Mechanical Ventilators

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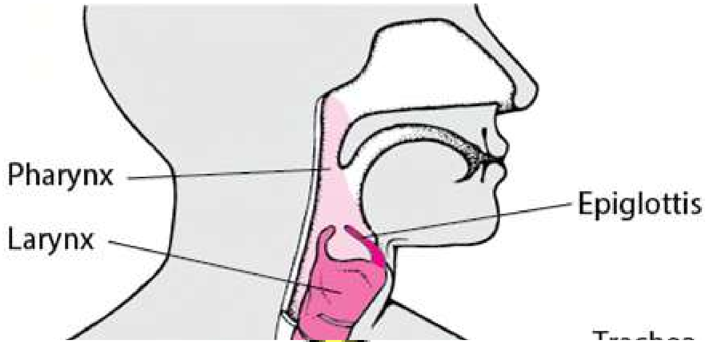
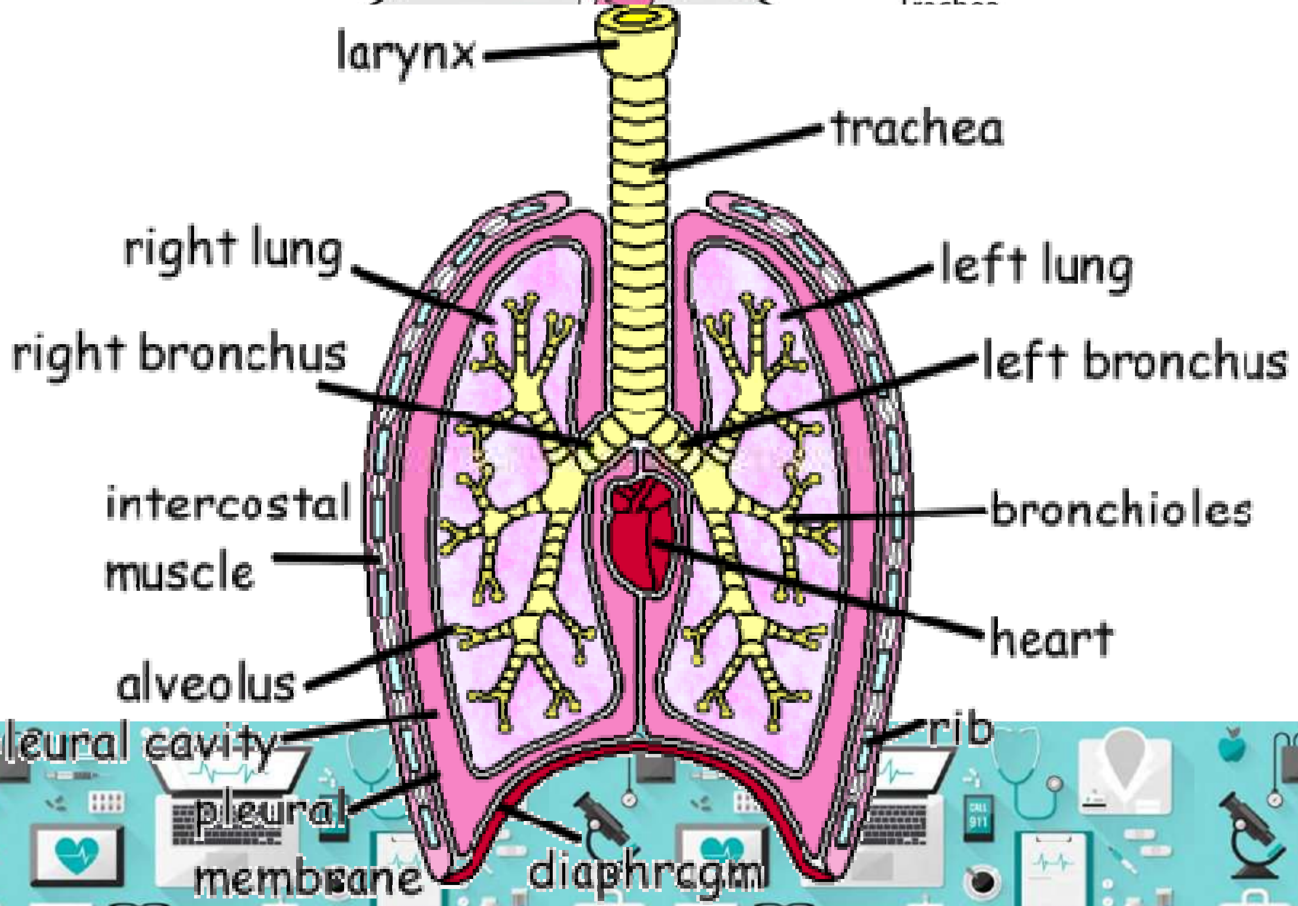
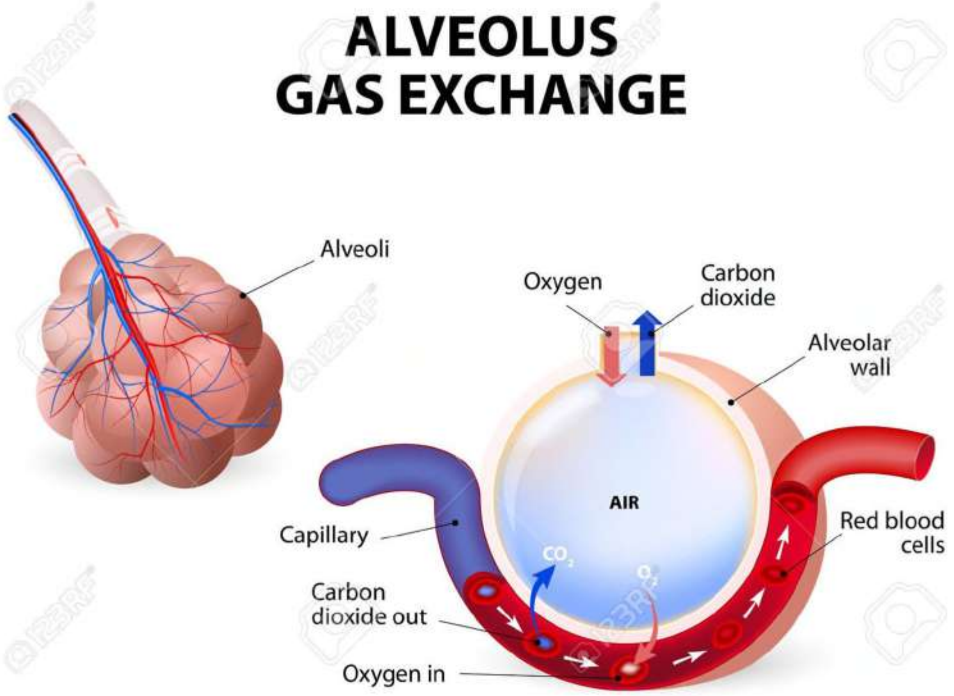
Summary

