

Pathophysiology of ventilation disorders and pulmonary gas exchange

Spirometry

Respiratory system - physiology

The main functions at the level of the lungs:

- ventilation
- diffusion
- perfusion

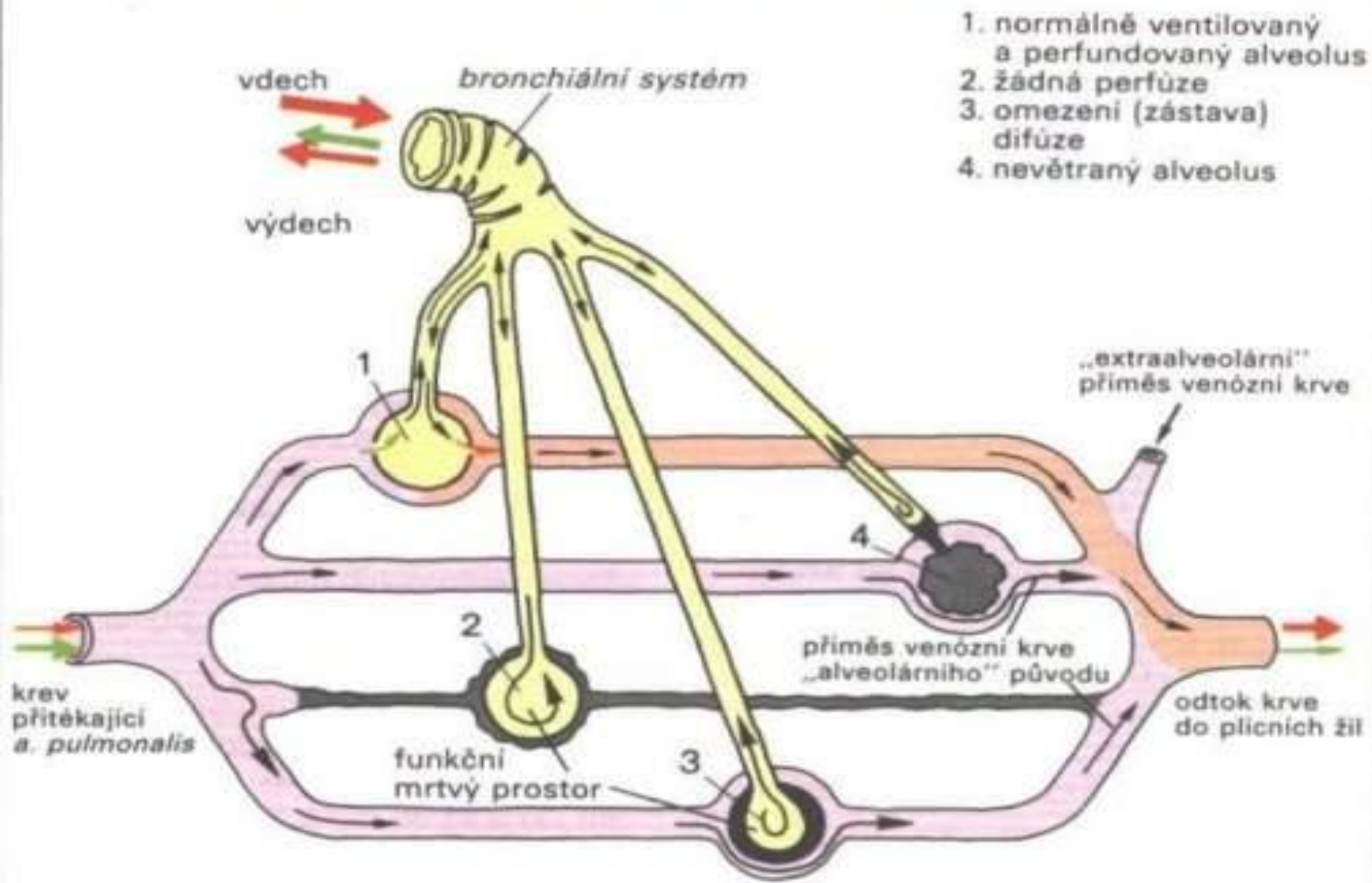
Alveolar ventilation

$$V_A = (V_T - V_D) \times f$$

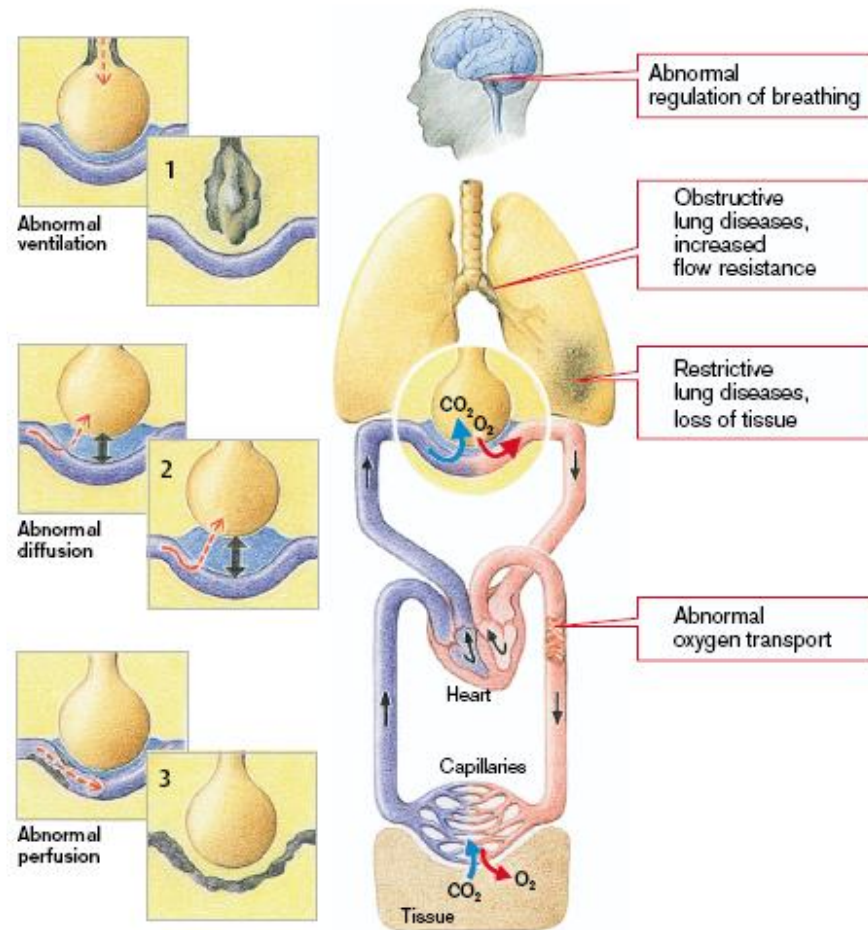
V_Ttidal volume

V_D dead volume

f respiratory rate



Pathophysiology of respiratory function



Ventilation disorders

- simple hypoventilation
- obstructive ventilatory disorders
(constriction of the airways)
- restrictive ventilatory disorders
(reduction of functional lung parenchyma or limitation of respiratory movements)
- mixed ventilation disorders

