mandatory ventilation (PC-CMV), pressure support ventilation (PSV), airway pressure release ventilation (APRV).

Table 1 shows a comparison between volume-control and pressure-control modes of ventilation.

Volume Control (VC)	**Pressure Control (PC)**
Set parameter: Tidal volume	Set parameter: airway pressure; pressure gradient
Airway pressure is variable	Tidal volume delivered is variable
Merits Constant tidal volume despite changing lung mechanics Better PaCO2 control Familiar mode	**Merits** Less barotrauma Higher mean airway pressure (better oxygenation) Descending ramp flows optimize distribution of ventilation
Demerits Fixed flows/flow starvation/double trigger High peak inspiratory pressure (PIP) leading to Barotrauma	**Demerits** Tidal volume varies with changes in lung characteristics requiring constant monitoring of tidal volume (Vt).
Monitoring: PIP	**Monitoring: Exhaled Vt**

Table 1: Volume Control (VC) versus Pressure Control (PC) modes of ventilation. PIP=Peak inspiratory pressure, Vt=Exhaled tidal volume

Phase variables:

The variables that control each phase of a breath are called phase variables. There are three phase variables: trigger (begins inspiration), target (limits inspiration), cycle (terminates inspiration).

1.) Trigger variables for beginning inspiration

Initiation of breath can be done by the machine or by the patient. Machine triggered breaths are known as time triggered breaths while patient triggered breaths can be pressure, flow or diaphragmatic signal triggered breaths.

Time triggering:

Time triggered breath is initiated solely by the machine. The operator sets a breath frequency for and a breath is delivered after a preset time is reached.

Pressure triggering:

The patient's inspiratory e ort causes a drop in pressure in airway and circuit as patient is breathing against a closed inspiratory port. When pressure falls below the predefined sensitivity threshold, machine switches from expiration to inspiration.

Flow triggering:

A base (bias) gas flow is delivered to patient which circulates in inspiratory and expiratory limbs continuously. In the absence of inspiration, inspiratory gas flow is same as expiratory gas flow. When gas is diverted from expiratory circuit to the patient at initiation of breath, there is discrepancy between these flows. When a flow sensitivity threshold is reached, a ventilator breath is triggered.

Volume triggering:

Some ventilators like Drager Babylog VN500 infant ventilators have volume triggering in which in which a breath is triggered when a preset volume is detected due to patient's e ort.

2.) Limit variables for inspiration (determine size of breath)

Limit variable determines the maximum value a variable can attain in inspiratory phase. It limits the magnitude of a parameter during inspiration but does not end inspiration.

Limit variable is commonly of following types:

- Inspiratory pressure
- Flow or Tidal volume

3.) Cycle variables for termination of inspiratory phase

The variable a ventilator determines for terminating inspiration is called cycling variable.

They are of several types:

Time cycling: The ventilator cycles into expiration and ends the inspiration once a predetermined inspiratory time has elapsed. Inspiratory time (Ti) can be set directly, or by setting ratio of inspiratory to expiratory time (I:E ratio), time spent in active state as fraction of total time (duty cycle=Ti/Ttot), inspiratory pause or it can be calculated from the set tidal volume and inspiratory flows (Ti=tidal volume/inspiratory flow).

Pressure cycling: Pressure cycling occurs when preset peak airway pressure has been reached. This is most often a safety feature with current modes of ventilation.

Flow cycling (or expiratory triggering): Inspiratory phase ends once flow has dropped to a predetermined value during inspiration eg pressure support ventilation (PSV)

Volume cycling: Some ventilators like Puritan Bennett 740 and 760 have volume cycling functions in which inspiration is terminated after a set volume has been delivered.

Baseline variable

Baseline pressure is the pressure level from which ventilator breath starts. It can be either zero (ZEEP) or more commonly above baseline, also known as positive end-expiratory pressure (PEEP). PEEP is an adjunctive treatment that improves oxygenation by increasing the end-expiratory lung volume (EELV). It can be combined with di erent modes of mechanical ventilation.

Outline of mode classification system:

For understanding the di erent modes of mechanical ventilation, it is essential to first know about the basic terminologies, which are described below:

Positive pressure ventilation:

Positive pressure ventilation increases Ptp by increasing alveolar pressure. In contrast, negative pressure ventilation increases Ptp by decreasing pleural pressure. During a positive pressure breath, pressures rise from baseline during inspiration and falls back to baseline during expiration. The definition of these pressures is given below:

a.) Baseline pressure: The baseline pressure could be atmospheric (taken as zero) or higher than atmospheric pressure if extrinsic or instrinsic PEEP is present.

b.) Peak inspiratory pressure (PIP or Ppeak): PIP is the highest pressure recorded at the end of

inspiration. It represents the transrespiratory pressures and is the combination of transairway (resistive) and alveolar (elastic) pressures.

c.) Plateau pressure (Pplat): Plateau pressure represents the alveolar pressures and is measured by a brief inspiratory hold (0.5-1.5 sec) during VC ventilation. During inspiratory hold, there is no air flow in the respiratory system and pressures inside the alveoli and mouth equalize (no gas flow).

d.) Baseline pressure (Pressure at end of exhalation): normally, at end exhalation, the pressure should return to baseline.

Figure 2 shows the various pressures related to positive pressure ventilation.

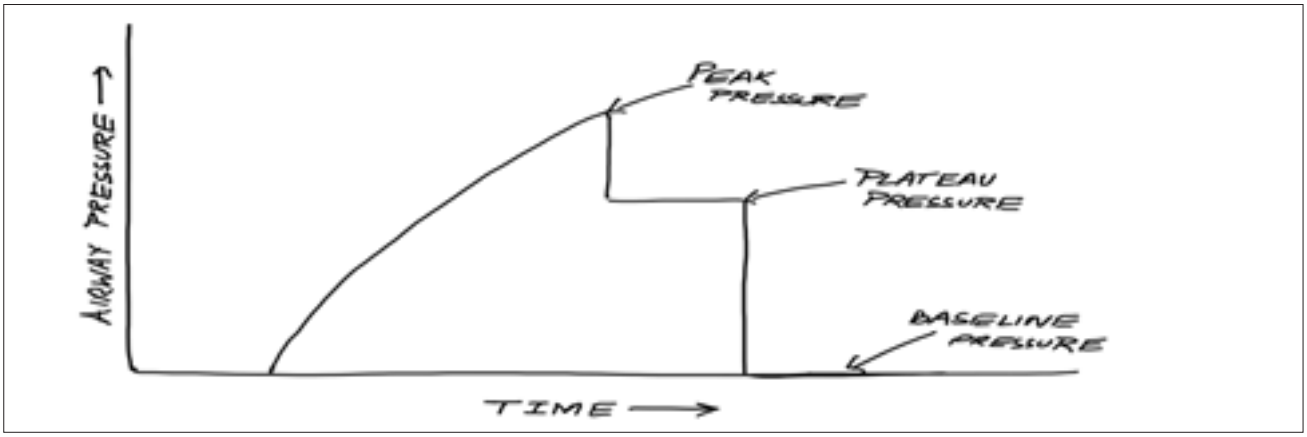


Figure 2: Airway pressure graph during volume control (VC) ventilation showing baseline pressure, peak pressure plateau pressure and auto-PEEP

Breath:

A breath is one cycle of positive flow (inspiration) and negative flow (expiration)

Types of breath:

A breath can be classified into following types depending upon the work done by patient or machine in trigger, limit and cycling of breath as shown below:

a) **Mandatory breath**
b) **Assisted breath**
c) **Supported breath**
d) **Spontaneous breath**

Table 2 shows the various types of breaths associated with mechanical ventilation.

