Artificial lung ventilation (neonatology)

This article discusses the use of ALV in neonatology. Other articles related to the topic: Introduction to artificial lung ventilation • Artificial lung ventilation

Objectives of artificial lung ventilation (ALV):

- adequate oxygenation (blood oxygenation);
- adequate ventilation (excretion of carbon dioxide);
- minimal lung damage (lowest possible pressures, early extubation).

Indication:

- Neonatal pneumopathy
- Heart failure
- Neuromuscular diseases
- Drug effects (e.g. general anaesthesia)
- Weakness
- Airway pathologies,...

Options for respiratory support for a newborn:

- Giving oxygen (oxygen therapy) – into an incubator or through low-flow nasal cannula
- Non-invasive respiratory support – high flow nasal cannula, nasal CPAP
- Conventional ventilation – mandatory or synchronized, pressure- or volume-controlled, hybrid modes
- Unconventional ventilation – high-frequency, jet
- Extracorporeal oxygenation (ECMO).

Monitoring during respiratory support

- non-invasive: blood oxygen saturation (pulse oximetry), breathing and heart rate, blood pressure, body temperature;
- blood gases;
  - normal range of p_aO_2: 7–10 kPa (50–75 mmHg);
  - normal range of p_aCO_2: 4.6–5.4 kPa (35–40 mmHg);
  - permissive hypercapnia (tolerance of higher p_aCO_2 during an acceptable pH level, i.e. pH > 7.25) reduces the risk of developing bronchopulmonary dysplasia;
  - hypocapnia: with each decrease in p_aCO_2 by 1 kPa, the cerebral blood flow decreases by about 30%; the risk of developing periventricular leukomalacia increases [1]
- X-ray of the chest (to assess lung inflation, verify the position of the endotracheal cannula, to diagnose lung pathologies).

Care of newborns with respiratory support

- Minimal manipulation, quiet environment, positioning (position changes help the movement of secrete in the airways), suctioning from the airways and physiotherapy (only in indicated cases), adequate nutrition.[1]

Oxigen giving

- Oxygen is given warm and humidified. Inhaled oxygen concentration (FiO_2 0.21 or 21% corresponds to air inhalation, FiO_2 1.0 or 100% corresponds to 100% oxygen inhalation) and blood oxygen saturation (using pulse oximetry) are monitored.
- It can be given in an incubator or through nasal cannulae. The disadvantage of giving to the incubator is the fluctuation of the level of oxygen administered each time the incubator door is opened.
- It is used in children with mild signs of RDS or TTN . In case of respiratory failure or the need for a high concentration of oxygen, it is necessary to provide adequate respiratory support (e.g. NCPAP or mechanical ventilation).[1]
- Target saturation: ≥ 95%.
  - For preterm neonates born before 28 weeks of gestation, target saturations of 91-95% are recommended for oxygen administration. In 2010, the results of the SUPPORT study comparing low (85-89%) and high (91-95%) target saturations were published. The group of children with low target saturations had a lower incidence of severe retinopathy of prematurity, but higher mortality, so now it is recommended to aim for higher saturations. However, the optimal saturation values are not yet fully understood.[2]
- Oxygen is toxic to tissues due to its ability to form oxygen free radicals such as superoxide (O_2^-) and hydroxyl (OH^-). To defend against these free oxygen radicals, tissues produce antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase. Despite this, breathing 100% oxygen is proven to damage the lungs. [1]

High Flow Nasal Cannula (HFNC)

- A nasal cannula with a high flow of air or an oxygen/air mixture is used as an alternative to NCPAP.[1]

Nasal CPAP (NCPAP)