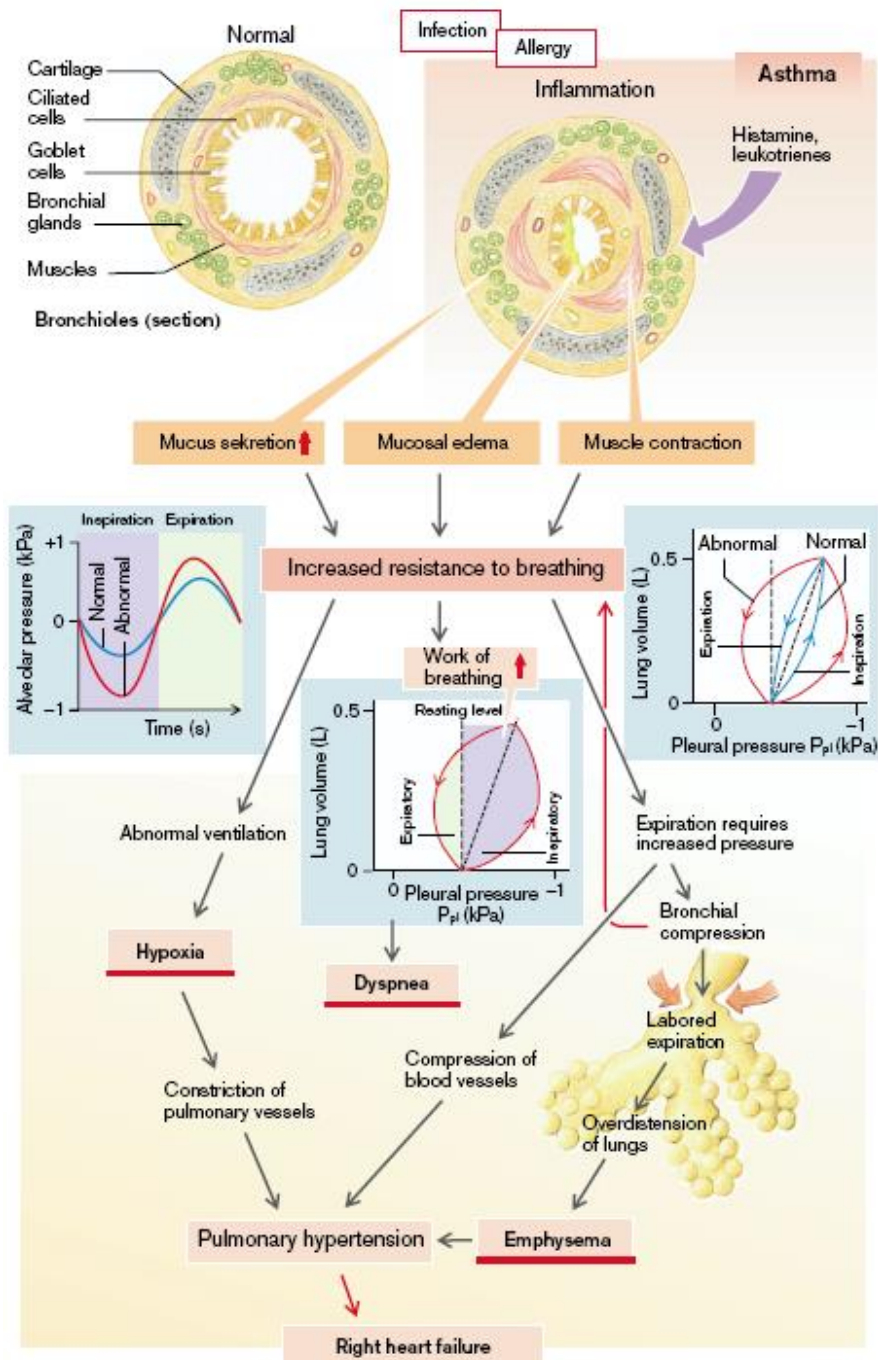
Simple hypoventilation

- usually extrapulmonary cause
 - CNS (poisoning, drugs, accidents)
 - upper airway obstruction
 - constriction of the bronchioles
 - lack of surfactant, fibrotic changes - changes in compliance
- Decrease of $V_A = (V_T - V_D) \times f$
- hypoxemia, hypercapnia

Obstructive pulmonary disorders

- localized obstruction
 - bronchial obstruction (foreign body, tumor, inflammation, nodules ..)
- generalized obstruction
 - reversible – asthma bronchiale
 - irreversible - COPD (emphysema, chronic bronchitis)

Obstructive pulmonary disorders



Asthma bronchiale

- chronic inflammatory disease of the airways characterized by an increased reactivity to different stimuli leading to variable airflow obstruction that is reversible, either spontaneously or after treatment.
- 2 to 3% of the population
- increasing incidence
- multifactorial disease