Breath	Trigger	Limit	Cycle
Mandatory	Machine	Machine	Machine
Assisted	Patient	Machine	Machine
Supported	Patient	Machine	Patient
Spontaneous	Patient	Patient	Patient

Table 2: Classification of breath into mandatory, assisted, supported and spontaneous types

Breath sequences:

Based on spontaneous and mandatory breaths, ventilators deliver only three breath sequences:

1. Continuous mandatory ventilation (CMV): all mandatory breaths
2. Intermittent mandatory ventilation (IMV): spontaneous breaths between mandatory breaths
3. Continuous spontaneous ventilation (CSV): all spontaneous breaths

So, with above basic understanding about the various terminologies, modes of ventilation are classified as follows:

A mode of ventilation refers to the method of inspiratory support provided by mechanical ventilator. **The modes of ventilation can be classified into two types:**

1. Traditional (older) modes of ventilation
2. Newer modes of ventilation

Traditional (older) modes:

Traditional modes of ventilation are further classified into:

1. **Mandatory (all breaths are mandatory):**
   - a) **Continuous mandatory ventilation (CMV)**
   - b) **Assist Control Ventilation (ACV)**
2. **Combined (both mandatory and spontaneous breaths):**
   - a) **Intermittent mandatory ventilation (IMV)**
   - b) **Synchronized intermittent mandatory ventilation (SIMV)**
   - c) **SIMV±PS**
3. **Spontaneous (only spontaneous breaths):**
   - a) **PSV±CPAP**

Continuous mandatory ventilation (CMV):

Machine decides all phases of breath. Only mandatory breaths are present.

Assist control ventilation (ACV):

In ACV, breaths can be triggered by patient (unlike CMV) if the set machine rate does not match patient's demands. There is a backup ventilator rate set on machine (if there is no patient triggering). However, breath once initiated is fully supported by the machine.

Intermittent mandatory ventilation (IMV):

Patient can breathe spontaneously between mandatory breaths (unlike above modes) without any assistance from machine. However, breath stacking may occur if patient is exhaling while the machine is delivering a breath as there is no synchrony between machine and patient.

Synchronized intermittent mandatory ventilation (SIMV):

In SIMV, the patient can breathe spontaneously between mandatory breaths. However, the ventilator synchronizes with patient's e orts by incorporating a 'synchronization window' before each time triggered breath wherein the ventilator synchronizes its breath with patient's breaths. Thus, breath stacking does not occur (unlike IMV). Machine senses & delivers breath in concert with patient's e ort.

SIMV+Pressure support (PS):

Along with SIMV, pressure support (PS) is applied to support the spontaneous breaths (to decrease work

of breathing required to overcome resistance of circuit and tube).

Pressure support ventilation (PSV):

In PSV, a certain amount of pressure support above baseline is added to each patient's breath to overcome ventilator circuit and endotracheal tube resistance.

Continuous positive airway pressure (CPAP):

In CPAP, continuous positive pressure is applied above the baseline in both inspiration and expiration. The patient breathes spontaneously at this baseline pressure throughout respiration. CPAP can also be applied non-invasively.

Table 3 summarizes the various modes of ventilation.

Mode	Control	Trigger	Limit	Cycle	Breath	Salient points
CMV	VC,PC	Time	Volume/Pressure	Time	Mandatory	Uncomfortable Sedation and paralysis needed
ACV	VC,PC	Time, Patient	Volume/Pressure	Time	Mandatory Assisted	Hyperventilation and respiratory alkalosis
IMV	VC,PC	Time, Patient	Volume/Pressure	Time Patient	Mandatory Spontaneous	Air trapping
SIMV	VC,PC	Time, Patient	Volume/Pressure	Time Patient	Mandatory Assisted Spontaneous	Synchronization window Less air trapping (unlike IMV)
SIMV+ PS	VC, PC	Time, Patient	Volume/Pressure	Time Patient Flow	Mandatory Assisted Spontaneous Supported	
PSV	Pressure	Patient	Pressure	Flow	Supported	Set pressure support appropriately
CPAP	Patient determined	Patient	Patient	Patient	Spontaneous	

Table 3: Summary of basic modes of ventilation; CMV=Continuous Mandatory Ventilation, ACV= Assist Control Ventilation, IMV=Intermittent Mandatory Ventilation, SIMV=Synchronized Intermittent Mandatory Ventilation, PSV=Pressure Support Ventilation, CPAP=Continuous Positive Airway pressure, VC=Volume Control, PC=Pressure Control, PS=Pressure Support

Limitations of older modes of ventilation

The older modes of ventilation do not have any feedback mechanism to adjust their output. So, they are not very sensitive to patient's demands. To overcome this problem, newer modes of ventilation have been developed which have many advanced features.

Newer modes of ventilation:

Closed loop modes based on feedback enhancements of conventional ventilator breaths:

The feedback mechanisms modify conventional breaths by adjusting breath delivery variables based on an algorithm. Therefore, physiologically targeted breath with better patient-ventilator synchrony is delivered. These feedback mechanisms are of several types:

1. **Feedback control of pressure targeted and flow targeted breaths**

   Feedback control of pressure and flow targeted breaths can be within a breath or between two breaths. These breaths are known as hybrid or dual control breaths.

a. **Dual control within a breath (DCWB; intra-breath control)**

   Volume assured pressure support (VAPS; Bird 8400) or Pressure augmentation mode (PAug; Bear 1000):

   VAPS breath is similar to pressure support (PSV) breath. However, the clinician additionally sets a minimum tidal volume (V_T), inspiratory flow and back up rate. So, the breath starts as a PSV but if desired V_T is not reached, it can switch over to flow targeted (VCV) breath within the same inspiratory time period.