- ❑ Mechanics of breathing
- ❑ Mechanical ventilators
- ❑ Types of Mechanical Ventilators
- ❑ Ventilation Modes
- ❑ Control/Setting parameters
- ❑ Monitored/displayed parameters
- ❑ Alarms
- ❑ Safety
- ❑ Maintenance

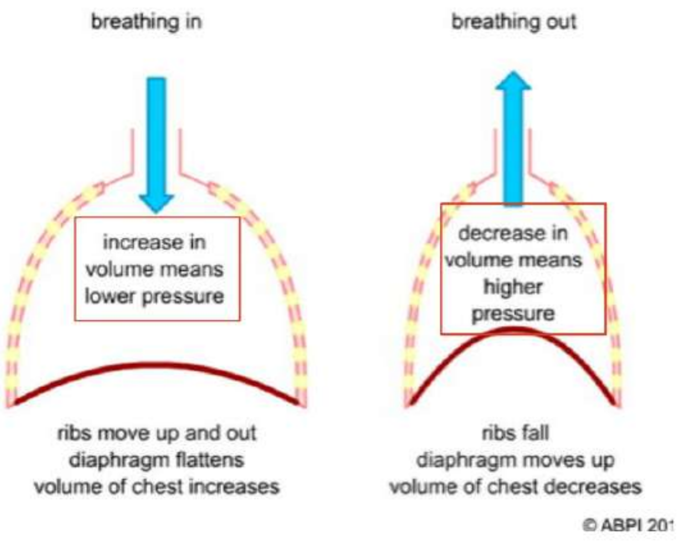
Recap on breathing

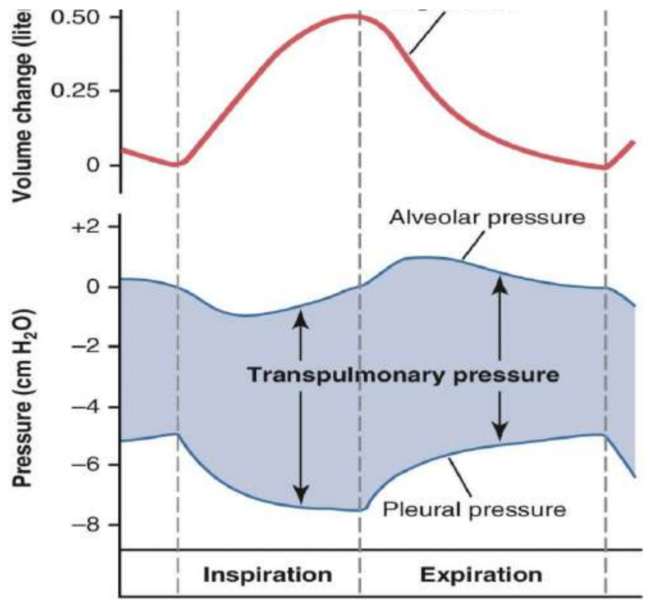






Mechanics of breathing





Breathing is a mechanical, automatic and rhythmic process, regulated by the higher centers through which, as a result of the contraction and relaxation of the skeletal muscles of the diaphragm, abdomen and rib cage, the exchange of air in the alveoli is promoted. During inspiration, the endo-alveolar pressure becomes slightly negative compared to the atmospheric pressure (-1cmH2O) and this causes a flow of air inwards along the respiratory tract. During normal exhalation, the endo-alveolar pressure rises up to about + 1cmH2O, causing an outward flow of air.

The father of all ventilators: Negative Pressure Ventilators

- Negative pressure ventilators were known as “iron lungs”
- The patient’s body was encased in an iron cylinder and negative pressure was generated
- The iron lung is still occasionally used today in patients with chronic disease.

Iron lung ward, Los Amigos Hospital, California, 1950s

Mechanical Ventilators (1/3)

Mechanical ventilators are life support devices that move gas (e.g., air and/or oxygen) to and from a patient's lungs.

These devices replace or support the activity of the inspiratory muscles by ensuring an adequate volume of gas to the lungs for patients who cannot breathe on their own, or who require assistance maintaining adequate ventilation because of illness, trauma, congenital defects, or the effects of drugs (e.g., anesthetics).

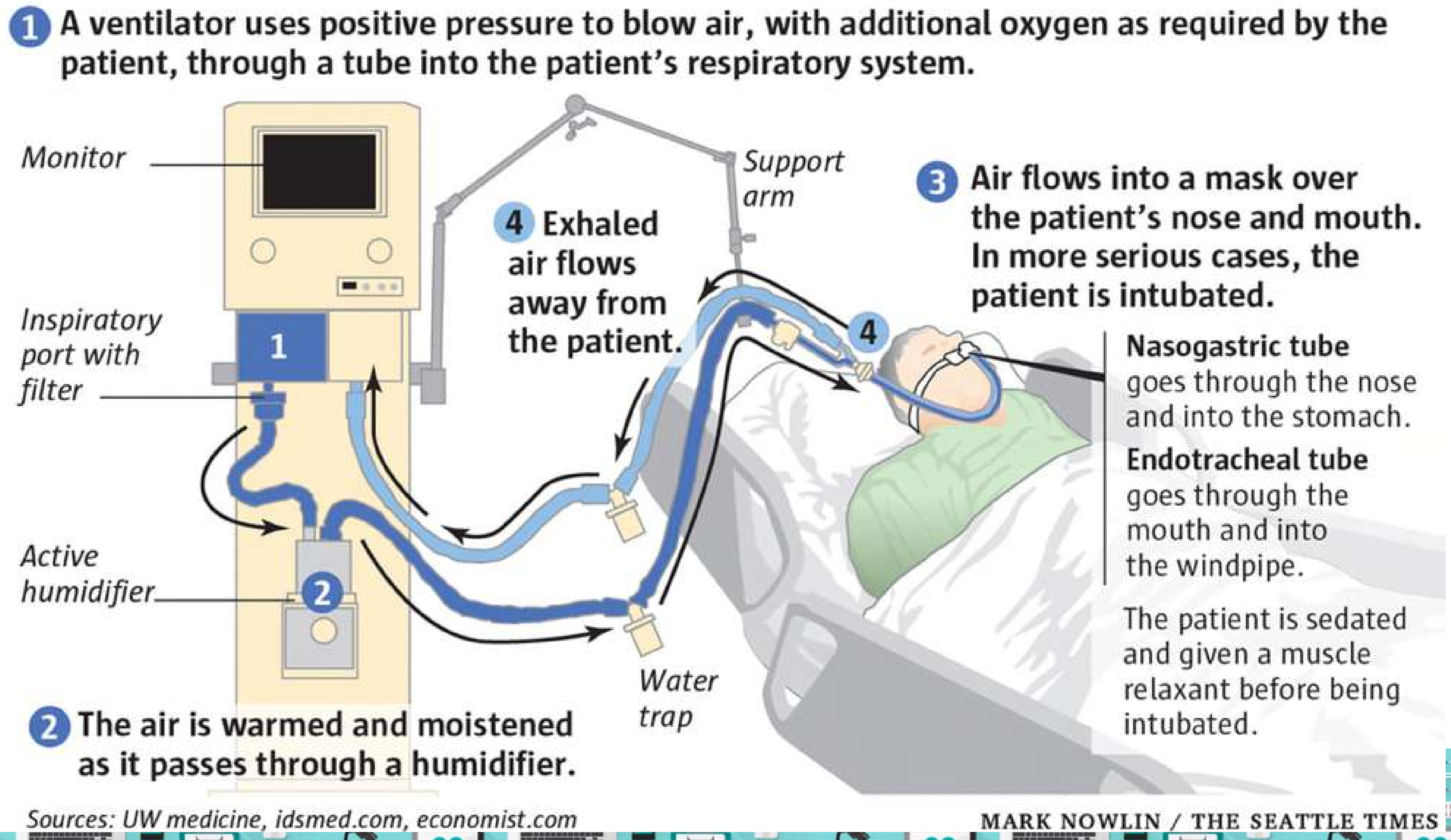
Mechanical Ventilators (2/3)