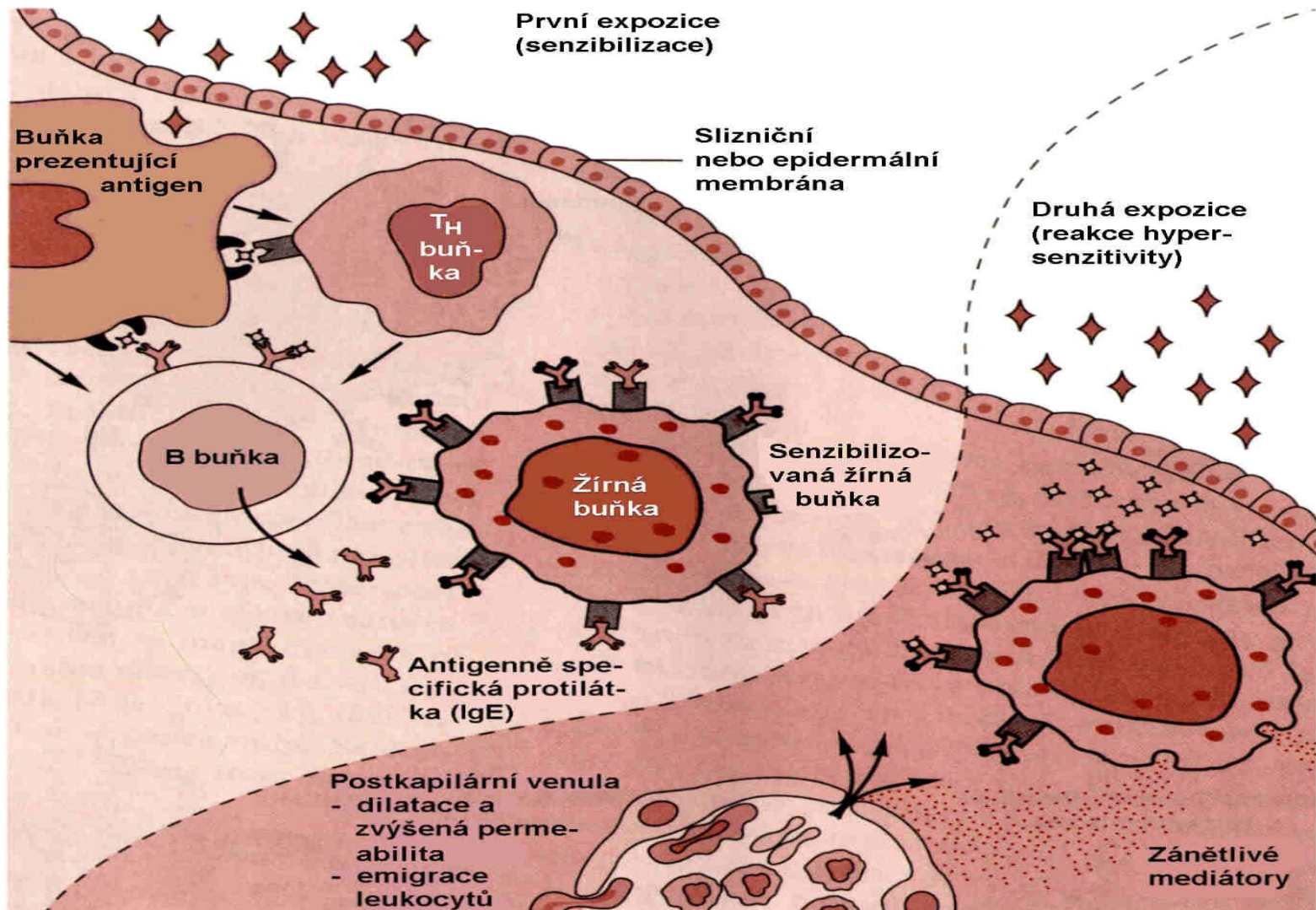
Asthma - Clinical symptoms

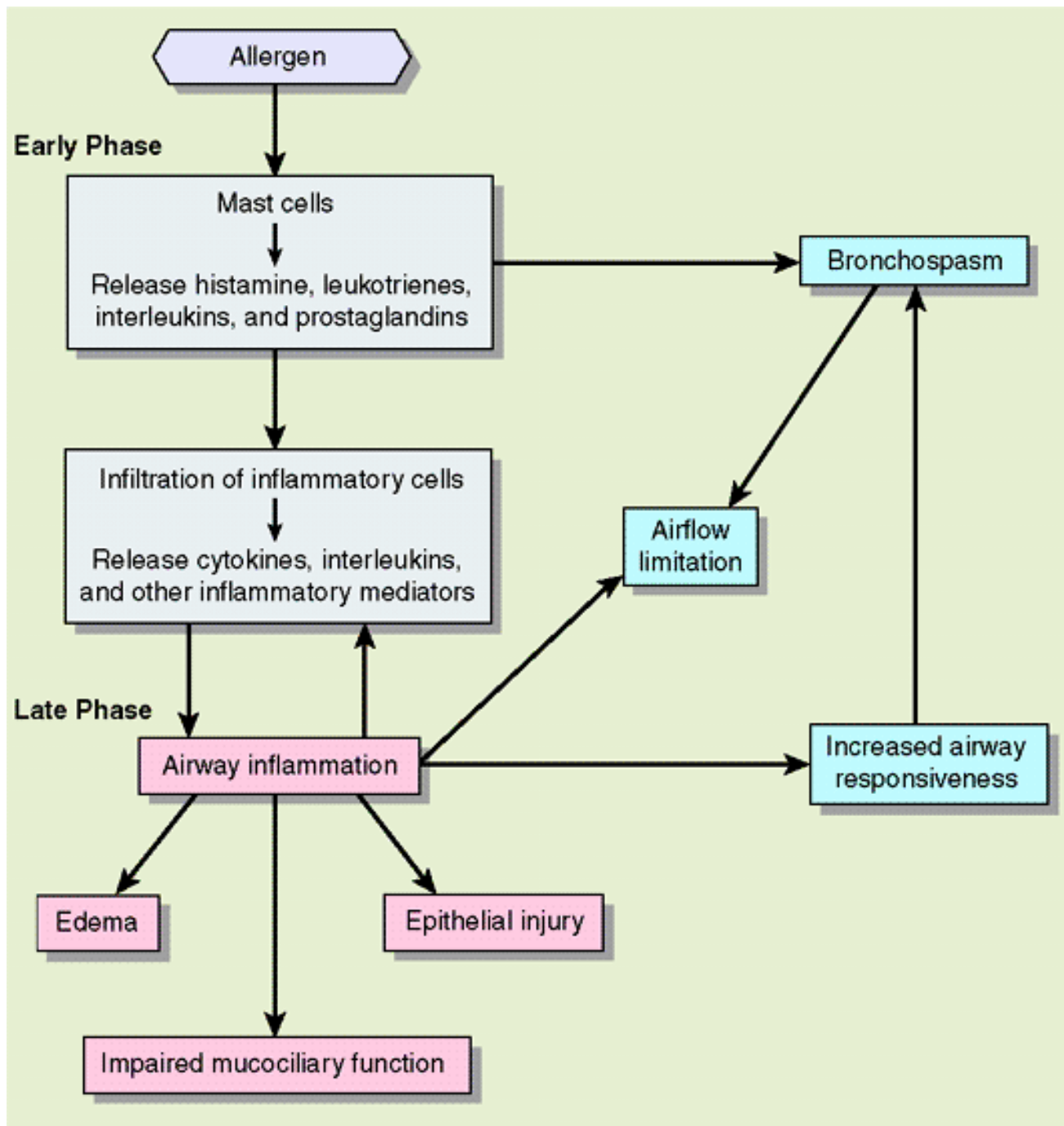
- difficulty breathing, wheezing breath, cough
- Asthma attacks alternating with periods without symptoms
- variability
 - seasonal
 - diurnal (night and morning attacks)
 - stress (exercise-induced asthma)

Asthma - classification

- atopic (allergic) asthma
 - Genetic predisposition + allergen
 - I.typ hypersen.
- non-atopic (non-allergic) asthma
 - endogenous A. (unknown cause)
 - Irritative a. (chem. comp., heat, cold)
 - Aspirin a. (and other drugs)

Type 1 hypersensitivity (IgE)





Asthma - phase of attack

- early (immediate response)
 - 30 min, mediators of mast cells
 - increased secretion of mucus, swelling of the mucous membrane
 - smooth muscle contraction (bronchospasm)
- the late response
 - after 4-6 hours, mediators, neutrophils, eosinophils
 - inflammation, eventually destruction of the epithelium

Asthma – pulmonary function

- at the rest
 - sometimes even without symptoms of obstruction
 - bronchoprovocation test
- in attack - signs of obstruction
 - reduced dynamic ventilatory parameters
 - improvement after bronchodilator

Treatment of asthma

- elimination or reduction of irritative factors
- anti-inflammatory therapy
- bronchodilator therapy
- hyposensitization

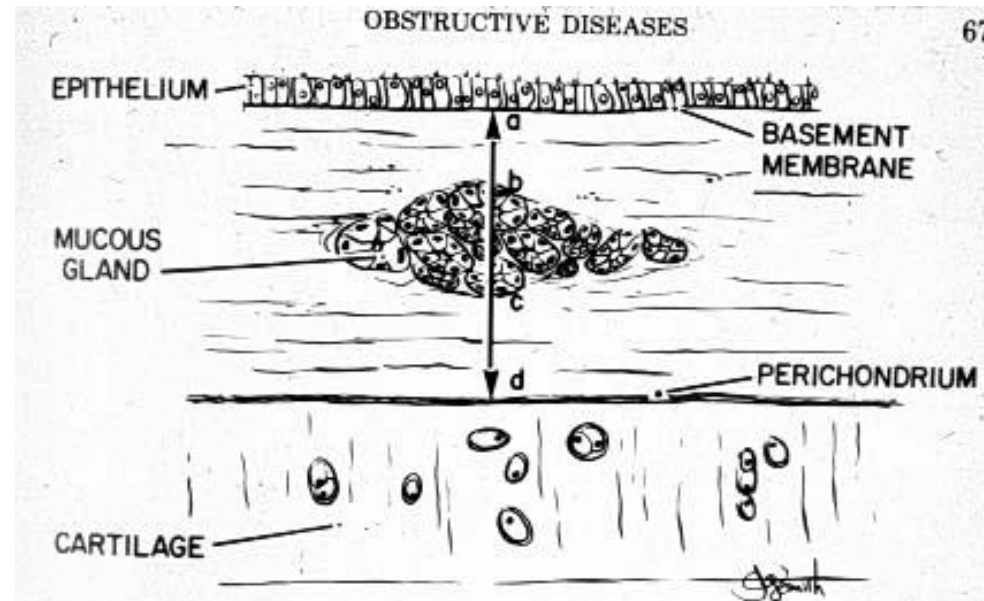
Chronic obstructive pulmonary disease (CHOPN, COPD)

- 5-20% of the adult population
- **30 x more common in smokers**
- Mortality - 5th place
- includes:
 - chronic bronchitis
 - pulmonary emphysema

1. Chronic bronchitis

Clinical definition:

disease with **hypersecretion of mucus** associated with chronic cough for at least **three months** in a year, for **2** consecutive years, to the exclusion of other pulmonary and cardiac diseases.

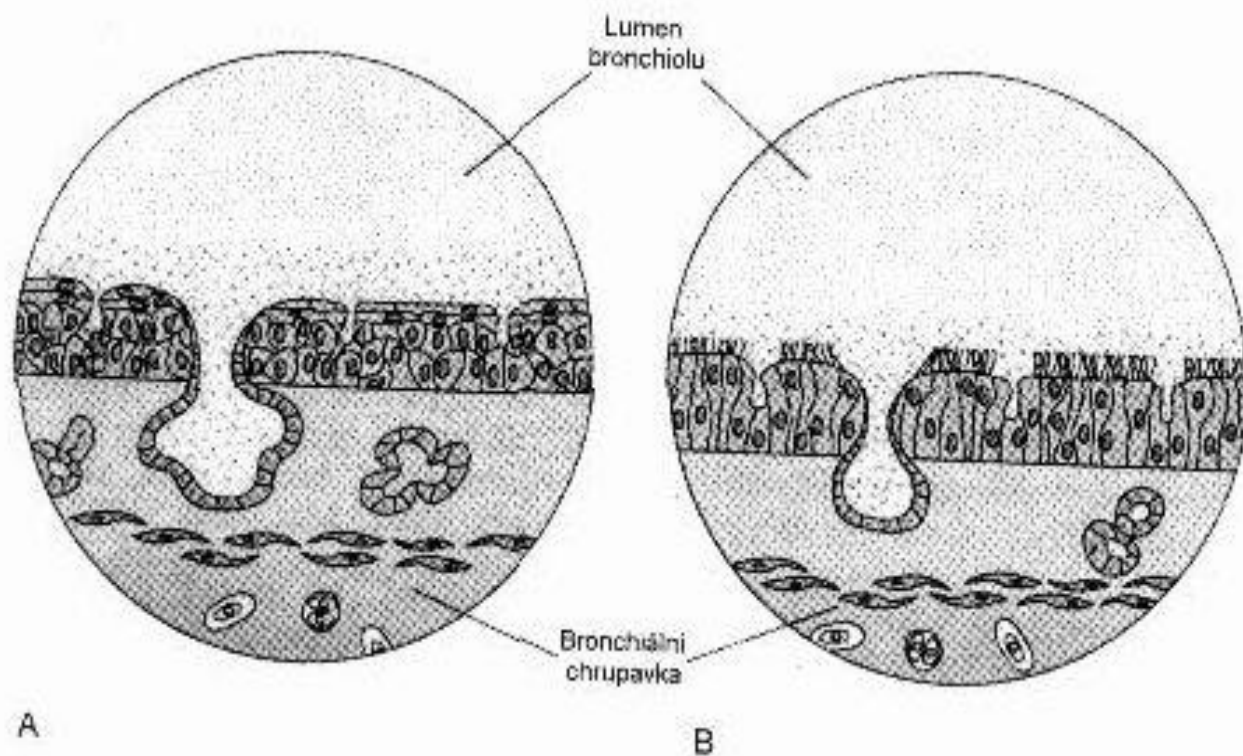


Chronic bronchitis - etiology

- **cigarette smoking**
- occupational exposure (oxides of S, N, formaldehyde)
- air pollution
- repeated respiratory infections