- CPAP (*Continuous positive airway pressure*) is positive pressure continuously flowing to the airways. With nasal CPAP, CPAP is given through short tubes inserted into the nostrils. The goal is to keep the alveoli and airways open and prevent them from collapsing during exhalation. When giving the CPAP, it is necessary to insert an orogastric tube to decompress the stomach.
- Indications: RDS, post-extubation respiratory support, apnoeic pauses (especially mixed and obstructive),...
- Setting: Neonates with RDS who have not been given surfactant usually need pressures around 5–8 cm H_2O; [1] with better lung compliance, lower pressures are sufficient. Pressures that are too high can cause the lungs to overexpand, resulting in impaired ventilation and carbon dioxide retention.
- Monitoring: CPAP and FiO_2 are adjusted depending on blood gas analysis. When high CPAP pressures and a high fraction of inhaled oxygen are required, intubation and artificial pulmonary ventilation are necessary.
- Complications: Bruising and damage to the skin of the nose and face are relatively common; pneumothorax may occur.[1]

Neonatal intubation

- Intubation is the insertion of an endotracheal (ET) tube into the trachea. Sterile ET cannulas without an inflatable cuff with an inner diameter of 2.5–4 mm are used (for neonates weighing < 1 kg: 2.5 mm; 1–2 kg: 3.0 mm; 2–3 kg: 3.5 mm ; over 3 kg: 4 mm). The ET cannula can be inserted through the mouth or nose. During oral intubation, the ET cannula insertion depth can be derived according to the formula: 6 + the child's weight in kg (ie, for a child weighing 1.5 kg, we fix the ET cannula at 7.5 cm at the level of the lips). In neonates, laryngoscopes with straight spoons of sizes 00 to 1 are used (size 00 for children weighing < 1 kg; size 0 for 1–3 kg; size 1 > 3 kg). A laryngoscope can be used to insert the ET cannula.[3] Successful intubation can be demonstrated by a clinical response (increased heart rate), visible chest movements, auscultation over the lungs or with a capnometer (measurement of exhaled carbon dioxide). Correct insertion position can be verified using a chest X-ray (the end of the ET cannula should be below the vocal cords and above the carina, or approximately at the Th1–Th4 level).
- There are different types of intubation - urgent (immediate) and elective (planned) intubation.
- Before elective intubation, premedication is recommended to prevent the release of stress hormones accompanied by an increase in blood and intracranial pressure (with the subsequent risk of developing intracranial bleeding).
- The combination used for premedication:
  - atropine (vagolytic effect – prevention of bradycardia caused by e.g. myorelaxant giving);
  - analgetics (fentanyl has a faster onset of action than morphine; it can cause stiffness of the chest wall, which can be alleviated by slow administration and subsequent giving of myorelaxation – suxamethonium);
  - myorelaxants (prevention of an increase in intracranial pressure; eg: mivacurium or succinylcholine).[1]

Endotracheal intubation [3]

Hmotnost dítěte:	**< 1 kg**	**1-2 kg**	**2-3 kg**	**> 3 kg**
Laryngoscope spoon size	00	0	0	1
ET cannula inner diameter:	2.5 mm	3.0 mm	3.5 mm	3.5–4 mm
Insertion depth (from lips)	6–7 cm	7–8 cm	8–9 cm	9 cm

Sedation during ventilation

Sedation

- Morphine is the golden standard for analgesia. In artificially ventilated neonates, an initial dose (50–150 μg/kg) followed by a continuous infusion (5–20 μg/kg/h) is used. Tolerance develops over time, so it is necessary to increase the dose. Withdrawal syndrome can occur after 48 hours of continuous morphine infusion, but is usually observed only after 4-5 days. To soften the withdrawal symptomes, morphine (in decreasing doses) or methadone, clonidine, or benzodiazepines are used.
- Chloral hydrate (30–50 mg/kg p.o. or p.r.), promethazine (0.5 mg/kg i.v./p.o.) and other drugs.[4]

Paralysis

- Indications: mature neonate with meconium aspiration syndrome, persistent pulmonary hypertension, or GBS sepsis who is restless, hypoxic, or asynchronous to the ventilator despite sedation. A newborn with congenital diaphragmatic hernia or severe pulmonary interstitial emphysema. A neonate who is actively exhaling against the ventilator despite sedation.[1]
- Pancuronium in the form of boluses - need to monitor fluid balance due to the risk of fluid retention;
- Vecuronium.[1]

