

# Mechanical ventilation

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*[Revision of terminology might be necessary.]*

**Mechanical ventilation (MV)**, is a form of breathing during which the flow of gases through the respiratory system is fully or partially achieved by a mechanical machine. Mechanical ventilation can be used for short or long periods in situations where the support of the patient's respiratory system is necessary due to the development of a severe ventilatory or oxygenation disorder, or if they are at risk of developing it.<sup>[1]</sup> Mechanical ventilation can be maintained non-invasively using various masks, or invasively, where the use of adequate advanced airway management utilizing e.g. endotracheal intubation or tracheostomy is necessary.

## Indication

Mechanical ventilation should be considered if clinical or laboratory **signs of insufficient oxygenation or ventilation** are present. The consideration of mechanical ventilation must concern the complete health state of the patient and can vary **individually** a lot. We assess the character of the underlying disease, the prognosis, risks and the responsiveness to conservative therapy. Criteria for indication can therefore differ source to source.

Criteria supporting the use of Mechanical ventilation

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$P_{aO_2} < 70$ mmHg if $F_iO_2 > 0,4$	$S_{aO_2} < 90$ % if $F_iO_2 > 0,60$
Freq > 35/min	Freq > 30/min
$P_aCO_2 > 55$ mmHg	$P_aCO_2 > 50$ mmHg
apnea	pH < 7,25

A specific group of indications is the protection from **the risk of aspiration** in patients with altered consciousness (overdose, craniotrauma) or in a state increasing the risk of aspiration concerning the gastrointestinal tract (bleeding from esophageal varices).

Mechanical ventilation is also indicated in pharmacologically induced ventilatory insufficiency, notably during **the conduction of general anaesthesia** (together with the protection of airways during the alteration of consciousness).

## Examples of states necessitating the mechanical ventilation in intensive care<sup>[3]</sup>

- **Processes filling the alveoli** – pneumonitis (infectious, aspiration), non-cardiogenic pulmonary edema/ARDS (infection, inhalation trauma, drowning, after transfusion, contusion, altitude sickness), cardiogenic pulmonary edema, pulmonary hemorrhage, tumor (e.g. choriocarcinoma), pulmonary alveolar proteinosis, intravascular hypervolemia.
- **Diseases of pulmonary vessels** – pulmonary thromboembolism, embolism by amniotic fluid, embolism by tumor mass.
- **Central airway obstruction** – tumor, laryngeal angioedema, tracheal stenosis.
- **Distal airway obstruction** – exacerbation of COPD, severe acute asthma.
- **Hypoventilation from central causes** – general anaesthesia, drug overdose.
- **Hypoventilation from peripheral neuro-muscular causes** – ALS, tetraplegia, Guillain-Barré syndrome, myasthenia gravis, tetanus, toxins (strychnin), muscular and myotonic dystrophias, myositides.
- **Hypoventilation due to a disease of the chest wall or the pleura** – kyphoscoliosis, trauma (flail chest), massive pleural exudate, pneumothorax.
- **Increase in required ventilation** – severe sepsis, septic shock, severe metabolic acidosis.

## Goals of the ventilation therapy

The ACCP conference in 1993 classified the goals of mechanical ventilation into physiological and clinical in the following way<sup>[4]</sup>.

- **Physiological goals** include:

- manipulation with the gas exchange in the lungs,
  - support of alveolar ventilation (manipulation with  $P_a\text{CO}_2$  and pH),
  - support of arterial oxygenation (manipulation with  $P_a\text{O}_2$ , the saturation of arterial blood by oxygen),
- influencing the pulmonary volumes,
  - increase of end-inspiratory pulmonary volume or the maintenance of functional residual capacity,
- decrease of respiratory effort,
  - synergy with respiratory muscle effort.
- Some of the main **clinical goals** include:
  - reversal of hypoxemia,
  - reversal of acute respiratory acidosis,
  - reversal of respiratory distress.

In some patients other goals of mechanical ventilation may be established. A special case of utilizing mechanical ventilation is the conduction of **inhalational anaesthesia**.