Chronic bronchitis - morphology

- hyperplasia and hypertrophy of mucous glands
- excess mucus in the airways
- inflammatory infiltration and swelling of the airway wall (narrowing)



Obr. 20.48 Sliznice dýchacích cest v normě (vpravo) a u chronické bronchitis (vlevo). U chronické bronchitis je patrný zvýšený počet žlázek v submukóze, zánětlivý otok a nadbytečný hlen, dále metaplázie epitelu k plochému typu. (NOW 12.15)

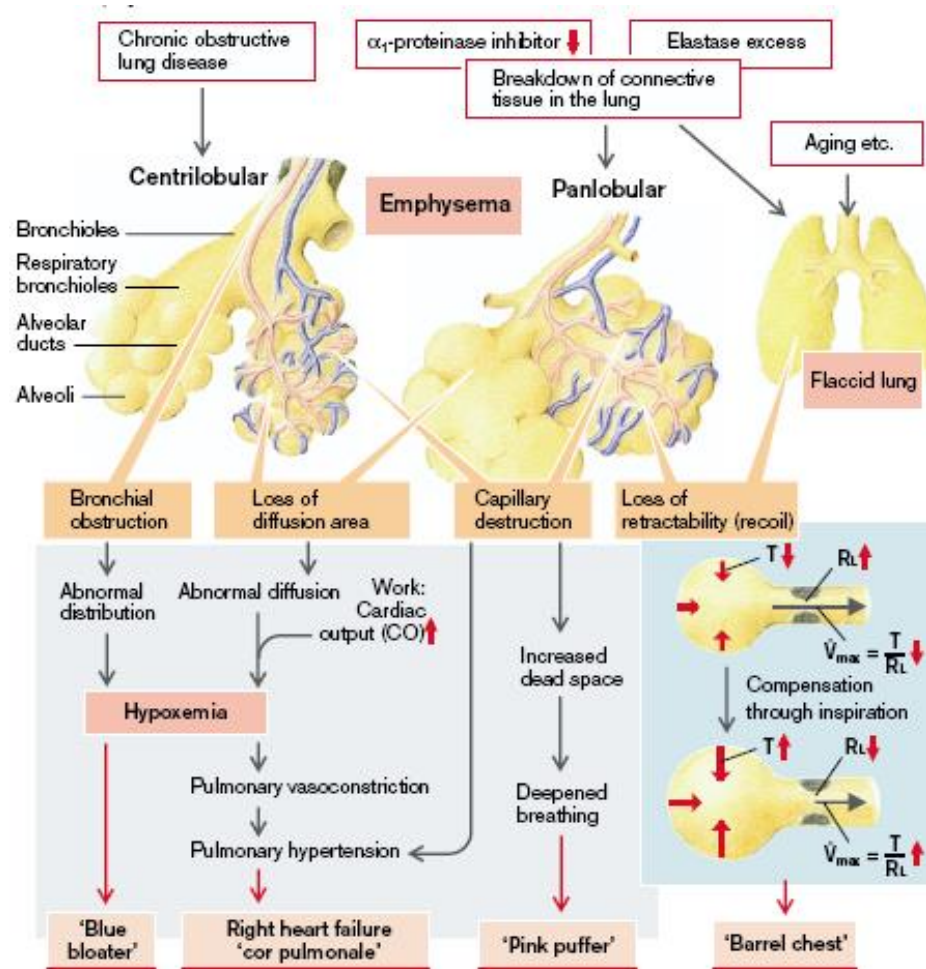
Chronic bronchitis – functional consequences

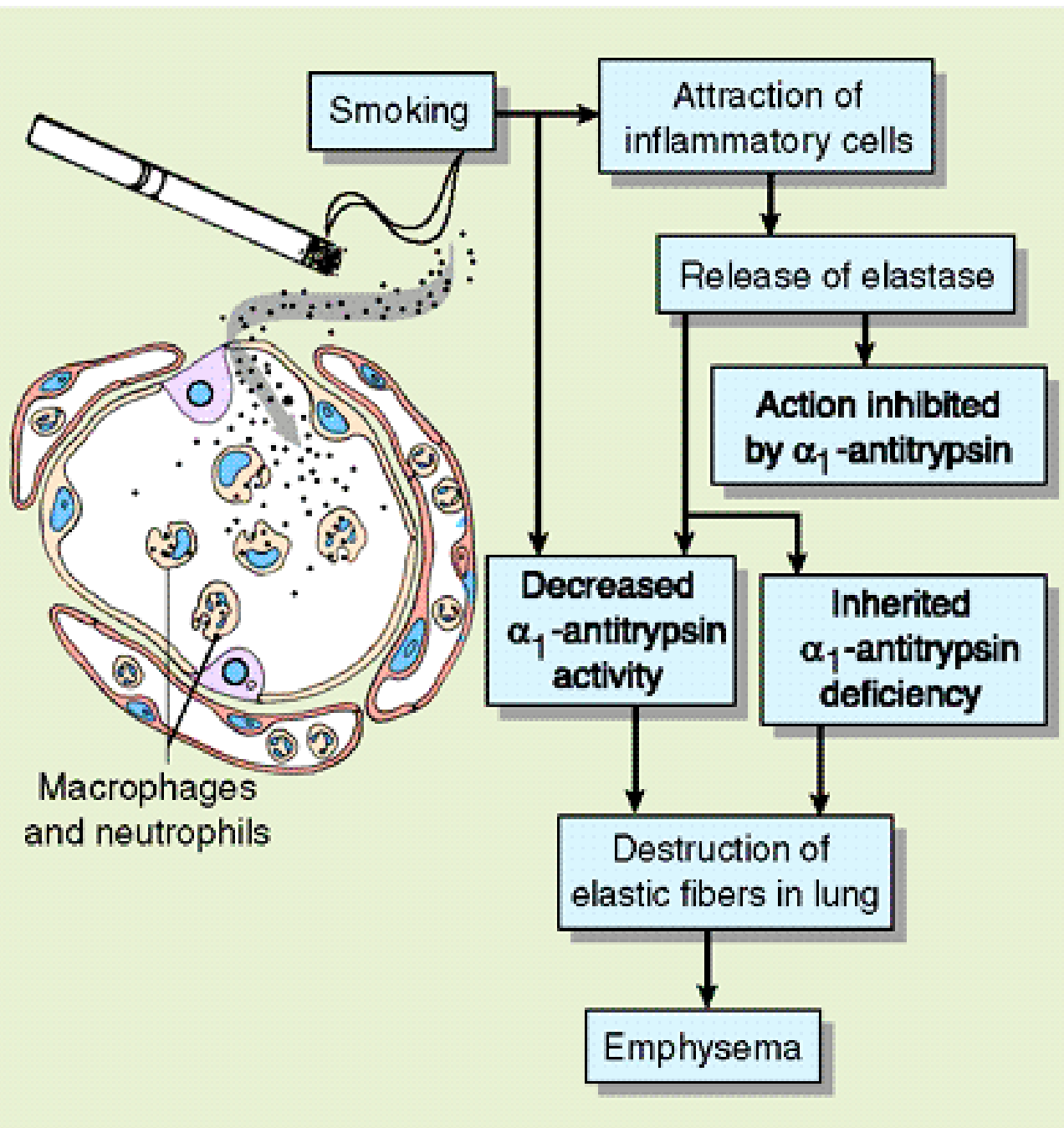
- constriction of small airways
 - expiratory obstruction - ↓ dynamic parameters
 - hypoxemia (cyanosis), hypercapnia and respiratory acidosis
 - normal pulmonary diffusion capacity for O₂