Conventional artificial lung ventilation

Variables of artificial lung ventilation

- **FiO_2 (*fraction of inspired oxygen*)** = oxygen concentration in inspired air (0.21-1.00 or 21-100%);
- **PIP (*peak inspiratory pressure*)** = maximum inspiratory pressure; opens the alveoli;
- **PEEP *(positive end-expiratory pressure*)** = positive end-expiratory pressure; prevents the collapse of the alveoli during exhalation; maintains functional residual lung capacity;
- **MAP (mean airway pressure)** = mean pressure in the airways; affects oxygenation; too high MAP reduces venous return and thereby reduces cardiac output;
  - MAP = (PIP — PEEP) × [Ti : (Ti + Te)] + PEEP.
- **V_T *(tidal volume*)**
- **Ti (iT)** = inspiratory time, **Te (eT)** = expiratory time;
- **respiratory rate** = number of breaths per minute; depends on the inspiratory and expiratory time (and vice versa).
- **lung compliance**
  - characterized by the compliance (elasticity and extensibility) of the alveoli, chest wall and lung parenchyma – the lower the compliance, the stiffer (less compliant) the lungs;
  - lung compliance is reduced in surfactant deficiency, pulmonary hypertension, ARDS, pneumonia, cardiopulmonary bypass,...
  - with reduced compliance, optimal PEEP, higher PIP and longer inspiratory time are needed.
- **airway resistance**
  - airway resistance is increased in bronchospasm or tracheobronchomalacia;
  - the endotracheal cannula also contributes to airway resistance – its resistance is inversely proportional to the fourth power of the diameter of the ET cannula (the narrower the ET cannula, the significantly higher the resistance);
  - with increased resistance, a lower respiratory frequency and a longer exhalation time are needed

Oxygenation

- blood oxygenation - sould be optimal according to the current needs of the organism
- is affected by hemoglobin binding capacity and cardiac output; also by pulmonary and cardiac shunts
- depends on fraction of inspired oxygen (FiO_2) and mean airway pressure (MAP)
  - MAP depends on PIP, PEEP, iT
- it is monitored by non-invasive measurement of hemoglobin saturation with oxygen; blood gas examination (paO_2 – partial pressure of oxygen in arterial blood) and lactate level
- oxygen consumption can be reduced by sedation, paralysis, hypothermia.

Ventilation

- excretion of carbon dioxide
- depends on minute ventilation (= tidal volume × respiratory rate)
  - tidal volume depends on the difference between PIP and PEEP
- it is monitored using blood gas tests ($paCO_2$ – partial pressure of carbon dioxide in arterial blood).
- so-called permissive hypercapnia is tolerated - i.e. a higher pCO_2 during acceptable pH level (usually pH > 7.25), which makes it possible to reduce the risk of pulmonary baro/volume trauma.

Types of conventional mechanical ventilation

- controlled ventilation (volume or pressure controlled);
- supportive ventilation modes (volume or pressure support);
- hybrid ventilation modes (combination of different ventilation modes).

Pressure controlled ventilation - PCV

PCV allows delivery of the set peak inspiratory pressure (PIP) and then passive expiration to atmospheric pressure or a preset positive pressure (PEEP) that prevents alveolar collapse. Tidal volumes depend on lung compliance and resistance.

- the number of breaths, PIP and PEEP are set;
- minute ventilation is monitored.

Volume controlled ventilation - VCV

VCV allows delivery of a set tidal volume (V_T) and then passive expiration to atmospheric pressure or preset positive pressure (PEEP) that prevents alveolar collapse. Peak inspiratory pressures (PIP) depend on pulmonary compliance and resistance.

- tidal volume, number of breaths (or minute ventilation) and PEEP are set;
- airway pressures are monitored.

Ventilation modes

The names and characteristics of the ventilation modes may vary depending on the manufacturer of the ventilator.

- **IPPV mode** - intermittent positive pressure ventilation
- **CMV mode** - Continuous Mandatory Ventilation

An unsynchronized ventilation mode that is used in paralyzed or apneic patients. The rate is set higher than the patient's spontaneous breathing rate.