## Types of mechanical ventilation

Mechanical ventilation can be classified based on the flow mechanism into the following 4 groups:

### Positive pressure ventilation,

The **most widespread type** of *MV*, also called "**conventional ventilation**", utilizes a breath frequency close to the physiological one and a magnitude of volume larger than that of the dead space. The magnitude of required pressure is decided by the desired flow, the compliance of the chest and the lungs, by the resistance of the ventilation circuit and the amount of end-expiratory alveolar pressure.

### Negative pressure ventilation,

The so-called iron lung used to be utilized more often, today it is seldom indicated. Patients with neuromuscular disorders are an example where this method helps us avoid the risk of complications associated with the airway management. <sup>[5]</sup>

### jet ventilation,

Utilizes a frequency of about 150 breaths per minute as air is funneled into a narrow point in the circuit (the jet). This increases the flow of air, making it reach the alveoli. Therefore, the maintenance of effective ventilation is allowed even in open airways, e.g. during operations of trachea in **chest surgery**, in ventilation alongside bronchopleural fistula, or during bronchoscopies in total anaesthesia.

### oscillatory ventilation.

Utilizes higher frequencies (3 to 15 Hz) and very low volumes, which allows the maintenance of practically constant pressure in the alveoli<sup>[6]</sup>. It is used for example during **MV in neonatology** in homogenic lung damage.<sup>[7]</sup> It can be used in adult patients during the therapy of the ARDS, but not as a first-line therapy.<sup>[6]</sup>

The jet and oscillation methods of ventilation utilize very low ventilation volumes and high breathing frequencies, resulting in lower risk of barotrauma in lungs.<sup>[8]</sup> Together they constitute the so called **high-frequency ventilation techniques - HFV**.<sup>[6]</sup>

## Mechanism of conventional mechanical ventilation

Breaths present during the MV are classified into 4 basic types: **mandatory breath** (a breath conducted fully by the ventilator), **assisted** (the breath is initiated by the patient, but its further continuation is fully conducted by the ventilator), **unassisted** (the ventilator increases the inspiratory flow in a breath that is otherwise conducted by the patient) and **spontaneous**. The process of a single ventilation cycle is divided in the following way based on the direction of movement of the gases inside the respiratory system.

### Breath cycle

#### 1. Inspiratory phase:

- **Initiation** – the signal to begin the cycle.
  - Preset time (if the breathing frequency is set to 15/min the ventilator activates once each 4 seconds)
  - Change of pressure in the circuit or a change in gas flow (triggered by the patient's activity). In the case of triggering guided by pressure change the process depends on the refractory capabilities of the lungs, which affects the speed of expiration – the inspiration is triggered only after the pressure in the lungs decreases below the set limit during the expiration. In the case of triggering by patient effort the ventilator can be set to a desired sensitivity level.
- **The limit** – the value of pressure or tidal volume after which the inspiratory phase is terminated.
- In mandatory breathing, in order to achieve the desired value, it is initially necessary to increase the pressure in the location of entry to the airways by "pressurization", the reaching of alveolar pressure. Further increase in pressure inside the circuit results in inflow of air into the lungs.

#### 2. Inspiratory pause: Aids the sufficient redistribution of gases in the airways by stopping their conducted movement.

#### 3. Expiratory phase: The ventilator isn't active, the patient breathes out passively or with the aid of expiratory

muscles.

- One of the basic ventilator settings is the inspiration to expiration ratio (**I:E**), which allows the regulation e.g. by prolonging the expirium during obstructive disorders (asthma bronchiale).
4. **Expiratory pause:** This phase is limited by the terminal outflow during the expirium on one side, and the initiation of the new cycle in the inspiration phase on the other.

## Classification of ventilation modes

Ventilation modes can be classified by multiple criteria. Based on synchronization with patient's breathing we can classify them into **synchronous** (the breaths are initiated by patient's effort, as in most adult MV modes) and **asynchronous** (used most often in neonatology). Furthermore, we can classify the modes by the level of breath support, which can range from simple support of spontaneous breathing by pressure, to ventilation conducted fully by the machine without any spontaneous activity by the patient.