The ventilator is capable of blowing a certain mixture of gases into the lungs and subsequently allows its exhalation, with a known frequency and with appropriate pressures. In order to deliver the necessary amount of oxygen to the patient and remove the carbon dioxide produced, the ventilator must allow:

- blowing into the lungs controlled quantities of air or gas mixtures;
- stop insufflation;
- let the exhaled gases exhale;
- repeat these operation continuously.

Mechanical ventilation, being at positive pressure, involves an enhancement of respiratory exchanges, with the reopening of poorly ventilated areas to ventilation, but at the same time it can cause injury to the respiratory system (barotrauma), that of course should be avoided.

Mechanical Ventilators (3/3)



Types of Mechanical Ventilators

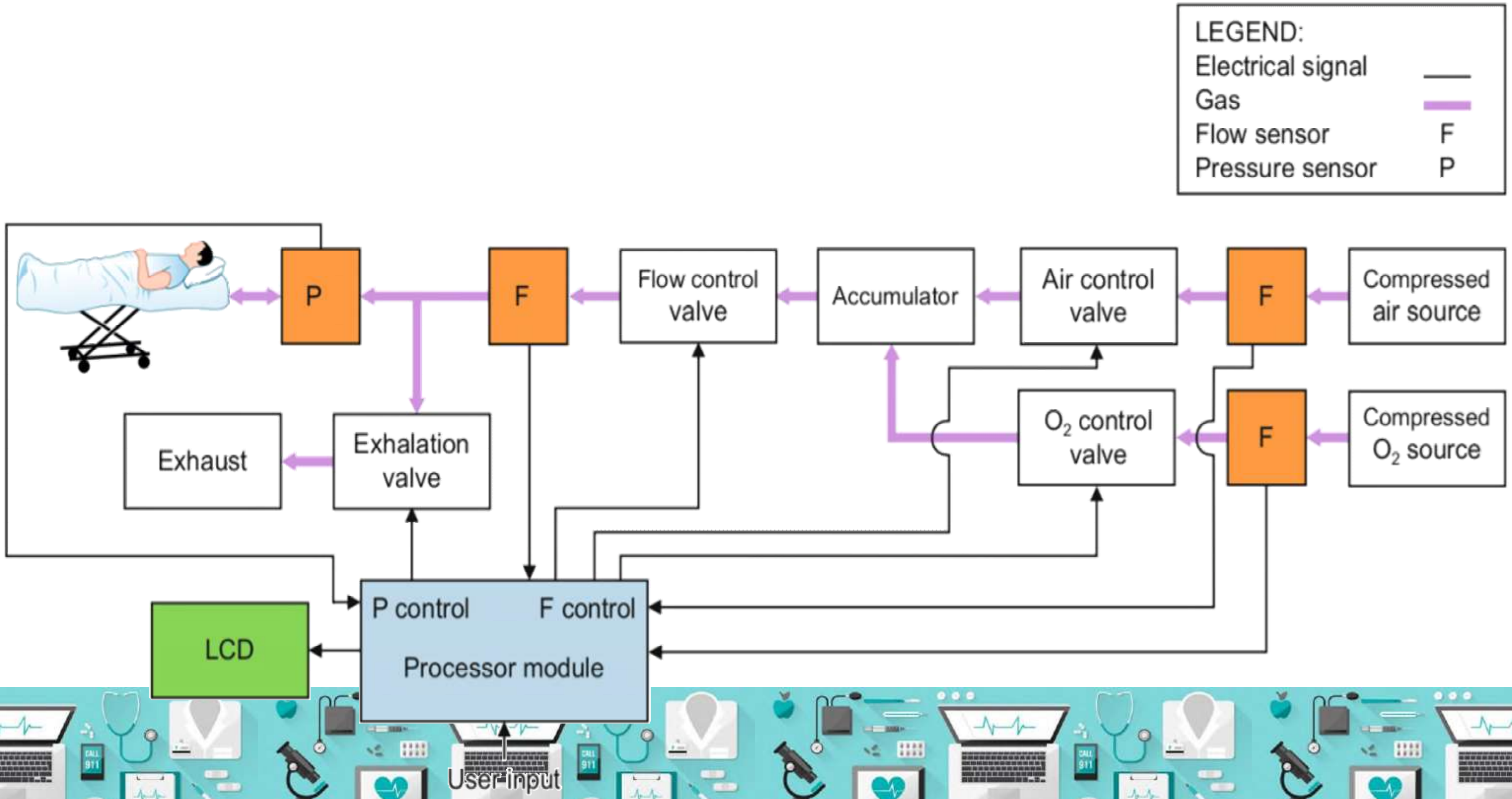
Types of Mechanical Ventilators

1. Mechanical ventilators for intensive or sub-intensive care;
2. Mechanical ventilators for transport in emergency / medical urgency.
3. Portable Ventilators

Ventilation could be

- INVASIVE if the patient is intubated (e.g., endotracheal tube or a tracheostomy tube)
- NON-INVASIVE if the patient is not intubated (breathing support administered through face or nasal masks, or a helmet).