- **IMV mode** - Intermittent Mandatory Ventilation

Unsynchronized ventilation mode. The frequency is set lower than the patient's spontaneous breathing rate, so the patient can breathe spontaneously between controlled breaths.

- **SIMV mode** - Synchronized Intermittent Mandatory Ventilation

Synchronized ventilation mode that supports the set number of breaths per minute. The patient's inspiratory effort (trigger) starts the controlled breath. If the patient is breathing faster, the ventilator will only support the set number of breaths. If the patient breathes slower than the set number of breaths, the ventilator synchronizes all breaths and additionally delivers the necessary number of breaths to reach the set number. PIP, PEEP, respiratory rate, inspiratory time and trigger (sensitivity of inspiratory effort) are set.

- **SIPPV** (Synchronized Intermittent Positive Pressure Ventilation) also known as **AC** (Assist Control) mode

Synchronized ventilation mode to support each inspiratory effort of the patient. Inspiratory support is terminated after the set inspiratory time has elapsed. If the patient breathes slower than the set number of breaths, the ventilator synchronizes all breaths and additionally delivers the necessary number of breaths to reach the set number. If the patient breathes faster than the set number of breaths, all breaths are supported and with a very high breathing frequency or a long inspiratory time there is a risk of air trapping in the lungs and therefore a risk of air leak. PIP, PEEP, respiratory rate, inspiratory time and trigger (sensitivity of inspiratory effort) are set.

- **PSV mode** - pressure support ventilation

Synchronized ventilation mode to support each inspiratory effort of the patient (similar to SIPPV). Inspiratory support is terminated when the flow rate drops to the set value. Inspiratory time is variable according to lung filling (inflation). The risk of air trapping and air leak is lower than with SIPPV mode. PIP, PEEP, respiratory rate and termination sensitivity (percentage of maximal inspiratory flow) are set.

- **VG mode** - volume guarantee

e (usually 4-7 ml/kg). It also measures the exhaled volume and accordingly delivers the necessary PIP to achieve the set tidal volume. The maximum PIP is set. If the set tidal volume is not changed at the set maximum PIP, an alarm is triggered. This mode is usually used in combination with PSV or SIPPV. Does not work with high air leakage.

High frequency ventilation (HFV)

Principle: exchange of very small respiratory volumes at a high frequency.

- tidal volumes are comparable to or less than dead space
- frequency is expressed in Hz (1 Hz = 1 cycle/s = 60 breaths/min.)

Advantages: the use of small breathing volumes makes it possible to reduce the risk of barotrauma.

Indications for HFV:

- pulmonary interstitial emphysema (PIE)
- air leak syndromes (pneumothorax, pulmonary interstitial emphysema)
- neonatal respiratory distress syndrome (RDS)
- pre-stage of extracorporeal support (PPHN, MAS, pneumonia, hypoplastic lungs, congenital diaphragmatic hernia)[5]

High frequency positive pressure ventilation (HFPPV)

- (respiration rate 60–100/min, volume: 3–4 ml/kg)

High frequency oscillatory ventilation (HFOV)

- uses permanent distension pressure (MAP, mean airway pressure) with very rapid pressure oscillation around MAP; this creates very small tidal volumes, often smaller than dead space
- indication:
  - failure of conventional ventilation in a full-term newborn (PPHN, MAS)
  - air leak syndromes (pneumothorax, pulmonary interstitial emphysema)
  - failure of conventional ventilation in premature newborns (severe respiratory distress syndrome of newborns, pulmonary interstitial emphysema, pulmonary hypoplasia) or to reduce barotrauma when high pressures are needed during conventional ventilation
- Variables:
  - frequency (Hz): 10 Hz = 10 cycles/s = 600 cycles/min.