Ventilation modes are usually classified in the following way:

- **modes with preset amount of tidal volume** (called *volume-regulated* or *volume-gated*),
  - these modes are suitable if the main goal of MV is a constant amount of minute ventilation, most often the control of  $P_{CO_2}$ ,
  - **VCV** (*A/CMV, volume-controlled ventilation*) – all breaths have an identical constant preset tidal volume and are initiated either by the ventilator after set time, or by the patient's own effort (pressure/flow),
    - commonly used initial mode, especially in anaesthesia, to ensure satisfactory tidal volumes and to ease the patient's breathing effort.
  - **SIMV** (*synchronized intermittent mandatory ventilation*) – in addition to breaths with constant volume conducted by the ventilator the patient can add his own breath with varying volume, unregulated by the ventilator,
- **modes with variable amount of tidal volume** (called *pressure-regulated* or *pressure-gated*),
  - The benefit of these modes is the "autoregulation" of reactions to changes in pressure in the patient's respiratory system,
  - **PCV** (*PC A/CV, pressure-controlled ventilation*) – all breaths (initiated by the patient or the machine) result in an increase of pressure in the circuit up to the preset value, which leads to a tidal volume dependent on compliance of the pulmonary tissue,
  - PC SIMV – breaths conducted by the ventilator like in PCV, but the patient can add their own breaths with their own volume,
  - **pressure-support ventilation** (*PSV – pressure support ventilation*, labeled *SPONT* on some ventilators) – the MV supplies pressure support increasing the flow of gases during the inspiration, initiation of breaths and the resulting tidal volume depend on patient's own effort,
  - SIMV with pressure support – a pressure support like that in PSV can be added to patient's breaths present in both types of SIMV,
  - BiPAP (*biphasic positive airway pressure, DuoPAP*) – the patient ventilates during constant positive pressure in the airways (*CPAP*), but the ventilator alternates higher and lower levels of pressure for inspiration and expiration in synchronization with incidental breathing effort by the patient. The mode allows for smooth transition between spontaneous breathing during positive pressure (like in *PSV*) and a regulated mode similar to *PCV*.
- **Pressure vs volume**<sup>[9]</sup>
  - There is no difference in mortality, oxygenation or breathing effort.
  - The benefit of pressure-regulated modes is in reaching lower peak pressures, a more homogenic distribution of gases, better synchronization of patient with the ventilator and faster weaning from the ventilator.
  - The benefit of volume-regulated modes is the security of constant tidal volume and minute ventilation.
- **New ventilation modes**
  - Due to the spread of microchips, current ventilators can utilize various complex ventilation systems. These can, for example, secure a specific tidal volume alongside a more physiological course of pressure change than a classical VCV thanks to the automatized measurement of pulmonary compliance. Unlike previous modes, usually found in every ventilation machine, new ventilation modes are usually manufacturer-specific. These include modes like *ASV*, *PRVC* or *PAV*.

## PEEP

The **PEEP** shortcut means *positive end-expiration pressure*. Its involvement in ventilatory modes is currently one of the basic parts of MV due to several positive effects. It **increases the FRC** (functional residual capacity) of the lungs, therefore it lowers the risk of compressive atelectases. Furthermore, it **limits lung damage** that would be caused by shear forces manifesting during the recurrent collapse and inflow of air into the alveoli during ventilation with high peak pressure accompanied by low PEEP level. It **increases the homogeneity of distribution** in patients with a significant disorder of uniform distribution of breathing gases (e.g. COPD). The use of PEEP in patients suffering from the restriction of flow in the airways (their collapse) **facilitates the initiation of inspirium** by reinforcing the airways at the end of the expirium.

Most commonly used values range between 3–5 cm H<sub>2</sub>O during preventive use <sup>[10]</sup>, but the values can range between 15–20 cm H<sub>2</sub>O in severe ARDS<sup>[11]</sup>.

The use of PEEP has no absolute contraindication. However, it should be used with caution, especially if high values are set, in patients with intracranial disease, unilateral focal lung processes, hypotension, hypovolemia or bronchopleural fistula.<sup>[10]</sup>

## Intrinsic PEEP

The intrinsic PEEP, aka **auto-PEEP**, is the result of insufficient expiration and the ensuing progressive air-trapping in the lungs. It may be caused by overly **high minute ventilation, expiratory resistance** (folded intubation tube), **obstructive disease** (asthma). It increases the risk of barotrauma or hypotension. Management of the causative state is the basis for the treatment.<sup>[10]</sup>