1. Mechanical ventilators for intensive or sub-intensive care



1. Mechanical ventilators for intensive or sub-intensive care

ICU ventilators typically consists of:

- Flexible breathing circuit
- Graphical user interface (GUI)
- Gas supply
- Heating and humidification devices for delivered gas
- Monitors and alarms.

1. Mechanical ventilators for intensive or sub-intensive care

- The **GUI** provides real-time information of measured parameters.
  Information can be presented as numerical values, in graphical waveforms or loops.

- The GUI controls the breath delivery unit. The processor module regulates the waveforms controlling the air and the O2 valves. It provides information on patient's inspiration and expiration.

- Based on user settings, ventilators control the fraction of inspired oxygen (FiO2) together with the pressure, the volume and the flow of the delivered positive-pressure breath.

- To produce a prescribed breathing pattern, various parameters can be independently set, such as ventilation mode and a number of parameters (e.g., tidal volume, respiratory rate, and inspired oxygen concentration - FiO2).

- Mechanical ventilators are equipped with **audible and visual alarms** to notify clinicians of changes in the patient's condition (throughout measured patient data) or of device problems.

- Many ventilators have **electrically powered control systems and air compressors**. Power is supplied by an electrical wall outlet with an internal battery backup.

1. Mechanical ventilators for intensive or sub-intensive care

- The flow of gas to the patient can be regulated by a **flow-control valve** on the ventilator.
- To obtain the desired FiO2 for delivery to the patient, **most ventilators mix air and oxygen internally**, although some models require an external gas blender.
- The **processor module** regulates the waveforms controlling the **air and the O2 valves**.
- **Two flow sensors provide air and O2 flow data to the processor module**.
- A **rigid accumulator** serves as the internal reservoir to supply flow on demand, to the patient.

1. Mechanical ventilators for intensive or sub-intensive care

- **During inspiratory gas delivery**, an **exhalation valve is closed** to maintain pressure in the breathing circuit and lungs and to direct all flow to the patient. .

- The gas is delivered to the patient through the flexible breathing circuit **A pressure sensor** in the patient circuit provides feedback to the processor module for maintain the positive end-expiratory pressure (PEEP).

- **After the inspiratory phase, the gas is released to ambient air the exhalation valve.**

- **Sensors within the ventilator or breathing circuit** can measure airway pressure or flow and provide feedback to the ventilator to automatically adjust its output.

2. Mechanical ventilators for transport in emergency/medical urgency

- Transport ventilators are designed to take the place of manual “bagging” in emergency or transport situations. Hand ventilation, performed even by nurses, respiratory therapists, emergency technicians, and other trained professionals, tends to be at too fast a rate and at an unstable tidal volume.

- Transport ventilators are well suited for **both pre-hospital and emergency department applications**, they also can be used in vehicles, in ambulances or the transport of ventilator-dependent patients in the hospital.

- Transport ventilators **have minimum performance requirements** in comparison with ICU’s ventilators.

- **Minimum alarms are also required**. The delivered O2 or O2/air mixture should be monitored with an O2 analyzer that includes an alarm for concentrations outside acceptable ranges.

3. Portable ventilators (Non-Invasive Ventilation)

- Portable ventilators provide **long-term ventilation support** for patients who do not require complex critical care ventilators. Most portable ventilators are simple to operate and **do not have the sophisticated controls,** these include appropriate controls for setting operating modes, breathing delivery parameters, and alarms.

- Some systems may also include **special breathing circuits, O2 accumulators, and heated humidifiers or heat/moisture exchangers (HMEs).**

- Power can be supplied through an **alternating-current (AC) line**, an external battery (e.g., a car battery), or an internal battery.

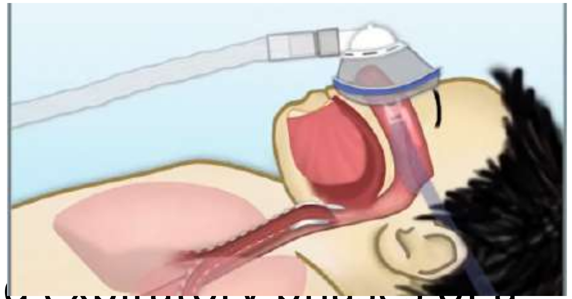
- **Passive one-way valves** within the ventilator allow the patient to breathe spontaneously. Placing an H- valve in the inspiratory limb reduces the work required for the patient to breathe spontaneously — called the work of breathing (WOB) — by allowing the patient to inhale room air directly through an open port in the valve instead of through the valves and tubing inside the ventilator.

- **The exhalation valve**, which occludes the exhalation limb during inhalation to divert gas into the patient's lungs and opens during exhalation to release the breath, is located close to the patient connection. This eliminates the need for an exhalation hose and simplifies the breathing circuit.

3. Non-Invasive Ventilators

1) Designed to apply continuous positive airway pressure to non-intubated patient:

- **Continuous positive airway pressure (CPAP):**
  - ✓ Can be used in spontaneously breathing patients who require short-term mechanical assistance.
  - ✓ The pressure level is the same for the inspiratory and expiratory phase.
  - ✓ The effectiveness of the treatment is closely related to the proper sealing of the nasal or oral-nasal mask to the face of the patient.



- **Bi-level positive airway pressure (BiPAP or BPAP):**
  - ✓ Allows clinicians to adjust two different pressures during the inspiratory and expiratory phases of a breath.
  - ✓ Can be used in spontaneously breathing patients who require short-term mechanical assistance.
  - ✓ These units can deliver air or a mixture of air and oxygen at high flow rates.
  - ✓ The effectiveness of the treatment is closely related to the proper sealing of the nasal or oral-nasal mask to the face of the patient. **There are also more novel helmets that can be used as an interface.**

3. Non-Invasive Ventilators

<u>2) Designed to deliver high flow rates with heated humidification to the non-intubated patients</u>

- **High-flow nasal cannula (HFNC), heated humidified high-flow (HHHF) therapy or high-flow nasal oxygen (HFNO)**:

  - ✓ The maximum flow varies according to the manufacturer and can go up to 50 to 70 L/min.
  - ✓ A specialized flowmeter and a heated humidifier are incorporated into the unit to deliver warm, humidified gases through a patient interface (nasal cannula).
  - ✓ There is a low level of positive pressure at the patient’s airway.
  - ✓ The FiO2 can be set by the clinician.
  - ✓ The effectiveness of the treatment is related to the high flow generated rather than the proper sealing of the nasal cannula (reduced exhaled air dispersion).

3. Non-Invasive Ventilators/novel helmet as interface for COVID-19

- NIV can be administered via face mask, which fits over the mouth and nose, or via transparent plastic helmet, which goes over a patient's head and seals around the neck. The helmet provides a pressurized system of oxygen-enriched air to help the patient breathe.