2. Emphysema- etiopathogenesis

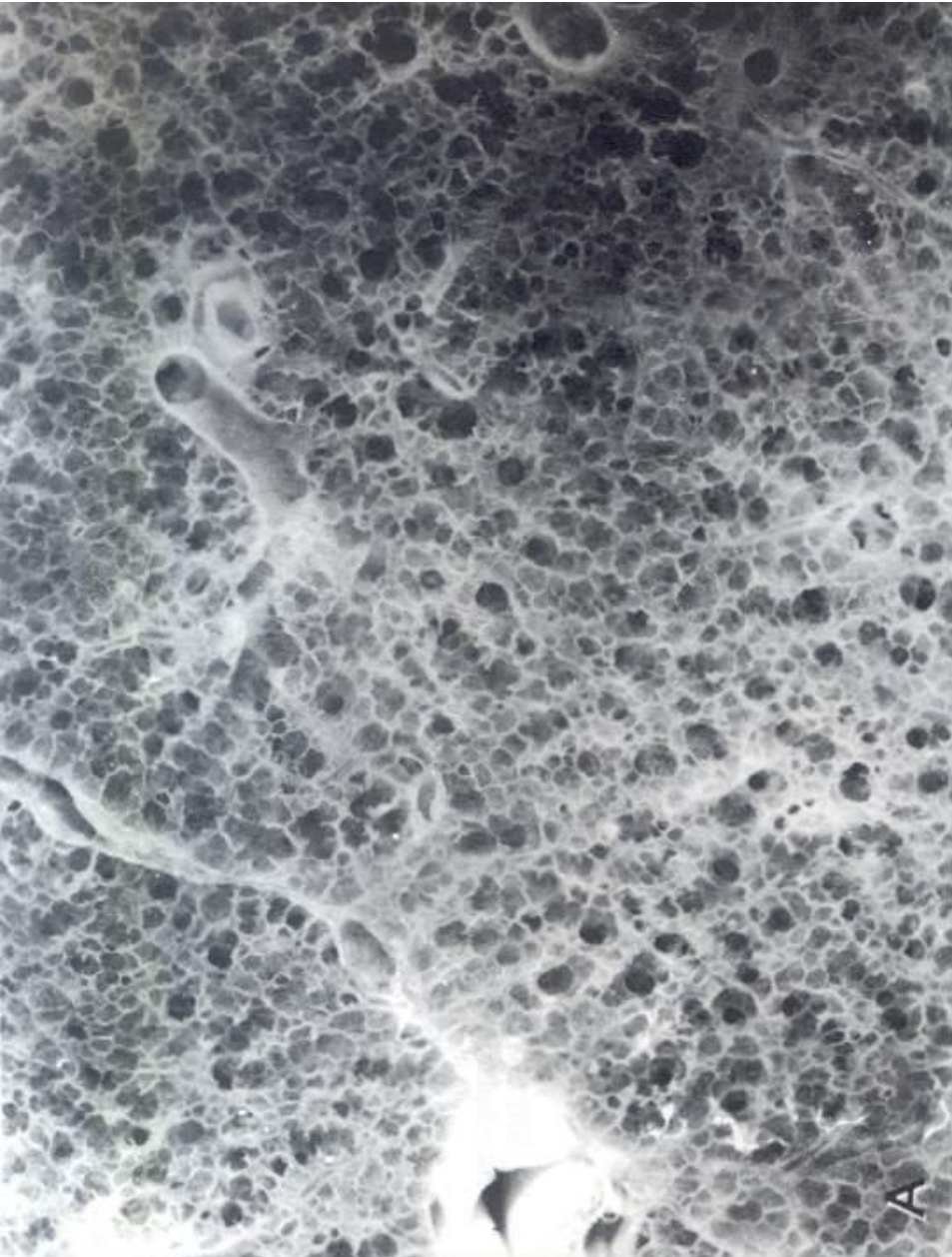
- imbalance in proteases and antiproteases
 - ↑ elastase
 - Smoking → inflammation → neutrophils
 - ↓ α 1-antitrypsin
 - smoking
 - genetic defect (MM homozygotes to 40 years)
- obstruction of bronchioles

Emphysema





Healthy lungs



Emphysematic lungs

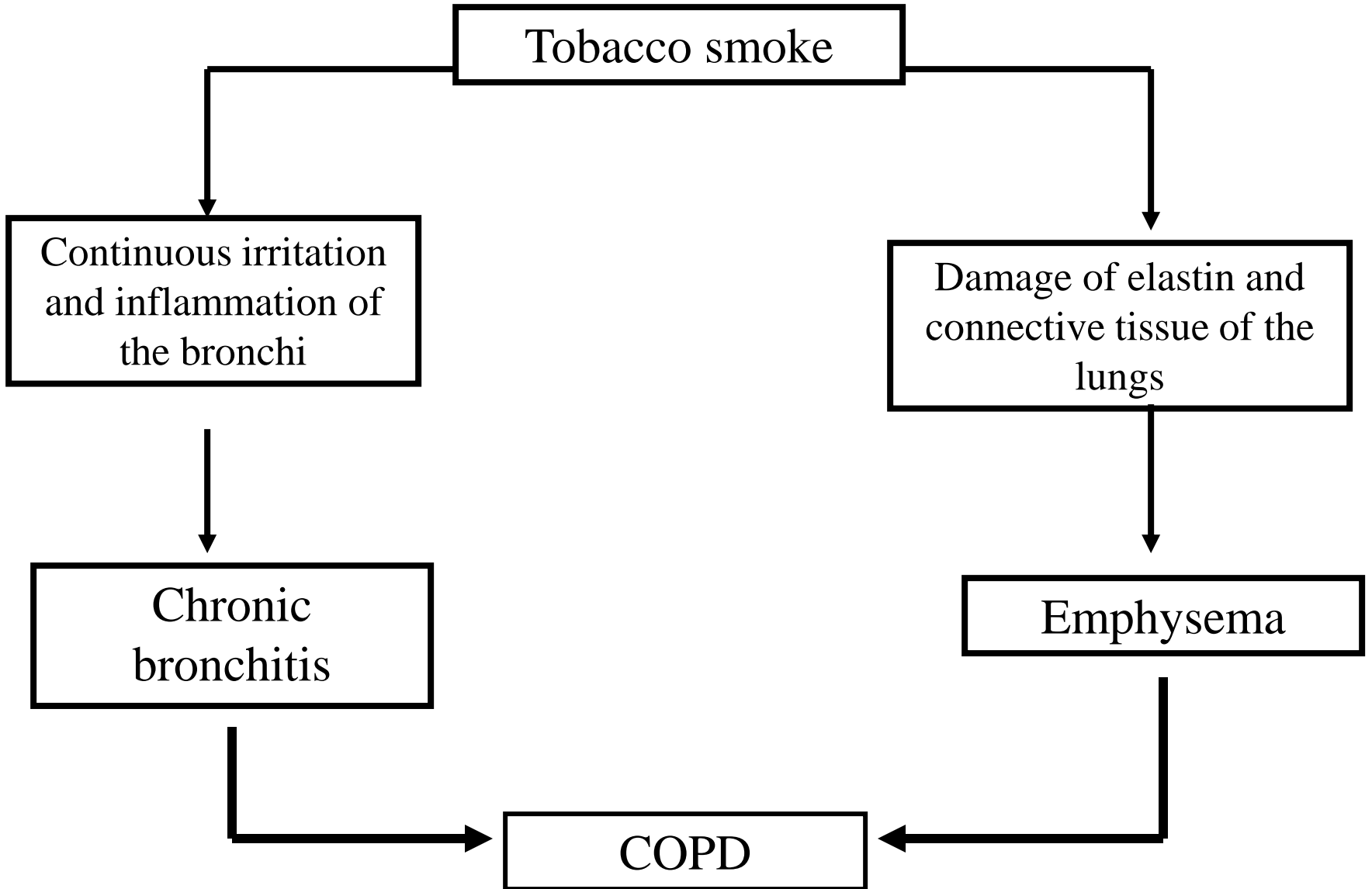


COPD – clinical symptoms

- increasing difficulty in breathing (years)
- shortness of breath, productive cough
- mainly bronchitis x mainly emphysema