## Overview of basic parameters in MV's setup

- **Ventilation mode**
- **V<sub>T</sub>** (TV) – tidal volume of a single breath (usually cca. 7 ml/kg of ideal weight)
- **PEEP** – 3–5 cm H<sub>2</sub>O as a standard
- **FiO<sub>2</sub>** – fraction of inspired oxygen, 0,3 (30 %) at minimum
- **Breathing frequency** (RR, f) – normally 10–14/min
- **P<sub>plateau</sub>**, P<sub>support</sub>, P<sub>high</sub>, P<sub>insp</sub>, PIP, ... – pressure values regulating the process of pressure-regulated breathing in various ventilation modes, set up depending on pulmonary compliance to cause adequate tidal volumes with minimum possible risk of pulmonary damage by barotrauma
- **I:E** – inspiration to expiration ratio – normally 1:2, asthma cca. 1:4, ARDS 2:1
- **Trigger** – the sensitivity of sensors to the patient's own inspiratory effort – usually cca. -2 cm H<sub>2</sub>O or the flow of 2 L/min

## Adverse effects and complications of MV

Adverse effects can be classified into pulmonary and extrapulmonary. Or based on their etiology into effects caused by airway management, effects of the MV itself and effects caused by immobilization and related problems. MV is associated with a greater risk of infectious complications resulting from the worsened function of the mucociliary transport during airway management, from administration of sedatives and even from positive pressure ventilation itself.

**Presence of the endotracheal tube** causes an increased risk of:

- sinusitis (without major clinical significance),
- ventilator pneumonia,
- tracheal stenoses,
- vocal chord damage,
- very rarely tracheo-esophageal or tracheo-vascular fistulae.

**Complications of mechanical ventilation** include:

- pneumothorax (if combined with acute hypotension, tachycardia or a sudden increase in maximum inspiratory pressure, it is necessary to keep an acute manifestation of **tension pneumothorax** in mind),
- oxygen toxicity,
- decreased urine excretion,
- affection of hepatic and gastrointestinal functions,
- lower venous blood return and afterload due to pressure change, can lead hypotension,
- VALI (*ventilator-associated lung injury*).

**VALI** is a general term describing pulmonary damage due to MV. (Some sources prefer the use of the term *VILI* – *ventilator-induced lung injury*. The definition varies, sometimes the terms are used interchangeably, other times VILI is considered the "process" and VALI the "result" <sup>[12]</sup>) It is caused by three main mechanisms: **structural disruption, surfactant dysfunction and "biotrauma"** (damage caused by inflammatory reaction). Morphologically, this group includes "classic barotrauma", the **presence of air outside alveolar space** (emphysema, pneumothorax, air embolism, ...), as well as other lung damage (**pulmonary edema, alveolar destruction** or the aftereffects of long-term positive pressure ventilation such as pseudocysts or bronchodysplasia).

The most significant forms of prevention of MV's adversary effects are the limiting of the ventilation's duration and the soonest possible extubation. Another forms of prevention are the elevation of the head, routine patient repositioning, the management of sufficient alimentation through a nasogastric tube and the administration of prophylactic pharmacotherapy (antithrombotics, H<sub>2</sub> antihistaminics).

## Termination of mechanical ventilation, weaning, long-term MV

Because of the common presence of MV's adverse effects, much effort is made to minimize the duration of its use. **Weaning** is the most common term used to describe this process, stressing its gradual character. However, newer publications use the term **discontinuation** more often, preferring a swift termination of the therapy. The adequate moment for the termination of MV is significant for the patient's prognosis – too early termination may lead to muscle weakness and an insufficient breathing gas exchange (possibly even demanding the restoration of MV), on the other hand, too late termination increases the risk of MV-associated damage to the patient.<sup>[13]</sup>

To initiate weaning, it is necessary that the patient's circulation is stable, the respiratory function and breathing effort values are good, airway reflexes are retained and no other state contraindicating the cessation of therapy is present (severe anemia, febrile state). Before removing the ventilator, or possibly extubation, it is important to assess the patient's ability to ventilate spontaneously with minimum or no support from the ventilator. Extubation of patients ventilated mechanically less than 24 hours can be done as soon as after 15 minutes of spontaneous ventilation, patients that have been intubated longer need a longer period. Regardless, it is always necessary to have the utilities for the repeated intubation and the continuation of MV ready. After terminating the MV the patient must be further monitored.

Patients indicated for longer term MV are **converted to tracheostomy** early.

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