   Recently, DCWB modes have been replaced by dual control breath to breath (DCBB) modes.

b. **Dual control breath to breath (DCBB; inter-breath control)**

   Pressure regulated volume control (PRVC; servo i):

   PRVC is DCBB mode in which pressure targeted breaths are delivered to achieve the desired V_T. There are various other proprietary names for PRVC like autoflow (Drager), adaptive pressure ventilation (Hamilton), VC+ (Covidien), volume targeted pressure control (Newport E 500).

   Initially, the desired V_T is set by operator along with FiO2, PEEP, trigger, inspiratory time and pressure limit. The ventilator then delivers one or more test breaths with a small inspiratory pressure (PCV) to calculate the V_T delivered by ventilator (not exhaled V_T) and the compliance of respiratory system. Each consecutive breath then uses the previous calculations to adjust its inspiratory pressure so that the set $V_T$can be achieved. The pressure change between breaths is limited to <3 cm H2 and the ventilator can increase its pressure level only upto 5 cm H2O below the maximum pressure limit set by operator.

   Volume support(VS; servo i)

   When DCBB mode is provided exclusively with flow cycling, this mode is referred to as volume support.VS is a spontaneous mode where 'minimum' $V_T$is set by operator along with FiO2, PEEP, and pressure limit. The patient triggers and breaths at his own rate and V_T. If V_T falls below the set value, pressure support is increased by ventilator in subsequent breaths to achieve the minimal V_T. So, VS behaves like PSV with volume targeting where PS changes from breath to breath.

   The *AutoMode*in Maquet (servo i, servo 300A)switches from control modes like VC, PRVC to VS (and from PC to PSV) if there are two consecutive triggering e orts from patient and vice versa if patient is apnoeic.

c. **Tidal volume feedback modes that enhance DCBB principle**

   SmartCare in Drager (also known as NeoGanesh):

   SmartCare is a modification of PSV wherein computerized feedback signals are taken from end-tidal CO2, respiratory rate and tidal volumeof the patient to adjust applied pressure support. These

feedback signals attempt to find the minimum pressure support level that can keeps the above parameters in a "clinician-set comfort zone". Thus, it acts as an automatic weaning mode.

2. **Feedback control based on respiratory mechanics**

Adaptive support ventilation (ASV; Hamilton):

ASV is based on principle of DCBB with an integrated V_T, frequency and I: E ratio algorithm. The operator sets predicted body weight (PBW), target minute ventilation (as % of normal minute ventilation), PEEP, FiO2, trigger and maximum pressure limit. Test breaths (pressure targeted) are then delivered by ventilator to calculate respiratory system mechanics. Thereafter, "minimal work" calculation is done to set the respiratory rate-V_T combination that leads to minimal work of breathing to achieve the target minute ventilation. The ventilator switches over from PC mode to PSV mode if patient's e orts increase. Thus, ASV also acts as weaning mode.

3. **Feedback systems driven by novel sensors of patient-e ort**

Proportional assist ventilation (PAV):

PAV is similar to PSV except that the pressure limit is not set by operator rather the ventilator amplifies patient's e orts by generating pressure in proportion to the instantaneous patient e ort. The patient controls his breathing pattern and amplitude and duration of ventilator assist synchronizes with patient's e orts.

Neutrally adjusted ventilatory assist (NAVA):

NAVA is a mode of ventilation for spontaneously breathing patients. It utilizes diaphragmatic electrical activity (Edi), measured by an esophageal catheter containing several electrodes placed in lower part of esophagus(at the level of diaphragm), to trigger and drive ventilator. The ventilator is triggered as soon as diaphragm contracts, thus improving patient-ventilator interaction. NAVA provides pressure and flow augmentation in proportion to diaphragmatic signals.

Other newer modes of ventilation

Airway pressure release ventilation (APRV)

APRV is also known as biphasic positive airway pressure (BIPAP) and bilevel airway pressure (Bilevel). APRV operates by time cycled switching between two pressure levels (Phigh20-30 cm H2O and Plow 0-5cm H2O) in a high flow CPAP circuit. Respiratory compliance and pressure di erence between the two CPAP levels determines the mechanically delivered V_T. The degree of ventilator support depends upon the duration of CPAP levels (Thigh 4-6sec and Tlow 0.5-1sec) and V_T. Patient can breathe spontaneously in both phases of ventilator cycle. Thus, APRV functions like PC,inverse ratio ventilation (PC-IRV)with unrestricted spontaneous breathing and only as PC-IRV when spontaneous breathing is absent.

Initial ventilator settings:

Initial ventilator settings include:

1. **Choice of inspired gas combination (eg oxygen and air combination)**
2. **Triggering mechanism (eg time, pressure, flow)**
3. **Volume control (VC) mode**

Main controls for improving oxygenation in VC mode:

- FiO2
- PEEP

- Inspiratory Time (Ti): determine duration of inspiration in seconds. Ti can be set directly or from following parameters:
    - Inspiration : Expiration ratio (I:E ratio): 1:2 (usually)
    - Total cycle time (TCT)= Inspiratory time (Ti) + Expiratory time (Te); Ti=TCT-Te
    - Inspiratory hold/pause (Pause time/Plateau time): Inspiratory hold increases inspiratory time and allows redistribution of flows between heterogeneous alveoli thus improving oxygenation

Main controls for improving ventilation in VC mode:

- Tidal volume
- Respiratory rate
- I:E ratio: More time for expiration can be given in obstructive airway diseases to minimize air trapping-

Other settings in VC mode:

- Inspiratory flows: 40-80 L/min. Flows can also be set from tidal volume (Vt) and Ti; as Vt= flow × Ti; flow=Vt/Ti
- Flow pattern: Rectangular, Sine, Ascending or Descending flow pattern can be set

4. Pressure control (PC) mode

Main controls for improving oxygenation in PC mode:

- FiO2
- PEEP
- I:E ratio to allow more time for inspiration

Main controls for improving ventilation in PC mode:

- PC above PEEP
- Respiratory rate
- I:E ratio to allow more time for expiration

Other settings in PC mode:

- Rise time (also known as inspiratory slope, P-ramp, plateau%, or slope rise time): Rise time allows synchrony between machine and patient. It is normally kept between 0.15-0.2 secs or 5-10%

5. Alarm limits for detecting unsafe events

Macintyre has prioritized unsafe events into di erent levels:

Level 1 events (life threatening situations eg loss of input power or ventilator malfunction, insu cient or excessive gas delivery to patient, exhalation valve failure). These alarm indicators are mandatory and nonannealing.

Level 2 events (life threatening situations if not corrected in timely fashion eg air-oxygen blender failure, inadequate or excess PEEP, auto-triggering, circuit leak, failure of humidification system). They may be self-cancelling alarms once the event ceases.

