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Theoretical part
Spirometry

Respiration includes several processes: **external respiration**, intake of O_2 and removal of CO_2 by the organism as a whole, transport of gases, and **internal respiration**, the use of O_2 and production of CO_2 by cells and the exchange of these gases between the cells and the fluid that surrounds them. In this practical, we will cover how the respiratory system operates with a focus on external respiration, i.e. the processes, which are responsible for intake of O_2 and removal of CO_2 by the lungs.
The respiratory system consists of an organ allowing gas exchange (the lungs) and the pump which ventilates the lungs. This pump comprises the chest wall, the respiratory muscles, which increase and decrease the volume of the thoracic cavity, the areas of the brain that regulate the activity of the respiratory muscles and the nerves connecting the brain and respiratory muscles.

Airways

After passing through the nasal cavity and pharynx, where the inhaled air is warmed and moistened, it continues down the windpipe and bronchi to the bronchioles and further down through alveolar ducts to alveolar sacks.

Functions of the airways:

- removal of impurities – they are trapped in a layer of mucus, which is then moved by the cilia towards the oral part of the pharynx (oropharynx)
- a barrier against penetration of any infection – submucosal lymphoid tissue
- adjusting the temperature of the inhaled air – the rich venous plexuses in the nasal cavity warm the air to body temperature and add moisture to it (humidify it)
- vocal ligaments → help create speech and the basic tone

The lungs and chest are elastic. Between the lungs and the chest wall there is normally only a very thin layer of liquid. The lungs glide easily over the chest wall, but cannot be separated from the wall. The pressure in the space between the lungs and the chest wall (interpleural, intrapleural, or pleural pressure) is lower than atmospheric pressure. Lung tissue stretches after birth and at the end of an expiration at rest its tendency to shrink is in equilibrium with the tendency of the chest wall to extend in the opposite direction. If a hole forms in the chest wall, the lungs collapse. After the lungs lose their elasticity, the thorax increases and gets a bulbous shape.
Inspiration is always active. The contraction of the inspiratory muscles increases the volume of the chest. Interpleural pressure at the base of the lungs, which is at the beginning of inspiration -2.5 mmHg (in relation to atmospheric pressure), decreases during respiration at rest to -6 mmHg. The lungs are stretched to a larger volume. Pressure in the airways becomes slightly negative, and thanks to the difference in pressure the air flows into the lungs. At the end of inspiration, lung elasticity begins to pull the chest wall back into the position for exhalation in which the elastic force of the lungs and that of the chest are balanced again. When you exhale, the airway pressure increases, it becomes slightly positive compared to atmospheric pressure and air flows out of the lungs. During respiration at rest, expiration is passive because it involves no muscles the contraction of which would cause a decrease of the thoracic volume. In the early phase of exhalation, however, the inspiratory muscles are active.

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Their contraction inhibits the force of the shrinking and exhalation slows down. During a strenuous inhalation the interpleural pressure can decrease by up to -30 mmHg. The lungs expand even more then. When the lung ventilation is increased, the deflation of lungs caused by an active contraction of expiratory muscles rises as well. The deflation actively reduces the intrathoracic volume.
Pneumothorax is defined as accumulation of air or another gas in the pleural cavity. The cause of a pneumothorax can be a burst of subpleural bullae, injuries to the chest, certain medical procedures (nerve block injections, cannulation of the subclavian vein, transbronchial lung biopsy, transparietal puncture with aspiration, thoracic puncture).

Types of pneumotoraxes

- According to etiology:
  - **traumatic** pneumothorax (due to an injury) occurs if the chest wall is perforated or during an injury of the esophagus, bronchi, and during rib fractures.
  - **spontaneous** pneumothorax
  - **primary** idiopathic pneumothorax (without any known cause) may occur in tall healthy young men with an incidence of pneumothoraxes in the family,
  - **secondary** pneumothorax arises as a consequence of lung diseases (such as COPD or cystic fibrosis),
  - **iatrogenic** pneumothorax (due to medical procedures) occurs during invasive medical examinations such as transparietal aspiration biopsy, subclavian vein catheterization, or mechanical ventilation with positive pressure.
  - **artificially induced** (deliberate) pneumothorax is used during thoracoscopy, an endoscopic examination the thoracic cavity.
- According to the communication of the pleural space with its surroundings
  - **open pneumothorax** (when the hole in the pleural space remains open, the air in the pleural cavity moves back and forth with each breath of the patient)
  - **closed pneumothorax** (when a small opening through which air enters the pleural cavity closes)
  - **valvular pneumothorax** (the tissue of the lungs or the chest wall covers the hole in such a way that a valve emerges, this valve allows air to flow inside during inspiration, but it prevents the air from leaving the pleural cavity during exhalation).