- Helmet ventilation is better tolerated by the patient and prevents virus aerosolization and spread within treatment facility

- For COVID-19 specifically, 20-30 percent of COVID-19 patients who received helmet ventilation avoided intubation, according to feedback from Italian doctors. Avoiding intubation is especially important for COVID-19 patients because 80 percent of intubated COVID-19 patients die. *

- It is noisy for the patient, they have to use earplugs or headphones. It can also create pressure on the armpits or the neck, but we have tips on how to minimize these issues. Skin necrosis, gastric distension, or eye irritation are occasionally observed during helmet NIV, while these may be results of long-term treatments with face masks.

* Yang X. Et al. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective, observational study. The Lancet Respiratory Medicine. 2020: 8(5):475-481.

Ventilation Modes

Ventilation Modes

- The way the machine ventilates the patients
- How much the patient will partecipate to their own breathing pattern

Volume modes	Control modes
Pressure modes	Assist modes

- A ventilator assists breathing using either pressure control or volume control
- A basic distinction in mechanical ventilation is whether each breath is initiated by the patient (assist mode) or by the machine (control mode). Dynamic hybrids of the two (assist-control modes) are also possible, and control mode without assist is now mostly obsolete.

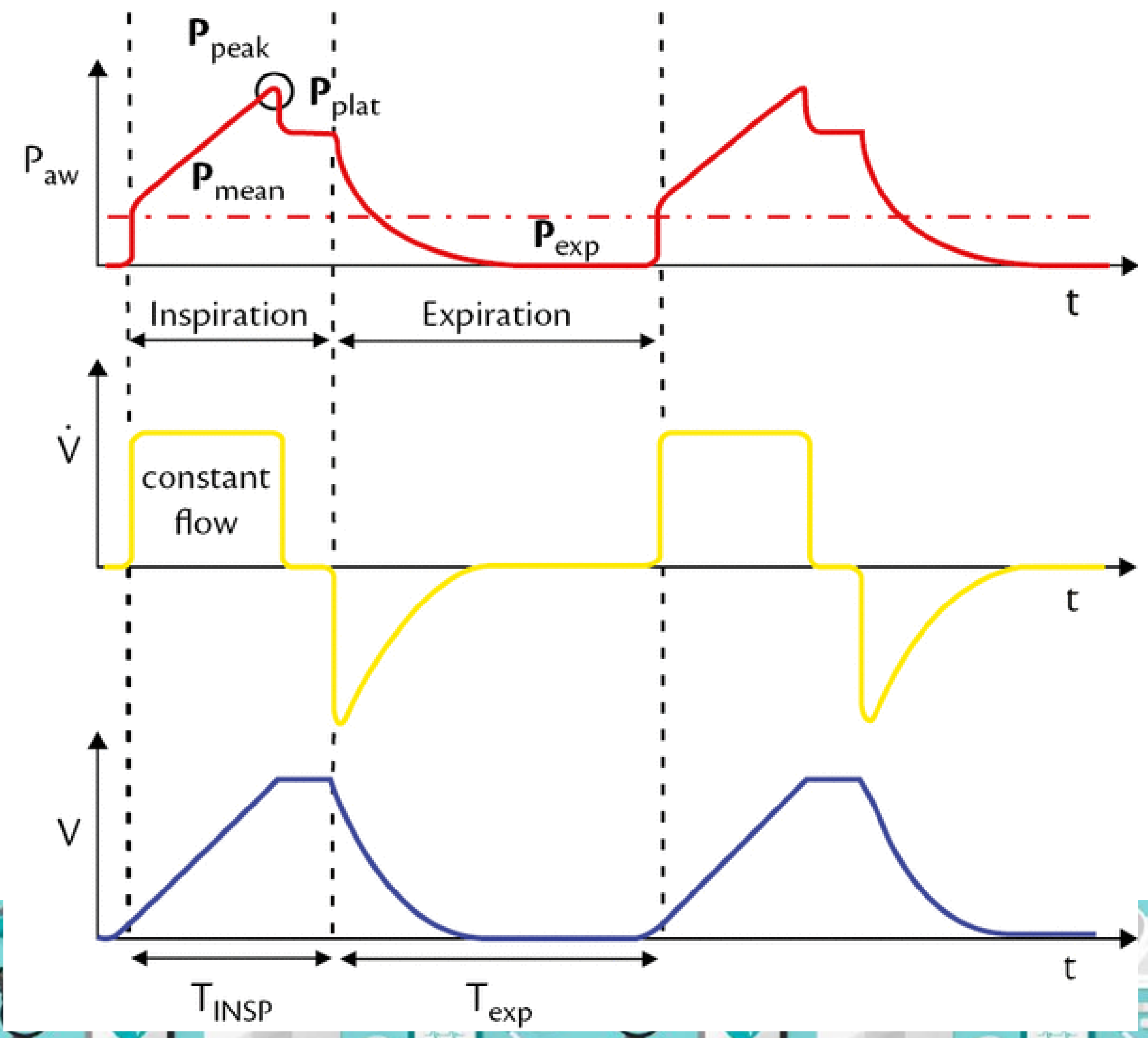
Volume Modes

- Volume controlled mode(CV)
- Volume Assisted mode(AV)
- Volume assist/control mode (VCAC)
- Syncronized intermittent mandatory volume (SIMV)

Volume controlled ventilatory mode

- Set volume delivered with each breath
- the machine generates flow to achieve a set volume known as TIDAL VOLUME: ***"the volume of air that is inspired or expired in a single breath during regular breathing!",*** pressure will vary, depending upon pulmonary compliance and airway resistance
- The patient cannot generate spontaneous breaths, volumes, or flow rates in this mode
- The independent variable is volume, The dependent variables are pressure and flow

Volume controlled ventilatory mode



<u>Peak inspiratory pressure</u>

Is the maximum pressure obtainable during active gas delivery. This pressure is a function of the compliance of the lung and thorax and the airway resistance including the contribution made by the tracheal tube and the ventilator circuit.

<u>Plateau pressure</u>

Is defined as the end inspiratory pressure during a period of no gas flow. It reflects lung and chest wall compliance

<u>End expiratory pressure</u>

Is the airway pressure at the end of the expiratory phase and is normally equal to atmospheric or the applied PEEP level.