Level 3 events (events which indicate changes in amount of ventilator support provided to patient due to changes in compliance, resistance, respiratory drive, auto-PEEP)

Final ventilator settings

The final ventilator settings are tailored by the required therapeutic end points of commonly encountered respiratory failure syndromes:

ARDS:

Goal is minimization of ventilator induced injury by using lung protective ventilation strategy which incorporates low tidal volumes to keep Plat< 30cm H2O and optimal PEEP. Optimal PEEP in ARDS should be able to recruit as many non-aerated alveoli as possible without inducing lung overdistension, hemodynamic impairment and global and regional disturbances of oxygen balance.

COPD:

Goal is to minimize dynamic hyperinflation and help in patient triggering by giving extrinsic PEEP in expiratory flow limitation. The ventilator adjustments are geared towards lowering mean expiratory flow (mean expiratory flow= Tidal volume (V_T)/expiratory time (T_E)]

Neuromuscular disease:

Goal is to rest the respiratory muscles, reverse altered sensorium and correct gas exchange.

Harmful e ects of ventilation

Mechanical ventilation is a double edged sword which has some deleterious e ects also, namely, pulmonary overdistension (leading to barotrauma, VILI, increased dead space), reduced diaphragmatic force generating capacity, ventilator-induced diaphragm dysfunction, pneumonia, reduced cardiac output and oxygen delivery, impaired renal function, hepatic congestion and reduced splanchnic blood flow.

Non Invasive Ventilation

Non-invasive ventilation (NIV) refers to technique of providing ventilatory support without bypassing the natural airway passage. It avoids any invasive airway access to support the ventilation. This avoids many of the complication that arises due to invasive airway access. Equipment required for NIV are simple, portable, easy to operate and require less training as compared to conventional mechanical ventilation.

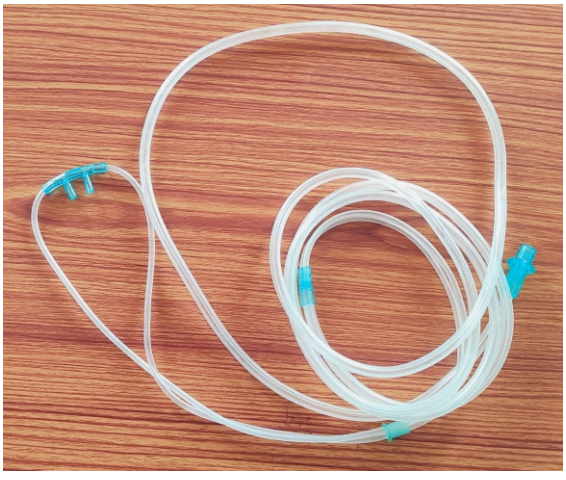
1. Historical background: The history of Non-invasive ventilation (NIV) ways back in the mid-eighteen century. Initial respirators worked on principle of negative pressure ventilation. In 1864, Alfred F. Jones' patented the first American tank respirator called iron lung, using non-invasive negative pressure ventilation. In 1878, Oertel described the use of intermittent positive pressure (NPPV) for the first time.

During the polio epidemic, very high mortality (more than 80%) triggered widespread use of respirators. However, initial designs used negative pressure ventilation and logistically di cult to operate, they reduced mortality to 50 %. Most of them were manual and hand operated. Over the past century, positive pressure ventilation (NPPV) has been dramatically improved and used to treat respiratory failure from multiple etiologies. It has been proven e ective in preventing intubation compared to standard oxygen therapy in the acute setting. NPPV encompasses several methods of respiratory support, the most common being Bilevel Positive Airway Pressure (BPAP).

Many studies have proved e cacy of NIV in respiratory failure. The latest American Thoracic Society/European Respiratory Journal guidelines support the use of NPPV in acute exacerbation of chronic obstructive pulmonary disease and acute respiratory failure secondary to cardiogenic pulmonary edema, where evidence and level of recommendation are the strongest.

2. NIV Types: NIV can be classified as A. CPAP, B. BIPAP, C. HFNO. Although some classification also includes low flow nasal cannula and other oxygen delivery devices in this classification but technically, they don't o er any ventilatory support, they just provide oxygen and hence should not be considered as ventilatory support.

A. CPAP (Continuous positive airway pressure): CPAP is a continuous positive pressure that is applied throughout the respiratory cycle, both in inspiration and expiration. It keeps the alveoli open and prevents its collapse. It also removes fluid from the lung and reduces pulmonary oedema. It also keeps the upper airway patent and prevents apnoea in patient with obstructive sleep apnoea. When used in BIPAP, CPAP is usually referred as PEEP (Positive End Expiratory Pressure).

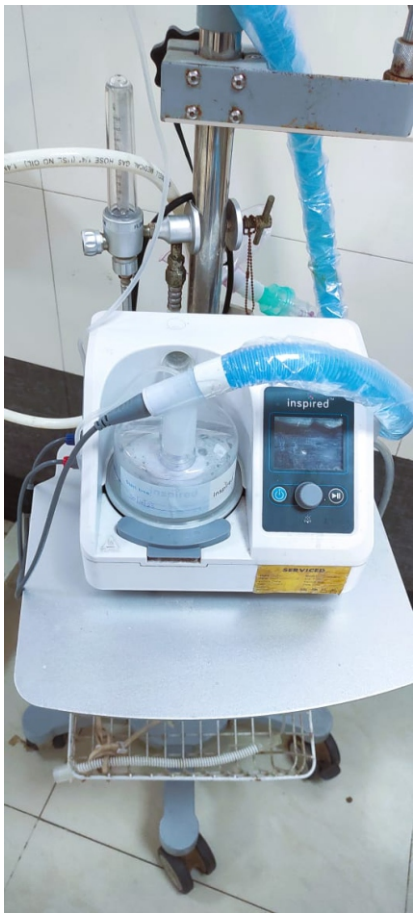


B. BIPAP (Bilevel Positive Airway Pressure): In this type of NIV the airway pressure changes with inspiration and expiration. There is a lower end expiratory airway pressure (EPAP) and a higher end inspiratory airway pressure (IPAP). The di erence between IPAP and EPAP is called Support Pressure (PS). It reduces the work of breathing along with benefits of CPAP.

C. HFNO (High Flow Nasal Oxygenation): It is commonly provided by a device called HFNC (High Flow Nasal Cannula). It provides warm and humidified oxygen with high flows. Owing to its high flow, HFNC provides some amount of CPAP or PEEP to the patient, thus providing some ventilatory support.

3. Positive Vs Negative pressure NIV: Negative pressure ventilation is a type of ventilation in which a negative airway pressure is generated by outward expansion of chest wall and pleura, thus sucking the air inside like a vacuum pump. It is physiological ventilation and normal physiological breathing occurs through negative pressure. The elastic recoil provides force for expiration. Positive pressure ventilation is a non-physiological ventilation in which air is forced inside the lungs with pressure and chest wall expands by the positive pressure created by this. Expiration is passive due to elastic recoil of lung and chest wall.