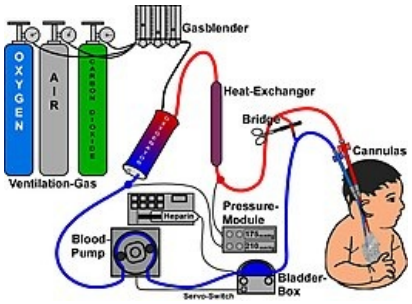
- MAP, mean airway pressure (cm H_2O) = mean pressure in the airways
  - a high MAP can reduce cardiac output by reducing venous return and thereby lowering blood pressure
- amplitude = delta P = fluctuation around MAP[6]

High frequency jet ventilation (HFJV)

- high velocity gas injection;
- frequency 240-600 breaths/min.;
- tidal volumes comparable to or slightly greater than dead space;
- exhalation is passive;
- indication: primarily pulmonary interstitial emphysema (PIE), otherwise see HFV.[5]

ECMO

🔎 *For more information see Extracorporeal membrane oxygenation (ECMO).*



ECMO scheme

Complications and negative effects of artificial lung ventilation

Complications of intubation

- injury, too deep ET cannula insertion - intubation into the right bronchus, pneumothorax, atelectasis.

Lung injury due to artificial pulmonary ventilation

- ***Ventilator-induced lung injury*** **(VILI)** is an acute injury to the airways and lung parenchyma caused by artificial lung ventilation;
  - pathophysiology of the VILI: lung damage (cellular and structural damage, alveolar edema) → inflammation → fibrotization and healing → disappearance of edema (reabsorption) → repairs (removal of intra-alveolar debris, restoration of the extracellular matrix, re-epithelialization of the alveolar surface, formation of new capillaries);
  - **barotrauma**: rupture of alveoli due to increased transalveolar pressure (high PIP); air leak syndromes (pneumothorax, pneumomediastinum, subcutaneous emphysema)
  - **volumetrauma**: damage by excessive lung inflation (high PEEP+VT);
  - **atelectotrauma**: damage by alveolar collapse with subsequent re-expansion (ventilation without PEEP or without surfactant);
  - **biotrauma**: induction of inflammation (activation of macrophages → release of cytokines TNF-α and IL-1 → stimulation of the vascular endothelium to release the *intercellular adhesion molecule-1* (ICAM-1) and E-selectin; adhesion of neutrophils to the endothelium and transmigration into the interstitial alveolar space;
  - **ergotrauma**: damage by dynamic parameters of ventilation;
  - dynamic stress (volume difference, pressure difference, high flow) is more harmful than static stress (PEEP);
- *ventilator-associated lung injury* (VALI) - the term is used when it is unclear whether there was a worsening of the lung disease itself or whether it was due to the contribution of artificial lung ventilation (causality is not clear).[7][8]
- auto-PEEP (intrinsic positive end expiratory pressure) - occurs when there is insufficient exhalation, PEEP gradually increases, the risk of barotrauma increases, the patient's ability to trigger inspiration deteriorates,
- heterogeneous ventilation - ventilation of different lung areas is different depending on alveolar compliance, airway resistance and dependence (upper vs. lower lung areas);
- ventilation/perfusion mismatch (increased dead space - areas relatively overventilated compared to perfusion; decreased shunts - areas relatively underventilated compared to perfusion);
- diaphragm muscle atrophy, respiratory muscle weakness,
- reduced mucociliary motility - leads to retention of secretes and development of pneumonia.[9]

Systemic complications of artificial lung ventilation

- reduced cardiac output, impaired hemodynamic monitoring,
- impaired perfusion of the splanchnic, stress ulcers of the digestive tract, hypomotility of the digestive tract,
- fluid retention,
- acute renal failure,
- increased intracranial pressure,
- inflammation,
- disturbed sleep[9]

Complications of the oxygen therapy

- The toxicity of the oxygen is caused by reactive oxygen species, which can damage tissues by inducing necrosis or apoptosis if the amount of reactive oxygen species exceeds the body's antioxidant capacity.

Links

Related articles

- Artificial lung ventilation
- Oxygen therapy
- Hyperbaric oxygenotherapy
- Oxygen toxicity

References

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