Volume Modes

Advantages

Ability to regulate both Tidal Volume and Minute Ventilation:*“the total volume of gas in litres expelled from the lungs per minute”*

Disadvantages

- **Increased monitoring of airway pressures.**
- **Airway pressures will increase if lung compliance decreases.**
- **Risk of barotrauma.**

Pressure Modes

- Pressure controlled mode (PCV)
- Pressure Support mode (PSV)
- Pressure assist/control mode (PCAC)
- Continuous positive airway pressure (CPAP)
- Positive expiratory pressure (PEEP)
- Noninvasive bilevel positive airway pressure ventilation (BiPAP)

Pressure controlled ventilation mode

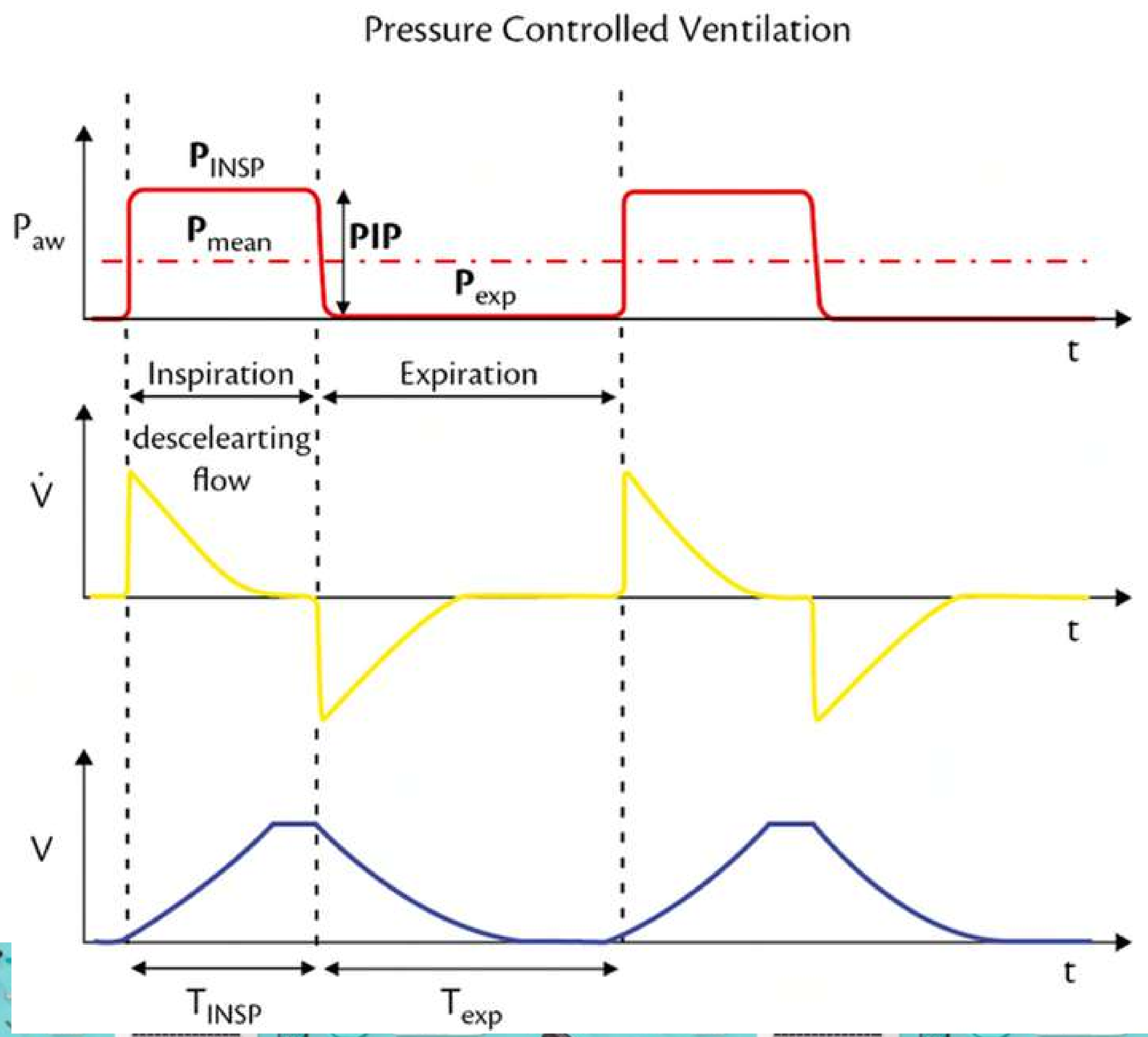
- Peak inspiratory pressure for each mechanical breath.

- Pressure remains constant, volume and minute ventilation will vary with changes in the patient's pulmonary compliance or airway resistance

- A pressure limit is set, the machine generates flow until the peak pressure limit is achieved. PAP or PIP - Peak Airway (inspiratory) Pressures: "***is the highest level of pressure applied to the lungs during inhalation expressed in cmH2O***"

- The independent variable is pressure, The dependent variable are volume and flow

Pressure controlled ventilation mode



Pressure Modes

Advantages

Lungs can be protected from excessive pressure, preventing ventilator-induced lung injury.

Disadvantages

- **No guaranteed minute ventilation.**
- **Increased monitoring of V_T required.**
- **Rapid changes in the compliance can cause hypoventilation/hypoxia.**

Dual Modes

- <u>Pressure regulated Volume controlled (PRVC)</u>

  - Is a combined mode between two control variables

  - When VC and PC are combined, the patient receives mandatory breaths that are volume-targeted, pressure-limited and time-cycled.

  - The ventilator delivers this pre-set volume at the lowest required peak pressure and adjust with each breath

Additional Modes

- High frequency ventilation (HFV)

A high-frequency ventilator uses positive pressure to deliver extremely small breaths at frequencies much higher than the normal breathing rate (e.g., >100 breaths/min). High-frequency ventilators were developed in an effort to reduce barotrauma and some of the deleterious hemodynamic effects associated with the high tidal volumes and pressures used with conventional ventilators.

Control/Setting parameters

Control/Setting parameters

- Respiratory rate
- Tidal Volume
- FiO2
- PEEP
- Flow rate
- I:E ratio
- Trigger

Control/Setting parameters

-Respiratory Rate

- The respiratory rate is the number of breaths the ventilator delivers to the patient each minute. The rate chosen depends on the tidal volume, the type of pulmonary pathology, and the patient's target $PaCO_2$ (Partial pressure of carbon dioxide).
- The respiratory rate parameters are set above and below this number and the alarm will then sound if the patient's actual rate is outside of the desired range.
- (The following are guidelines.) For patients with obstructive lung disease, the rate should be set at 6-8 breaths/minute to avoid the development of auto-PEEP and hyperventilation, or "blowing off CO_2"
- Patients with restrictive lung disease usually tolerate a range of 12-20 breaths/minute. Patients with normal pulmonary mechanics can tolerate a rate of 8-12 breaths/minute. The patient should be monitored on the initial rate setting and adjustments made as necessary.

Control/Setting parameters

- Tidal Volume

- The tidal volume is the volume of gas the ventilator delivers to the patient with each breath. The tidal volume parameters are set above and below the desired number, and the alarm will sound if the patient’s actual tidal volume is outside of the desired range. This is especially helpful if the patient is breathing spontaneously between ventilator-delivered breaths, since the patient’s own tidal volume can be compared with the tidal volume delivered by the ventilator.