4. High flow Nasal Cannula Oxygen Non- Invasive Ventilation: High-Flow Nasal Oxygen (HFNO) administration is a relatively new technique that is used in the intensive care unit (ICU), and increasingly in the operating room (OR). HFNO has become popular in the ICU for management of patients with acute hypoxemic respiratory failure when attempting to avoid intubation or to help after extubation. Sometimes in ICU and anesthesia, HFNO has been referred to as THRIVE—an abbreviation for Transnasal Humidified Rapid-Insu ation Ventilatory Exchange. When patients are administered low flow nasal O_2, the oxygen flow rates are typically between 2–10 liters/minute (L/M). Spontaneously breathing patients typically have an inspiratory flow rate (IFR) of 20–40 L/M. Once the IFR exceeds the flow of O_2 coming from the nasal cannulae, room air will be entrained which dilutes the FiO_2. The e ective delivered oxygen concentration (which reaches the lungs) is usually 25–30%, if a patient is receiving 2–4 L/M of nasal O_2. In contrast, HFNO uses oxygen flows of 50–100 L/M. With this technique, the high flows delivered via the specially designed nasal cannulae now exceed the patient's IFR. Therefore, there is little entrainment of room air which allows the delivery of a high FiO_2 (95–100%).



The components of a HFNO system are:

1. An electrically powered high-pressure oxygen/air supply (ideally with a blender to blend air into the gas flow to reduce the FiO_2 if needed)
2. A flowmeter capable of flows of up to 100 liters per minute
3. A humidifier capable of fully humidifying the inspired oxygen/air mixture

4. Wide bore tubing to deliver gas from the gas supply to the nasal cannulae
5. Specialized wide bore nasal cannulae, which convey the oxygen/air blend from the gas tubing to the patient's nose.

Beneficial physiologic e ects of HFNO

HFNO has a number of beneficial e ects not provided by standard nasal cannula. At high flow rates, it can provide continuous positive airway pressure (CPAP), washes out CO_2 from the respiratory dead space, and assists the process of oxygen di usion into the alveoli (replacing oxygen which has been absorbed). In addition, it can reduce the work of breathing and reduce airway resistance.

Contraindications to and risks of HFNO

A. Relative contraindications to HFNO are

1. Partial nasal obstruction
2. Disrupted airway, e.g., laryngeal fracture, mucosal tear, or tracheal rupture
3. Need for laser or diathermy (electrosurgery) in proximity to the administration of HFNO which increases fire risk.
4. Contagious pulmonary infections, such as tuberculosis, COVID 19
5. Nasal infection resulting in pulmonary seeding with HFNO use is a theoretical concern. However, there is no evidence to date that demonstrates pulmonary seeding with HFNO.
6. Contraindications to high concentrations of oxygen (e.g., prior bleomycin chemotherapy)
7. Inability to tolerate hypercarbia if HFNO is used with prolonged apnea (e.g., patients with sickle cell anemia, pulmonary hypertension, intracranial hypertension, and some forms of congenital heart disease)

B. Absolute contraindications to HFNO are

1. Known or suspected skull base fractures, CSF leaks, or any other communication from the nasal to the intracranial space
2. Significant pneumothorax which has not been treated with a chest tube. The CPAP e ect may expand the pneumothorax.
3. Complete nasal obstruction
4. Active epistaxis or recent functional endoscopic sinus surgery (FESS).

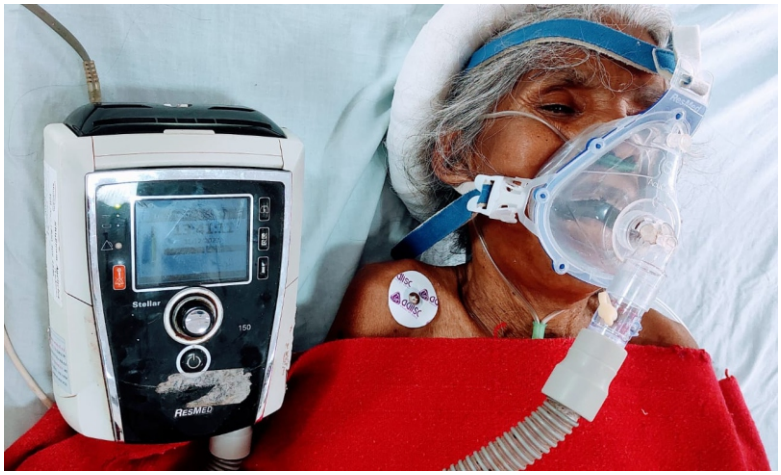


PHOTO of Bi-PAP/HFNC,

PHOTO of BiPAP Mask, A- Nasal, B- Oral, C- Oro Nasal D-Hood

PHOTO of Patient on HFNO/BiPAP

5. Indications and Contradictions of NIV: NIV is strongly recommendation for the following in the setting of acute respiratory failure (ARF):

- BPAP for acute or acute-on-chronic respiratory acidosis secondary to COPD exacerbation where pH </= 7.35
- BPAP is the prevention of endotracheal intubation and mechanical ventilation in a patient that is not immediately deteriorating.
- BPAP or continuous positive airway pressure (CPAP) for cardiogenic pulmonary edema
- Early NIV for immunocompromised patients with ARF
- Post-operative ARF
- As palliation to dyspneic patients in the setting of terminal cancer or other terminal conditions
- Chest trauma patients with ARF
- Prevention of post-extubation respiratory failure in high-risk patients

In addition, NPPV has been e ective in treating various chronic respiratory diseases. These diseases include chronic stable COPD with hypercapnia, obesity hypoventilation syndrome, obstructive sleep apnea, respiratory failure secondary to neuromuscular disease, and restrictive thoracic disorders.

Absolute Contraindications:

- Facial trauma/burns
- Fixed upper airway obstruction
- Active vomiting
- Respiratory or cardiac arrest

Relative Contraindications

- A recent facial, upper airway, or upper GI tract surgery
- Inability to protect the airway
- Life-threatening hypoxemia
- Medical or hemodynamic instability (hypotensive shock, myocardial infarction requiring intervention, uncontrolled ischemia or arrhythmias)
- Altered mental status/agitation
- Bowel obstruction
- Copious respiratory secretions
- Focal consolidation
- Undrained pneumothorax

Clinical prerequisite to start NIV:

- Patient cooperation (an essential component that excludes

agitated, belligerent, or comatose patients)

- Dyspnea (moderate to severe, but short of respiratory failure)
- Tachypnea (>24 breaths/min)
- Increased work of breathing (accessory muscle use, pursed-lips breathing)
- Respiratory acidosis (pH range 7.10-7.35)
- Hypoxemia (PaO_2/FIO_2< 200 mm Hg, best in rapidly reversible causes of hypoxemia)

5. **Equipment for Non Invasive Ventilation:** To initiate NIV, an interface and a positive pressure source is required. There can be many interface that may be used for providing NIV such as nasal mask, face mask, helmet etc. but face mask is most commonly used interface. Mask should be soft and tight fitting so that no air leak should occur. Mask should cover both nostrils and mouth. It should cover from bridge of the nose to below lower lips. It must have adjustable straps to keep the mask in place and air release valve to expel expiratory air. Typically, the smallest mask providing a proper fit is the most e ective. Straps hold the mask in place, with care to minimize excess pressure on the face or nose. Leaks are the bane of all of the interfaces, but excess pressure applied with the straps increases the risk of pressure necrosis and skin breakdown. Straps should be tight enough to prevent leaks, but with enough slack to allow passage of one or two fingers between the face and the straps. Source of positive pressure can be a portable CPAP/BIPAP machine or an standard ventilator with NIV mode.