Static lung volumes

- ***Tidal volume*** **(TV)** – the volume of air that enters the lungs during each inspiration (or the volume that is exhaled during every expiration).
- ***Inspiratory reserve volume (IRV)*** – the maximal amount of additional air that can be drawn into the lungs by determined effort after a normal inspiration at rest.
- ***Expiratory reserve volume (ERV)*** – the additional amount of air that can be exhaled from the lungs by determined effort after a normal expiration.
- ***Residual volume (RV)*** – the volume of air still remaining in the lungs after the most forcible expiration possible.
  - Collapse volume – the volume of air that is moved out of lungs when they collapse
  - Minimal volume – the volume of air that enters the lungs during the first inhalation of newborns

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Respiratory dead space

Respiratory dead space is the space in the airways that is ventilated, but is not involved in gas exchange with the blood. The dead space of a healthy individual includes the area of the upper respiratory tract and bronchi up until the air sacks (alveoli) and its volume is approximately 150 ml. These areas are referred to as **anatomical** dead space. Under normal circumstances, the anatomical dead space is the same as the **physiological** one. The physiological dead space increases if a part of the alveoli is ventilated but not filled with blood (without perfusion). During an artificial extension of the airways, **artificially enlarged dead space** arises. The more we increase the volume of the airways, the bigger the dead space becomes and the less air reaches the lungs.

Lung capacities

The capacity is the sum of various volumes.

- ***Vital capacity (VC)*** – the maximum volume of air that can be exhaled after the deepest inhalation or that can be inhaled after the deepest exhalation; the sum of the tidal volume and the inspiratory and expiratory reserve volume.
- ***Total lung capacity (TLC)*** – the volume of air in the lungs at maximal inflation, the sum of the vital capacity and residual volume.
- ***Functional residual capacity (FRC)* –** the volume of air that remains in the lungs after the end of expiration at rest

The measurement of vital lung capacity is the most commonly used clinical measure of lung function. It provides useful information about the strength of the respiratory muscles, and other aspects of lung function.

- ***Inspiratory capacity (IC)*** – inspiratory reserve volume plus the tidal volume (IC)
- ***Expiratory capacity (EC)*** – expiratory reserve volume plus the tidal volume (EC

Dynamic lung volumes

- ***Lung ventilation, respiratory minute volume (VE)*** – the volume of air inhaled in one minute by a healthy individual is approximately 6 litres (500 ml per one inspiration, 12 inspirations per minute) = minute volume.
- ***Maximal minute ventilation (MVV***) – the largest volume of air that can be inhaled and exhaled in 1 minute with volitional effort in a healthy individual is 125–170 l/min.

Individual stages of expiration

- ***The forced vital capacity of the lungs during the first second (FEV_1)*** – a part of the vital capacity exhaled during the first second of forced expiration.
- ***Forced vital capacity (FVC)*** – the volume of air that we can exhale after a maximal inhalation with maximal effort.

Examination of the **forced expiration and inspiration** (spirogram: *flow/volume* curve, and *volume/time* curve).

- FVC – forced vital capacity; the maximum volume of air that can be exhaled sharply after the maximal inspiration.
- FEV_1 – the volume of air exhaled during the first second of a forced breath; the volume of air exhaled with maximal force in 1 second after a maximal inspiration.

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- FEV_1/FVC (%) – the Tiffeneau-Pinelli index, around 80%.
- PEF – peak expiratory flow; the highest forced expiratory flow measured at the peak of a forced expiration (corresponds to the air in the upper respiratory tract).
- MEF – maximal expiratory flows (speeds) at various levels of FVC, which is yet to be exhaled (usually 75%, 50% and 25% of the FVC).
- FEF – forced expiratory flows at various levels of already exhaled FVC (25%, 50% and 75%).
- The average speed 25%–75%
- PIF — the peak inspiratory flow achieved during the peak of an inspiration.
- MIF50 – medium inhalation flow at the level of 50% of the inhaled FVC.

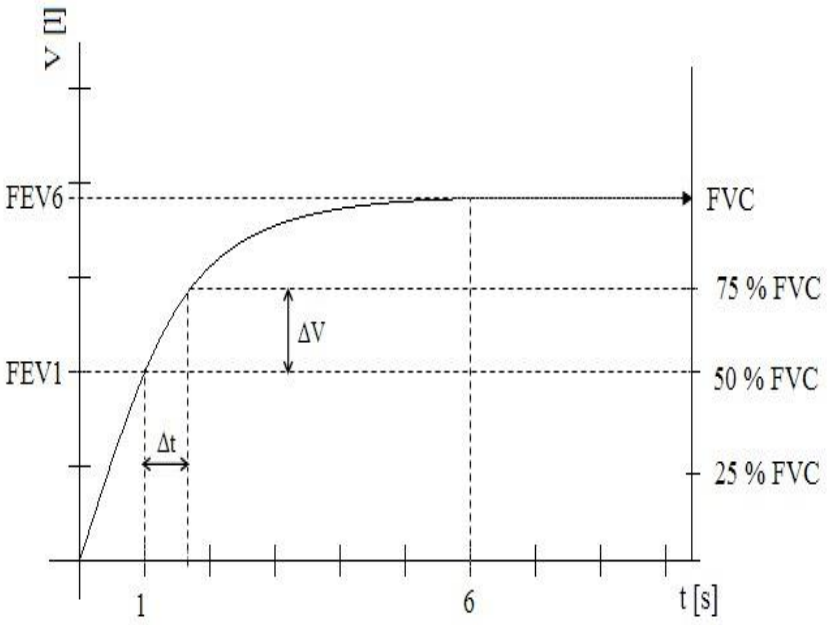

Figure: Individual stages of exhaling the vital lung capacity. Volume/time curve.