COPD - treatment

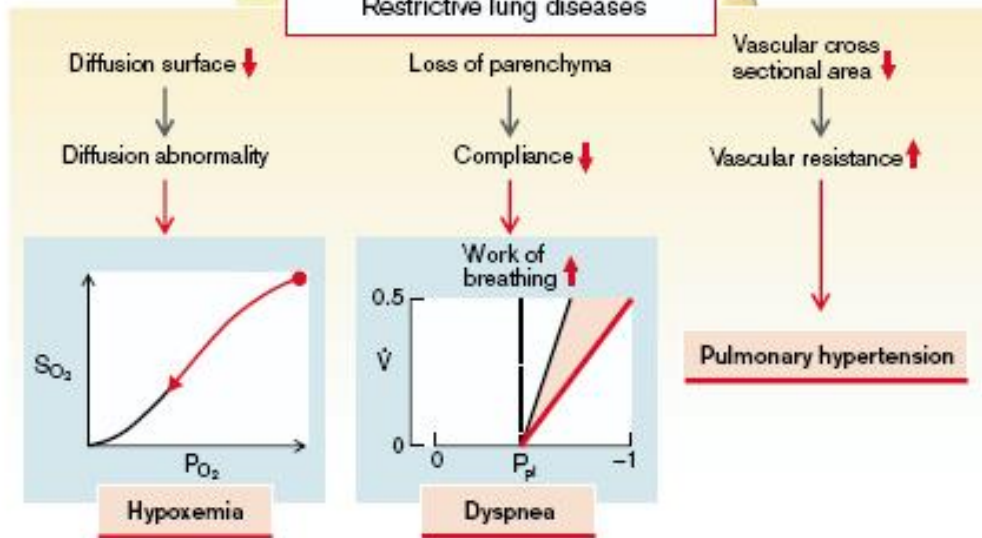
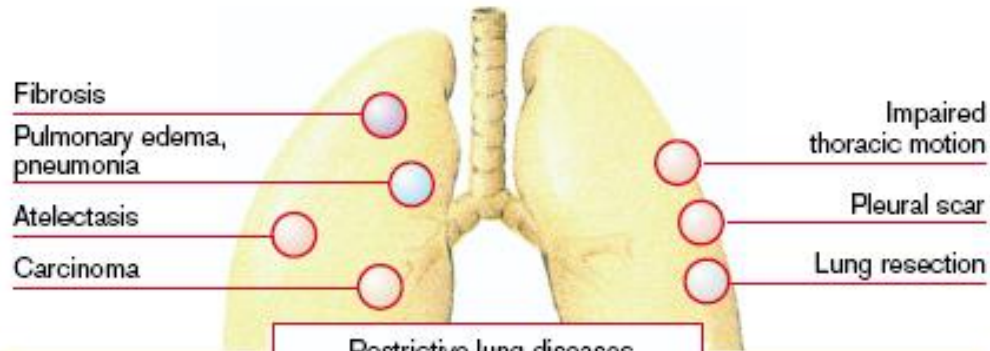
- Influencing of obstruction (bronchodilator)
- Influencing of infection (antibiotics)
- Removing mucus (expectorants)
- Oxygen therapy
- Rehabilitation, spa
- Surgical therapy
- Substitution of α 1-antitrypsin



Restrictive lung disorders

- **restriction**
 - reduction of functional lung parenchyma or limitation of respiratory movements
 - **limited expansion of the lung:**
- **from external causes** (resection, pleural disease, chest wall, neuromuscular system, extreme obesity)
- **change in the lung parenchyma** (inflammation, tumor, interstitial lung disease - usually combined with impaired diffusion)

Restrictive lung disorders



Spirometry

The terms to describe breathing

Hyperpnea	increased breathing movement
Eupnea	normal breathing movements
Hypopnea	decreased breathing movements
Apnea	arrested breathing
Bradypnea	decreased rate of breathing
Tachypnea	increased rate of breathing
Dyspnea	labored breathing (subjective feeling)
Asphyxia	inability to breathe
Orthopnea	labored breathing, except in the sitting or upright position

Definitions of certain pulmonary function parameters

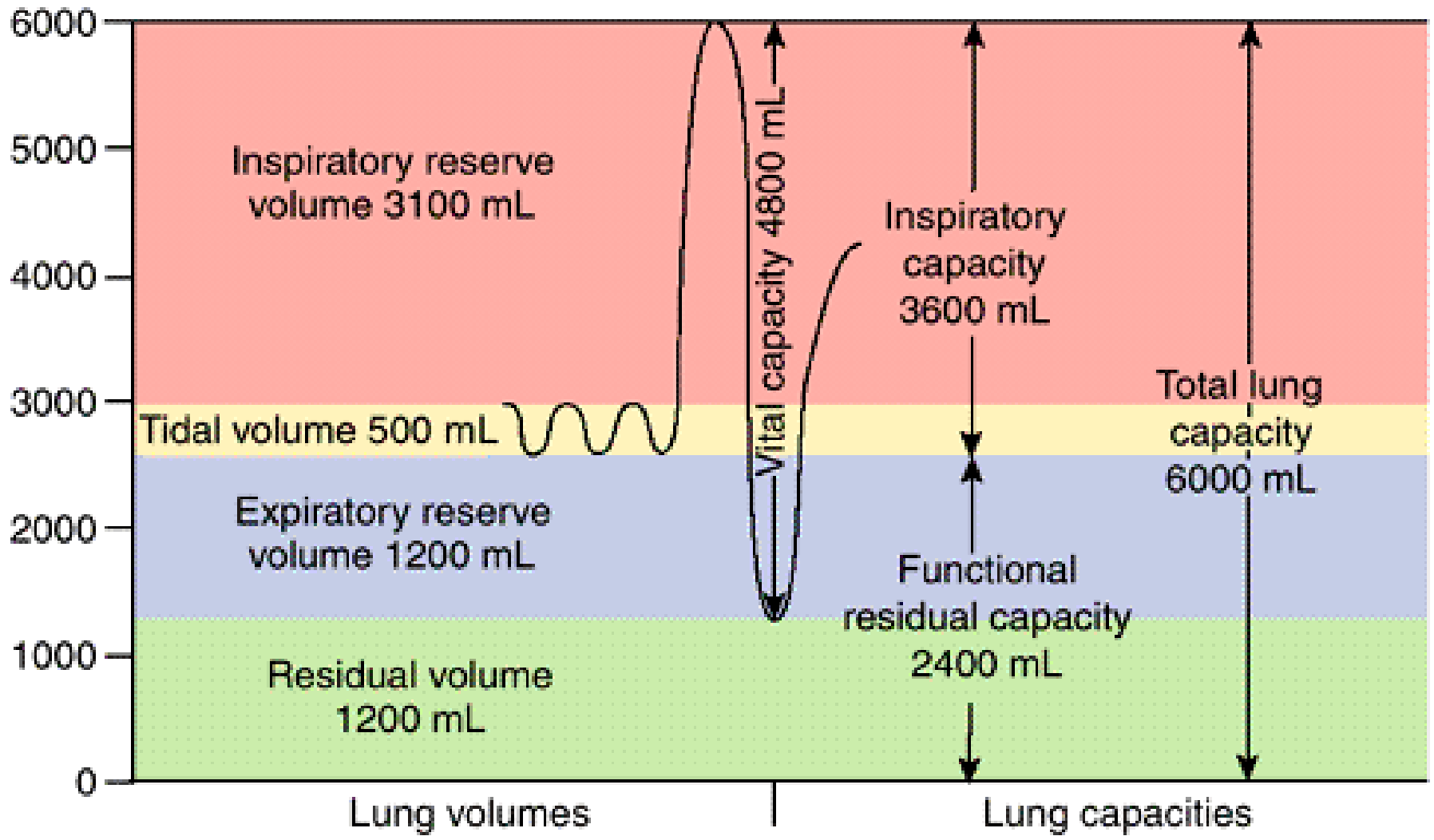
Tidal volume (V_T)	volume of normal inspiration and expiration
Vital capacity (VC)	volume of maximal expiration after maximal inspiration
Maximal breathing capacity (\dot{V}_{max})	maximal ventilation (L/min) achieved in a short period of time (usually 10 s)
Compliance (C)	lung distensibility
Forced expiration volume (FEV_1)	maximal volume expired in 1 second
Functional residual capacity (FRC)	total residual volume after normal expiration

Limitation of spirometry

- measured only exchanging volumes during breathing (no residual volumes)
- measured under the non-physiological conditions
- requires the cooperation of the patient