6. **Modes of Ventilation in NIV:** Various modes of NIV are available and can di er to some extant from machine to machine. However, some common modes of NIV available in almost all machines are:

   A. Spontaneous modes: In this mode, only Spontaneous breaths are given and no controlled breaths are allowed. Patient triggers the breath and preset pressure support (IPAP- EPAP) is provided by the machine. Tidal volume delivered depends upon lung compliance and support pressure. Because each cycle is terminated by a flow criterion rather than by volume or time, the patient retains control of cycle length as well as its depth and flow profile This mode is also called 'pressure support ventilation' (PSV).

   B. Timed/ controlled mode: In this mode, all breaths are controlled and given by machine. No spontaneous breathes are allowed. Breath is triggered by time as set by setting respiratory rate. Either tidal volume or support pressure is set which determines the delivered tidal volume. Cycle is terminated by time and patient has no control over it. It can lead to asynchronous respiration especially if patient is fully awake. It can be used for short time in COPD with high PCO2 but there is risk of aspiration.

   C. Spontaneous-timed mode: it is combination of spontaneous and timed mode. All spontaneous breaths are supported and controlled breaths are given is respiratory rate is below preset value.

D. Pressure controlled (PC): In PC ventilation, both the inspiratory pressure and the inspiratory time are set and fixed. This di ers from BiPAP in which the patient controls the inspiratory time. This modality may be useful in the neuromuscular disease patient who does not have the respiratory muscle strength to generate an adequate inspiratory time. Setting an increased inspiratory time may increase the tidal volume provided, but it may also increase patient-ventilator dyssynchrony if the set inspiratory time is longer than the patient's desired inspiratory time.

E. Average volume assured Pressure support (AVAPS): AVAPS is another option in neuromuscular disease patients and severe obesity-hypoventilation syndrome. It should be noted that AVAPS is not generally used for those patients with acute respiratory distress and is better suited for management as they recover or have recovered from their acute decompensated state. As with any pressure-cycled mode, the dependent variable is volume and it may vary widely if there is patient dyssynchrony, changes in lung compliance, or changes in resistance that can occur with changes in body position that occurs in the very morbidly obese. A fixed pressure support setting will not compensate for these changes, and, as a result, delivered tidal volume will fall. AVAPS allows a target tidal volume to be identified with a range of pressure support settings that fluctuate to meet the target tidal volume. AVAPS uses an internal algorithm to make changes in the pressure support supplied to achieve the target volume, but these changes are small and occur over minutes (typically 1-2.5 cm water per minute). That is why rapidly changing, acute respiratory conditions are not suited for AVAPS as the ventilator adjustments may not be timely enough to meet the patient's requirements. Typically, the pressure support required to produce the target volume during bedside titration is used to identify the minimal pressure with the set minimal pressure (min P), typically 2-3 cm water lower to allow flexibility for adjustment in the AVAPS mode. The maximal pressure (max P) is typically set in the 20-25 cm water range as higher pressures are not well tolerated. The min P is at least 8 cm water and usually higher. Additional parameters that are part of AVAPS setting are the target tidal volume, respiratory rate, EPAP, and inspiratory time.

8. IPAP and EPAP in NIV: Initial IPAP/EPAP settings are as follows:

- Start at 10 cm water/5 cm water
- Pressures less than 8 cm water/4 cm water not advised as this may be inadequate
- Initial adjustments to achieve tidal volume of 5-7 mL/kg (IPAP and/or EPAP)

Subsequent adjustments based on arterial blood gas values are as follows:

- Increase IPAP by 2 cm water if persistent hypercapnia
- Increase IPAP and EPAP by 2 cm water if persistent hypoxemia
- Maximal IPAP limited to 20-25 cm water (avoids gastric distension, improves patient comfort)

- Maximal EPAP limited to 10-15 cm water

- Maximal EPAP limited to 10-15 cm water
- FIO_2 at 1.0 and adjust to lowest level with an acceptable pulse oximetry value
- Back up respiratory rate 12-16 breaths/minute

Monitoring of Patient Receiving Non-Invasive Ventilation in the Acute Care Setting:

1. **BEDSIDE OBSERVATION**
   - Consciousness level
   - Comfort level
   - Chest movements
   - Accessory muscle use
   - Patient-ventilator synchrony

2. **VITAL SIGNS**
   - Respiratory Rate
   - Exhaled tidal volume (and flow, volume, and pressure waveform for poor synchrony problems)
   - Heart rate
   - Blood Pressure
   - Continuous electrocardiography
3. **GAS EXCHANGE**
   - Pulseoximetry
   - Arterial blood gas analysis as clinically indicated

Predictors of success, with a response to a trial of NIV (1-2 h), are as follows:

- Decrease in $PaCO_2$ greater than 8 mm Hg
- Improvement in pH greater than 0.06
- Correction of respiratory acidosis

Predictors of failure are as follows:

- Severity of illness - Acidosis (pH < 7.25), hypercapnia (>80 and pH < 7.25), Acute Physiology and Chronic Health Evaluation II (APACHE II) score higher than 20
- Level of consciousness - Neurologic score (>4 = stuporous, arousal only after vigorous stimulation; inconsistently follows commands), encephalopathy score (>3 = major confusion, daytime sleepiness or agitation), Glasgow Coma Scale score lower than 8
- Failure of improvement with 12-24 hours of noninvasive ventilation

Late admission predictors of failure (>48 h after initiation of noninvasive ventilation) are as follows:

- Lower functional status (Activity score < 2 = dyspnea light activity)
- Initial acidosis (pH ≤7.22)
- Hospital complications (pneumonia, shock, coma)

Certain patients may benefit from a trial of therapy; however, limiting trials is important to avoid delays in definitive therapy. Trials may be as short as a few minutes, in patients with immediate failure, and

probably should not exceed 2 hours if patients fail to improve.