- The usual setting is 5-15 cc/kg, based on compliance, resistance, and type of pathology. Patients with normal lungs can tolerate a tidal volume of 12-15 cc/kg, whereas patients with restrictive lung disease may need a tidal volume of 5-8 cc/kg.

Control/Setting parameters

- FiO2

- The fractional inspired oxygen is the amount of oxygen delivered to the patient.
- It can range from 21% (room air) to 100%. It's recommended that the FiO2 be set at 1.0 (100%) upon the initiation of mechanical ventilation to allow the patient to get used to the ventilator without experiencing hypoxia.
- However, 100% oxygen should not be used continuously for long periods of time because of the risk of oxygen toxicity.
- Oxygen toxicity causes structural changes at the alveolar-capillary membrane, pulmonary edema, atelectasis, and decreased PaO2. Once the patient is stabilized, theFiO2 can be weaned down based on pulse oximetry and arterial blood gas values.
- The FiO2 should only be as high as is necessary to keep the PaO2 in the desired range.
- Most ventilators have a temporary 100% oxygen setting that delivers 100% oxygen for only a few breaths. This should always be used prior to and after suctioning; during bronchoscopy, chest physiotherapy, or other stressful procedures; and during patient transport.

Control/Setting parameters
-PEEP (Positive end-expiratory pressure)

- PEEP reinflates collapsed alveoli and supports and maintains alveolar inflation during exhalation
  - Increase the functional residual capacity
  - Useful to treat refractionary hypoxemia
- The initial PEEP level may be set at 5cmH2O
- Auto-PEEP is present when the end-expiratory pressure does not return to baseline pressure at the end of expiration

Control/Setting parameters
- Flow Rate

- The flow rate is the speed with which the tidal volume is delivered. The usual setting is 40-100liters per minute.
- The peak flow rate is the maximum flow delivered by the ventilator during inspiration
- Peak flow rates of 60liters per minutes may be sufficient
- The inspiratory flow needs to be sufficient to overcome pulmonary and ventilator impedance otherwise the work of breathing is increased
- Higher rates are frequently necessary in patients with bronchoconstriction

Control/Setting parameters

- Inspiratory:Expiratory (I:E) ratio

- The I:E ratio is usually set at 1:2 or 1:1.5 to approximate the normal physiology of inspiration and expiration.
- Occasionally, a longer inspiratory than expiratory time is desired to allow more time to oxygenate the patient's lungs.
- I:E ratio may be altered by manipulating any one or a combination of the following controls:
  - Flow rate
  - Inspiratory time
  - Frequency
  - Minute volume (tidal volume and frequency)

Control/Setting parameters

-Triggers

- They are used to trigger the ventilator
- Ventilators can be time, pressure and flow triggered
- Time triggered is for patients who cannot breathe on their own
- Pressure and flow triggered are for assisting breathing
- According to the set threshold, the sensitivity will be higher or lower
- The smaller the set value, the more sensitive the flow/volume trigger, and vice versa.

Monitored/displayed parameters

Intensive care ventilators are equipped with sensors to detect both equipment-related problems and changes in patient status. Monitored ventilation parameters include:

- **Airway pressure**
- **Peak inspiratory pressure**
- **PEEP pressure**
- **Tidal volume**
- **Minute volume**
- **Spontaneous minute volume**
- **FiO2**
- **Respiratory rates**
- **I:E ratio**
- **Resistance**
- **Static and dynamic compliance**
- **Oxygen concentrations**
- **Volumes of inhaled and exhaled gases**

Alarms

Alarms

Ventilator alarms are crucial for safeguarding the health and lives of patients.
Therefore, it is vital that they be readily detected in even the busiest, noisiest hospital departments. Alarm-enhancement systems, which communicate ventilator alarms to locations where they are more likely to be detected by caregivers, can be helpful.

There are four basic categories of ventilator alarm integration:

- Integration with physiologic monitors
- Inclusion in centralized monitoring systems
- Integration with nurse call systems
- Remote annunciators

Patient Alarms

Intensive care ventilators are equipped with audible and visual alarms to notify clinicians of changes in the patient's Condition:

- **Low/high FiO_2**
- **Low/high minute volume**
- **Low/high inspiratory pressure**
- **Loss of PEEP**
- **Apnea**
- **Continuous high pressure/occlusion**
- **Inverse I:E ratio**
- **High PEEP**
- **Breathing circuit disconnect**

Equipment Alarms

Intensive care ventilators are equipped with audible and visual alarms to notify device problems:

- **Gas supply failure**
- **Power failure**
- **Vent inoperative**
- **Low battery**
- **Self-diagnostics**

Safety and Maintenance

Safety

MAUDE

Manufacturer And User facility Device Experience database

Device Problems	MDRs with this Device Problem
Device Displays Incorrect Message	13%
Device Operates Differently Than Expected	10%
Mechanical Problem	6%
No Display/Image	5%
Device Inoperable	5%
Battery Problem	4%
Circuit Failure	4%
Failure to Calibrate	4%
Failure to Charge	3%
Device Operational Issue	3%
Failure to Recalibrate	3%
Incorrect Or Inadequate Test Results	2%
Failure to Power Up	2%
Output Problem	2%
Appropriate Term/Code Not Available	2%
Failure of Device to Self-Test	1%
Protective Measures Problem	1%
Power Problem	1%
Device Alarm System	1%
Erratic or Intermittent Display	1%

Maintenance

Inspection

- Legibility of labels
- Manual of instructions
- Visual check
- Gas connection check
- Software check

Maintenance

- Cleaning of filters
- Touch screen calibration
- Update of the software
- Calibration of the pressure

Functional testing

- Check of batteries
- Check of the turbine
- Check of the fan
- Check of the display values
- Check of the gas pressures
- Check the alarms
- Check the user interfance

Electrical safety checks

- Checks in accordance with CEI EN 62353:2015

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ORIGINAL PAPER

Check for updates

Clinical needs and technical requirements for ventilators for COVID-19 treatment critical patients: an evidence-based comparison for adult and pediatric age

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Abstract
The spread of severe acute respiratory syndrome coronavirus 2, taking on pandemic proportions, is placing extraordinary and unprecedented demands on healthcare systems worldwide. The increasing number of critical patients who, experiencing respiratory failure from acute respiratory distress syndrome, need respiratory support, has been leading countries to race against time in arranging new Intensive Care Units (ICUs) and in finding affordable and practical solutions to manage patients in each stage of the disease. The simultaneous worldwide emergency caused serious problems for mechanical ventilators supply. This chaotic scenario generated, indeed, a frenetic race to buy life-saving ventilators. However, the variety of mechanical ventilators designs, together with the limitations in time and resources, make the decision-making processes on ventilators procurement crucial and not counterbalanced by the evaluation of devices quality. This paper aimed at offering an overview of how evidence-based approach for health technologies evaluation, might provide support during Corona Virus Disease 2019 (COVID-19) pandemic in ICUs management and critical equipment supply. We compared and combined all the publicly available indications on the essential requirements that ICU ventilators might meet to be considered acceptable for treating COVID-19 patients in severe to critical illnesses. We hope that the critical analysis of these data might help readers to understand how structured decision-making processes based on evidence, evaluating the safety and effectiveness of a given medical device and the effects of its introduction in a healthcare setting, are able to optimize time and resources allocation that should be considered essential, especially during pandemic period.