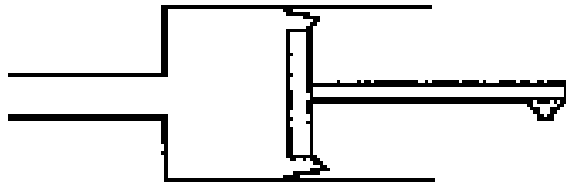
Spirometric values

- ***static***
= time independent
- ***dynamic***
= time dependent

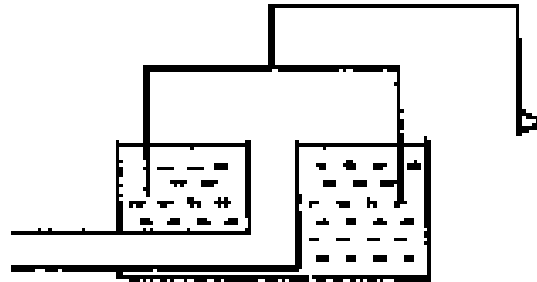


Principles of spirometers

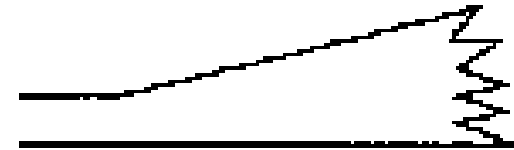
Rolling Seal



Water Sealed

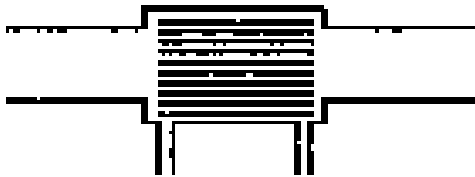


Bellows

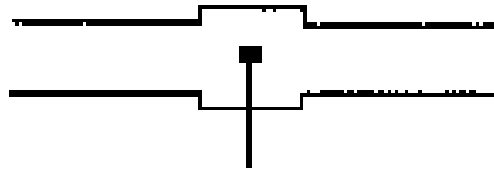


Flow Sensors

Pneumotach



Hot-Wire

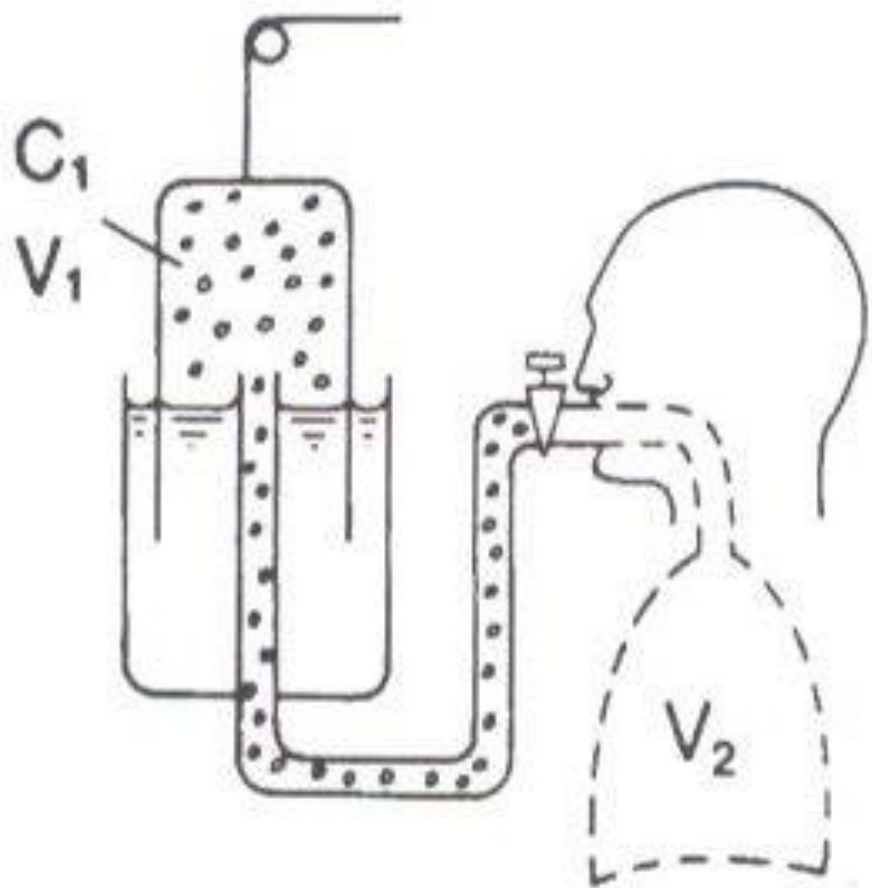


Turbine

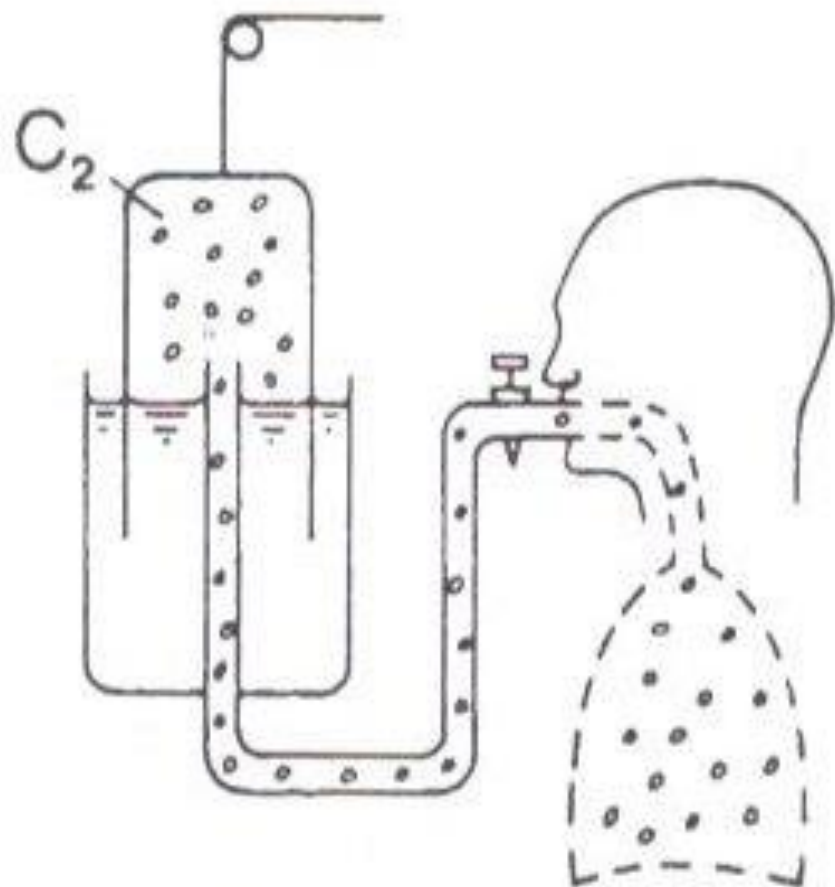


Static lung volumes

- **TLC** - total lung capacity (about 6 l)
- **RV** - residual volume (spirometer can not measure!)
- **ERC** - expiratory reserve volume (about 1.5 liters)
- **IRV** - inspiratory reserve volume (about 2.5 liters)
- **FRC** - functional residual capacity $ERV + RV$
- **VC** - vital capacity, $TLC - RV$
- tidal volume of about 0.5 l