Objective criteria for discontinuation are important to limit trials in patients in whom noninvasive ventilation ultimately fails. This specifically refers to intubation criteria, which carry a subjective element but have been defined in the literature in investigational studies. All these criteria are subject to some degree of interpretation in the context of the patient's clinical status. Importantly, recognize the following as guidelines to assist with the decision to intubate a patient. Most patients who meet these criteria are candidates for intubation, but a few may be able to be managed with continued noninvasive ventilation.

Prediction of failure to high-flow nasal cannula oxygen

Although the focus has been on noninvasive ventilation (NIV), there has been increasing use of high-flow nasal cannula (HFNC) oxygen in clinical situations where NIV had previously been used. This also warrants objective measures that may identify patients in whom HFNC oxygen support fails and who require intubation. This is important, as delayed intubation of patients with progressive hypoxemic respiratory failure has been associated with increased mortality. This led to the identification of the ROX index, defined as the ratio of pulse oximetry oxygen saturation and fraction of inspired oxygen to respiratory rate [(SpO_2/FIO_2)/RR]. In an inception and validation cohort of patients with pneumonia and on HFNC oxygen, values of the ROX index greater than 4.88 measured at 2, 6, and 12 hours, 18 and 24 hours after initiation of HFNC were found to identify those patients who would not need intubation.[9] Lower ROX index scores not only identified those requiring intubation, but was also associated with poor outcomes, specifically mortality. The authors identified the hours between the 12th and 24th hours as the most vulnerable in their cohort, with an increased risk of failure in those with ROX index scores lower than 3.85.

Intubation criteria

Major criteria (any one of the following) are as follows[10,11]:

- Respiratory arrest
- Loss of consciousness with respiratory pauses
- Gasping for air
- Psychomotor agitation requiring sedation
- Heart rate less than 50 bpm with loss of alertness
- Hemodynamic instability with systolic blood pressure less than 70 mm Hg

Minor criteria (two of the following) are as follows:

- Respiratory rate greater than 35 breaths/minute
- pH less than 7.25 and decreased from onset
- PaO_2 less than 45 mm Hg despite oxygen
- Increase in encephalopathy or decreased level of consciousness

Intubation guidelines

Any one of the following[12]:

- pH less than 7.20
- pH 7.20–7.25 on 2 occasions 1 hour apart
- Hypercapnic coma (Glasgow Coma Scale score < 8 and $PaCO_2$ >60 mm Hg)

- PaO_2 less than 45 mm Hg
- Cardiopulmonary arrest

Two or more of the following in the context of respiratory distress:

- Respiratory rate greater than 35 breaths/minute or less than 6 breaths/minute
- Tidal volume less than 5 mL/kg
- Blood pressure changes, with systolic less than 90 mm Hg
- Oxygen desaturation to less than 90% despite adequate supplemental oxygen
- Hypercapnia ($PaCO_2$ >10 mm increase) or acidosis (pH decline >0.08) from baseline
- Obtundation
- Diaphoresis
- Abdominal paradox
- 11. Predictors of success and failure in NIV

12. Objective criteria for discontinuation of NIV

13. Major and minor criteria for Intubation of patients using NIV

14. Benefits and limitations of NIV in COPD: Patients with underlying chronic obstructive pulmonary disease (COPD) who present with an exacerbation of their COPD and hypercapnic respiratory distress or respiratory failure are the group most likely to be successfully treated with noninvasive ventilation (NIV). Exacerbations increase the work of breathing in these patients and may exceed the patient's ability to adequately ventilate through a variety of mechanisms, including increasing hyperinflation with decreased diaphragmatic excursion and strength, increasing intrinsic positive end-expiratory pressure (PEEP), ine ective or inadequate tidal volume generation, respiratory patterns, and increased respiratory frequency. Noninvasive ventilation e ectively unloads the respiratory muscles, increasing tidal volume, decreasing the respiratory rate, and decreasing the diaphragmatic work of breathing, which translates to an improvement in oxygenation, a reduction in hypercapnia, and an improvement in dyspnea. COPD is an ideal condition for noninvasive ventilation, given the rapid reversibility with treatment and added support that can be provided by noninvasive ventilation. Most experience with noninvasive ventilation has accrued with either bilevel positive airway pressure (BiPAP) or pressure support ventilation, less so with volume ventilation and continuous positive airway pressure (CPAP), which is infrequently used as a mode of ventilatory support in these patients.

15. NIV in CHF and Cardiogenic Pulmonary edema. Respiratory insu ciency due to cardiogenic pulmonary edema or congestive heart failure (CHF) is another condition that is e ectively treated with noninvasive ventilation (NIV). Respiratory failure due to heart failure is potentially a rapidly reversible condition, similar in its reversibility to decompensated chronic obstructive pulmonary disease (COPD), and noninvasive ventilation is an ideal adjunct to the other treatments used in the management of CHF.

The pathophysiology of respiratory failure in CHF is related to a combination of pulmonary vascular congestion, interstitial edema, and alveolar fluid accumulation. This leads initially to hypoxemic respiratory failure, and patients with CHF who further deteriorate manifest hypercapnic respiratory failure. Positive-pressure ventilation is beneficial because it recruits alveoli, increases functional residual capacity, and allows breathing on the more compliant portion of the lung's pressure-volume curve, thereby decreasing the work of breathing, improving ventilation-perfusion relationships, and eventually correcting hypoxemia and hypercapnia. Positive intrathoracic pressure also decreases

preload and left ventricular afterload, both beneficial e ects in patients with intravascular volume overload.

These beneficial e ects can be achieved with continuous positive airway pressure (CPAP), which has been recommended as a first-line therapy in CHF patients. The other ventilator modalities, such as bilevel positive airway pressure (BiPAP), pressure support ventilation, or volume ventilation, have also been used and some controversy exists regarding their e cacy when compared with CPAP.

Noninvasive ventilation is well suited for patients with cardiogenic pulmonary edema.

CPAP and BiPAP modalities both are e ective, with CPAP possibly being more e ective.

The greatest benefits are realized in relief of symptoms and dyspnea.

A decrease in intubation and mortality rates is not a universal experience.

Patients with hypercapnic respiratory acidosis may derive the greatest benefit from noninvasive ventilation.

Importantly, adjust to standard therapy, including diuresis.

Benefit may be seen with as few as 2 hours of support.

16. Postextubation non-invasive Ventilation support: Postextubation respiratory insu ciency requiring reintubation can occur in more than 20% of patients. Many of the pathophysiologic derangements discussed in earlier sections also occur in the postextubation period, including increased respiratory load, hyperinflation, diaphragmatic dysfunction, and increases in preload and afterload, all of which can contribute singly or in unison to hypercapnia, hypoxemia, and eventual respiratory failure. In addition, patients may have incurred some upper airway trauma with intubation or may have developed upper airway edema, which, in turn, can contribute to partial upper airway obstruction, which is another factor contributing to an increased respiratory workload.