Keywords Intensive care ventilators · Mechanical ventilators · COVID-19 · Emergency · Ventilators' essential technical requirements · Pediatric

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Table 1 Compares a number of intensive care ventilators' technical specifications gathered form NHS [19, 20], WHO [11] and CONSIP S.p.A. [21] (held by the Italian Ministry of Economy and Finance, it is the purchasing centre of the Italian Public Administration sector). Technical indicators were grouped into eleven classes: (i) controls/setting ranges, (ii) invasive and non-invasive ventilation modes, (iii) patient assessment tools, (iv) integrated capabilities, (v) monitored/displayed parameters, (vi) patient alarms, (vii) equipment alarms, (viii) display, (ix) patient transport capability, (x) on-board air compressor or turbine, (xi) internal back-up battery. Each detailed indicator has been made explicit according to the data retrieved from the three organizations websites

TECHNICAL SPECIFICATIONS	CONSIP S.p.A RECOMMENDED INTENSIVE CARE VENTILATORS' SPECIFICATIONS	NHS RECOMMENDED INTENSIVE CARE VENTILATORS' SPECIFICATIONS	WHO RECOMMENDED INTENSIVE CARE VENTILATORS' SPECIFICATIONS
ISO 80601-2-12:2011 COMPLIANT		Required	Required
PATIENT TYPE	Adult, pediatric	Adult	Adult, pediatric
CONTROLS/SETTING RANGES			
Tidal volume, mL		Required at least one setting of 400 ml, Preferred: 350–450 or 250–600 or up to 800	20–2000
Respiratory rate, breaths/min		10–30	10–60
Trigger mechanism	pressure, flow with high sensitivity (>0,3 l/min)	Required	
FiO2, %	21–100	Required at least 50% or 60% and 100% options. Preferred 30–100 (35–80% for CPAP)	21–100
Inspiratory flow rate, L/min	0–200	0–100	1–160
Inspiratory pressure, cm H2O		15–40	0–40
IE ratio	Adjustable	Required, 1:2 (i.e. expiration lasts twice as long as inspiration) Preferred: adjustable (1:1–1:3)	Required
PEEP/CPAP, cm H2O		5–20 (5–15 for CPAP)	0–20
Pressure support, cm H2O	Required	0–35 (max 70)	5–20 adjustable
Leak compensation	Required		
INVASIVE and NON INVASIVE VENTILATION MODES			
CMV - volume controlled (VCV)	Required	Required	Required
Volume assist/control mode (VCAC)	Required		
Synchronized Intermittent Mandatory Ventilation (SIMV)		Preferred	Required
CMV- pressure controlled (PCV)	Required	Required	Required
Pressure support mode (PSV)	Required		Required
Pressure assist/control mode (PCAC)	Required		
Pressure Regulated Volume Controlled (PRVC)		Required	Required
Non-invasive ventilation (CPAP, BIPAP)	Required	Required	Required
High-frequency ventilation	Preferred		
PATIENT ASSESSMENT TOOLS			
Maximum waveforms displayed	At least 3 waveforms displayed at the same time		At least 3
Lung recruitment tools (PV loops)	At least 2 loops at the same time		At least 3
Capnography/CO2 monitoring	Required	Preferred	
Other patient assessment tools	Required: Endotracheal and tracheostomy tube compensation		
INTEGRATED CAPABILITIES			
Integrated nebulizer	Required		
Other integrated capabilities	Preferred inlet gas supply (O2),		Required, inlet gas supply (O2) pressure range 35 psi to 65 ps.

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OSPEDALE PEDIATRICO

TECHNICAL SPECIFICATIONS	CONSIP S.p.A RECOMMENDED INTENSIVE CARE VENTILATORS' SPECIFICATIONS	NHS RECOMMENDED INTENSIVE CARE VENTILATORS' SPECIFICATIONS	WHO RECOMMENDED INTENSIVE CARE VENTILATORS' SPECIFICATIONS
MONITORED/DISPLAYED PARAMETERS			
Peak inspiratory pressure	Required		Required
Airway pressure		Required	Required
PEEP pressure	Required	Required	Required
Tidal volume	Required	Required	Required
Minute volume	Required		Required
Spontaneous minute volume	Required		
FiO2 (analyzed %)	Required	Required	Required
Respiratory rate	Required	Required	Required
Resistance	Required		
Static and dynamic Compliance	Required		
IE ratio			Required
Others	Continuous high pressure/occlusion, Required	Required: Ventilation mode	
PATIENT ALARMS			
Low/high FiO2	Visual and audible Required		Visual and audible Required
Low minute volume	Visual and audible Required		Visual and audible Required
High minute volume	Visual and audible Required		Visual and audible Required
Low inspiratory pressure	Required	Required	Visual and audible Required
High pressure	Required	Required	Visual and audible Required
Loss of PEEP		Required	
Apnea	Required		Visual and audible Required (adjustable)
Continuous high pressure/occlusion			Visual and audible Required
Inverse IE ratio			
High respiratory rate	Visual and audible Required		Visual and audible Required
High PEEP		Required	Visual and audible Required
Breathing circuit disconnect	Required	required	Visual and audible Required
High/low Tidal Volume	Required	Required	Required
EQUIPMENT ALARMS			
Gas supply failure	Visual and audible Required	Required	Visual and audible Required
Power failure	Visual and audible Required	Required	Visual and audible Required
Vent inoperative		Required	Visual and audible Required
Low battery	Required		Visual and audible Required
Self-diagnostics			Visual and audible Required
DISPLAY			
Type	touch screen		
Size, cm (in)	>30 (12)		
PATIENT TRANSPORT CAPABILITY	**Required**		**Required**
Optional equipment required for patient transport	Cart		Cart
ON-BOARD AIR COMPRESSOR OR TURBINE	**Required**		**Required Air Compressor, Air turbine is an alternative**
INTERNAL BACK-UP BATTERY	**Required**	**Required**	**Required**
Operating time, hr	>30 min	>20 min	≥1

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