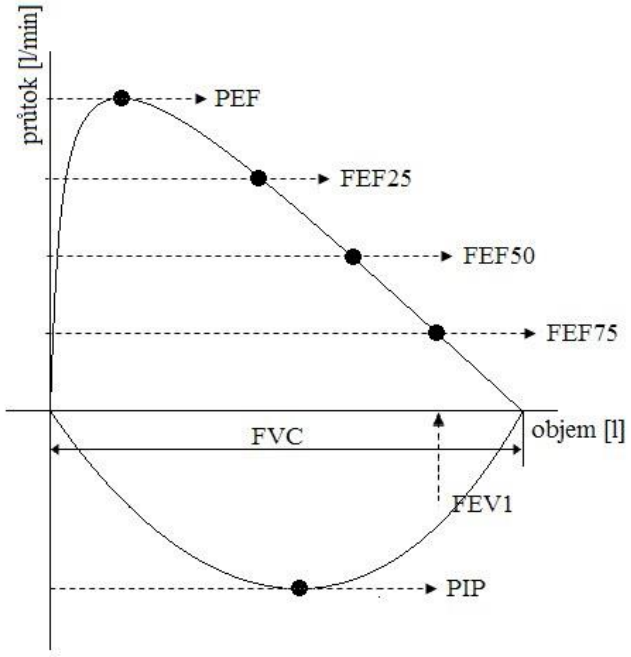

Figure: Individual stages of exhaling the vital lung capacity. Flow/volume curve.

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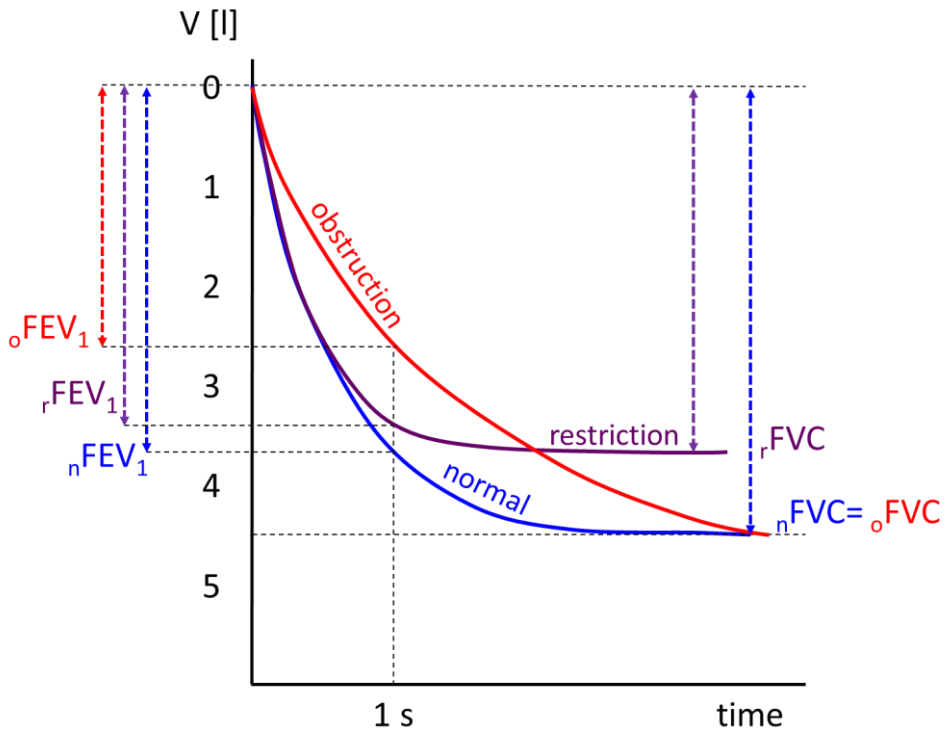
Individual stages of expiration

The recording of exhalation of vital lung capacity is an essential functional examination of lung ventilation. Changes to the shape of the curve are, in some diseases of the respiratory organs, so characteristic that they provide valuable diagnostic information.



FVC: force vital capacity, FEV_1: the forced vital capacity of the lungs during the first second, o: obstruction, r: restriction, n: normal

Obstructive lung disorders (↓ FEV_1)

- tracheal stenosis
- asthma bronchiale
- COPD
- a tumour in the airways

Restrictive lung disorders (↓ FVC)

- pulmonary causes
  - pulmonary fibrosis
  - resection of the lung
  - pulmonary edema
  - pneumonia
- extrapulmonary causes
  - ascites
  - kyphoscoliosis
  - burns
  - high position of the diaphragm

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