Noninvasive ventilation can ameliorate some of the pathophysiologic derangements that occur following extubation and has been used in 2 primary postextubation scenarios. Patients in whom weaning trials have failed or those who do not meet extubation criteria have been extubated to noninvasive ventilation support as part of an early extubation approach or as an adjunct to weaning. Early extubation with noninvasive ventilation support may be able to prevent some of the complications associated with endotracheal intubation, specifically nosocomial pneumonia. In addition, noninvasive ventilation allows for speech with preservation of oropharyngeal function. Noninvasive ventilation has also been applied to patients who were identified as candidates for extubation based on weaning and/or extubation criteria but then developed postextubation respiratory distress.

While mixed groups of patients are encountered, the vast majority of patients managed with postextubation noninvasive ventilation support have had underlying chronic obstructive pulmonary disease (COPD), and this is the population that seems especially suited to noninvasive ventilation in general and, specifically, to noninvasive ventilation–supported weaning.

17. NIV in community acquired pneumonia, immunocompromised patients, asthma, postoperative patients, rib fractures, ARDS: In community-acquired pneumonia, note the following:

- Noninvasive ventilation not established to be beneficial
- Secretions may be limiting factor
- Improvement with noninvasive ventilation best achieved in patients also with COPD
- Hypercapnic respiratory acidosis may define group likely to respond

- Decrease in intubation rate and mortality may be limited to those also with COPD

In immunocompromised patients and hypoxemic respiratory failure, note the following:

- Solid organ transplantation- Single-center trial, approximately 50 patients; subgroup with cardiogenic pulmonary edema fared best
- Febrile neutropenic patients - Single-center trial, approximately 50 patients; mostly hematologic malignancies or bone marrow transplantations; benefit of noninvasive ventilation in those with an identified cause of pneumonia; severity of illness relatively modest

In asthmapatients, note the following:

- Similar pathophysiology to COPD; limited reported experience with noninvasive ventilation
- Mostly case series with reported benefit
- Prospective, randomized studies based on emergency department settings
- Improvement in spirometry main outcome measure
- Fewer admissions with noninvasive ventilation; intubation not an outcome measure
- Hypercapnic asthma patients not represented in randomized trials
- Noninvasive ventilation probably beneficial, but experience limited

In postoperative patients, note the following:

- Postoperative hypoxemia related to atelectasis or pulmonary edema
- Occurrence following multiple types of surgery (eg, lung, cardiac, abdominal)
- Randomized trials with postoperative continuous positive airway pressure (CPAP) demonstrate benefit
- Applied as prophylactic support or with development of hypoxemia
- Benefit noted with level CPAP levels in 7.5- to 10-cm water range
- Lower intubation rates, days in ICU, and pneumonia
- High-flow nasal cannula oxygen option (50 L/min and $FiO_2 = 0.50$) may be comparable to noninvasive ventilation

With rib fractures (traumatic, with nonpenetrating chest injuries), note the following:

- Older single report using low-level CPAP (5 cm water)
- Fewer episodes of pneumonia, duration of hospitalization
- No mortality benefit: Hernandez et al found that in patients with hypoxemia related to severe thoracic trauma, noninvasive mechanical ventilation reduced intubation rates.

For do-not-intubate status (advanced disease or terminal malignancy),[64] note the following:

- Numerous case series
- COPD patients comprise most patients
- Most with hypercapnic respiratory failure
- Report of 60% success rate, but discharge home rate of 40-50%
- Median survival following treatment 179 days in one series
- One-year survival rate of 30%

- Some with more distress from the mask and noninvasive ventilation than benefit
- Issues with resource utilization and prolonging the inevitable
- Better outcomes in CHF, awake patients, and those with strong cough (mobilized secretions)
- Benefit in patients with malignancy if treating reversible condition
- Benefit in dyspnea relief for patients with terminal malignancy

For acute respiratory distress syndrome,note the following:

- Not recommended as first-line therapy in management
- Limited experience, but may benefit those who do not require immediate intubation

18. Complications of NIV and management including gastric aspirations: For facial and nasal pressure injury and sores, note the following:

- Result of tight mask seals used to attain adequate inspiratory volumes
- Minimize pressure by intermittent application of noninvasive ventilation
- Schedule breaks (30-90 min) to minimize e ects of mask pressure
- Balance strap tension to minimize mask leaks without excessive mask pressures
- Cover vulnerable areas (erythematous points of contact) with protective dressings

For gastric distension, note the following:

- Rarely a problem
- Avoid by limiting peak inspiratory pressures to less than 25 cm water
- Nasogastric tubes can be placed but can worsen leaks from the mask
- Nasogastric tube also bypasses the lower esophageal sphincter and permits reflux

For dry mucous membranes and thick secretions, note the following:

- Seen in patients with extended use of noninvasive ventilation
- Provide humidification for noninvasive ventilation devices
- Provide daily oral care

For aspiration of gastric contents, note the following:

- Especially if emesis during noninvasive ventilation
- Avoid noninvasive ventilation in patient with ongoing emesis or hematemesis

Complications of both noninvasive and invasive ventilation

These include the following:

- Barotrauma (significantly less risk with noninvasive ventilation)
- Hypotension related to positive intrathoracic pressure (support with fluids)

Complications avoided by noninvasive ventilation

These include the following:

- Ventilator-associated pneumonia
- Sinusitis
- Reduction in need for sedative agents - Sedatives used in less than 15% of noninvasive ventilation patients in one survey.

ROX index: ROX index is used to predict failure from HFNC. It is helpful in preventing delay in intubation by early prediction of HFNC failure. It is defined as the ratio of oxygen saturation as measured by pulse oximetry/FIO2 to respiratory rate.

Prediction accuracy of the ROX index increased over time with AUC of 0.679 at 2 h, 0.703 at 6 hours and 0.759 at 12 hours.

ROX: 4.88 at 2, 6 and 12 hours after HFNC initiation was associated with a lower risk for intubation.

Predictors of HFNC failure include:

- ROX <:2.85 at 2 hours
- ROX <:3.47 at 6 hours
- ROX <:3.85 at 12 hours

Given the increasing use of HFNC in the management of ARF due to a variety of etiologies, some investigators proposed that the Berlin definition of ARDS be expanded to include patients treated with HFNC with at least 30 L/min who fulfilled the other criteria for the Berlin definition of ARDS. As the PaO2/FiO2 under-recognizes the diagnosis of ARDS, a SpO2/FiO2 value of ≤315 may be considered instead of a PaO2/FiO2 value of ≤300 for diagnosing the condition in resource-constrained settings.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