Před ekvilibrací



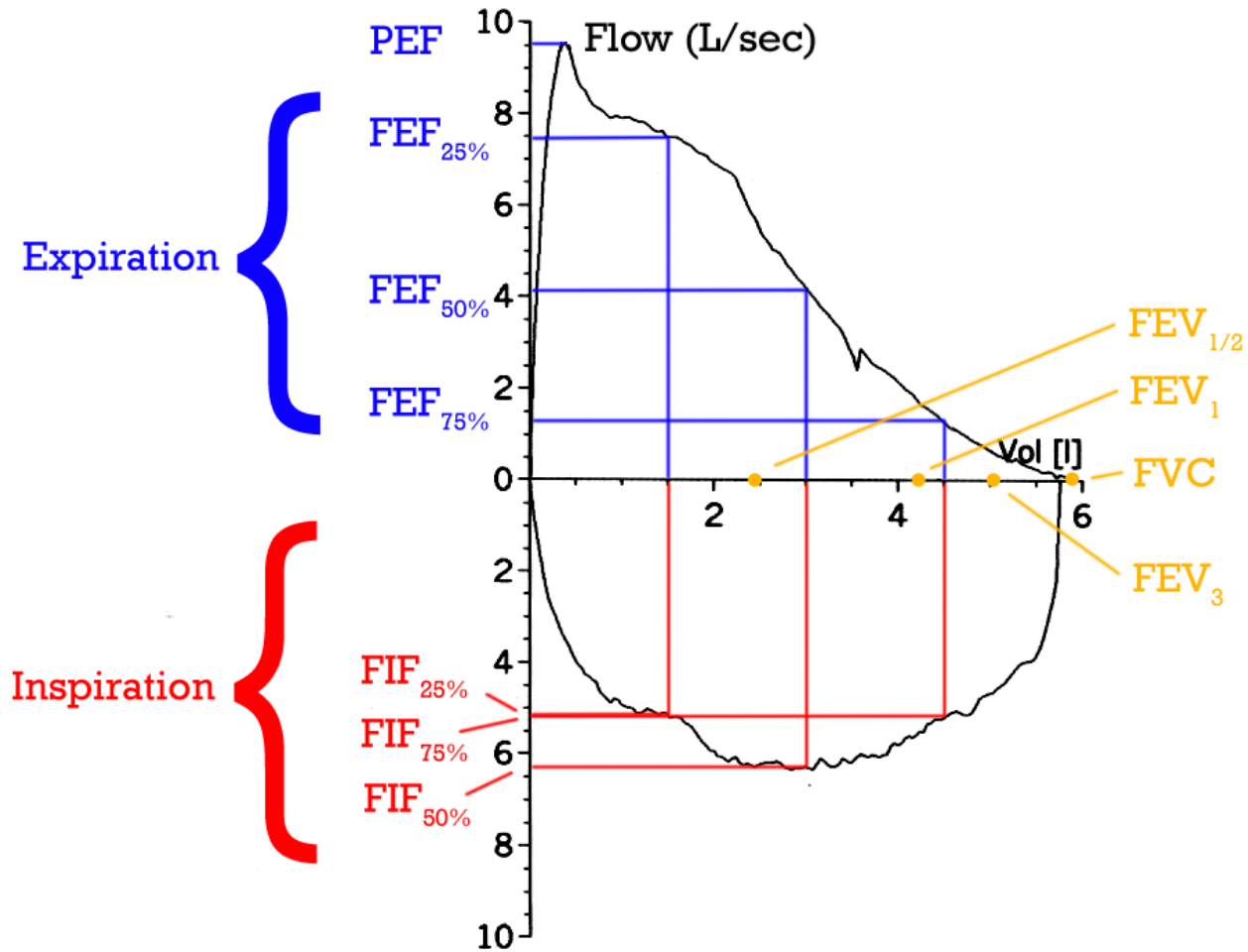
Po ekvilibraci

$$C_1 * V_1 = C_2 * (V_1 + V_2)$$

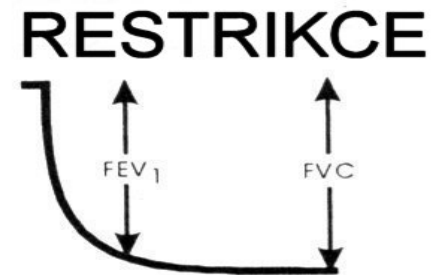
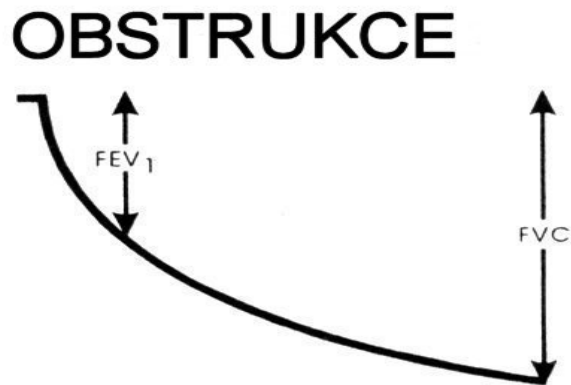
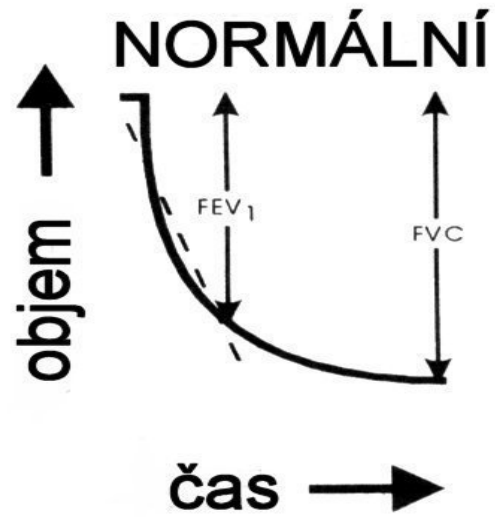
Dynamic parameters

- FVC - forced vital capacity ("as much and as quickly as possible")
- FEV1 - expiration-second capacity
- FEV1/FVC - second capacity for FVC ratio
- FEF25-75% - average flow velocity in the middle half of the FVC
- PEF - peak expiratory flow rate
- Vmax 50%, 25% Vmax - maximal flow after exhalation 50% respectively. 75% of vital capacity

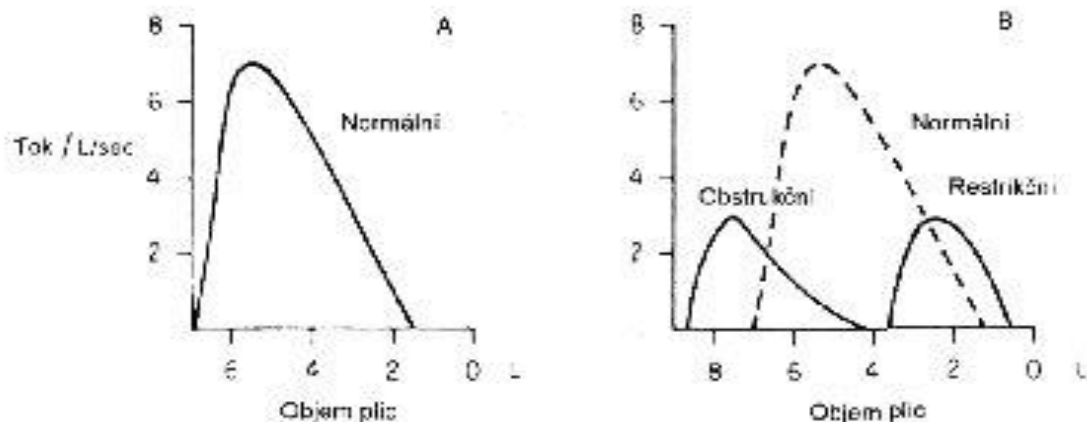
Loop flow/volume



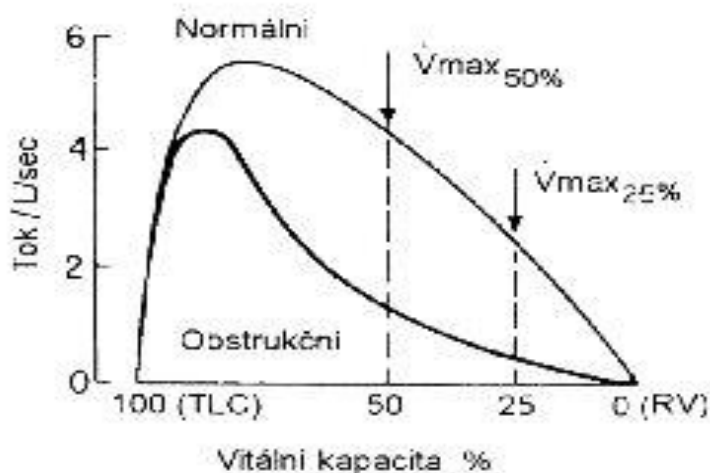
Volume-time curve



Loop flow/volume



Obr. 20.35 Expirační křivky tok - objem u obstrukčních a restrikčních nemocí. (WPF 1.5)



Obr. 20.36 Příklad expirační křivky tok - objem u chronické obstrukční plicní nemoci. Křivka má typický konkávní tvar. Šipky ukazují maximální tok V_{max} poté, co bylo vydechnuto 50% nebo 75% vitální kapacity (- zůstává 25% TLC). (WPF 1.8)

Spirometry in obstructive disorders

- **dynamic ventilation parameters** ↓
 - **volumes during forced exhalation**
 - FEV1 ↓, ↓ FEV1/FVC (%), standard 80%, FVC ± ↓
 - **flow (velocity)**
 - PEF ↓, ↓ MEF 50%, MEF ↓ 75% ↓ 25% MEF
 - ↓ FEF 25-50%
- **static lung volumes** ↑
 - **residual volumes**
 - ↑ RV, FRC ↑, ↑ TLC

Spirometry in restrictive disorders

- **static lung volumes** ↓
 - residual volumes
 - ↓ **RV, FRC** ↓, ↓ **TLC**
- **Dynamic ventilation parameters** ± ↔
 - **volumes during forced exhalation**
 - ↓ **FEV1**, ± ↑ **FEV1/FVC (%)**, standard 80%, **FVC** ↓
 - **flow (velocity)**
 - **PEF** ↓, ↓ **MEF 50%**, **MEF** ↓ **75%** ↓ **25%** **MEF**
± ↑ **FEF 25-50%**

Obstructive diseases

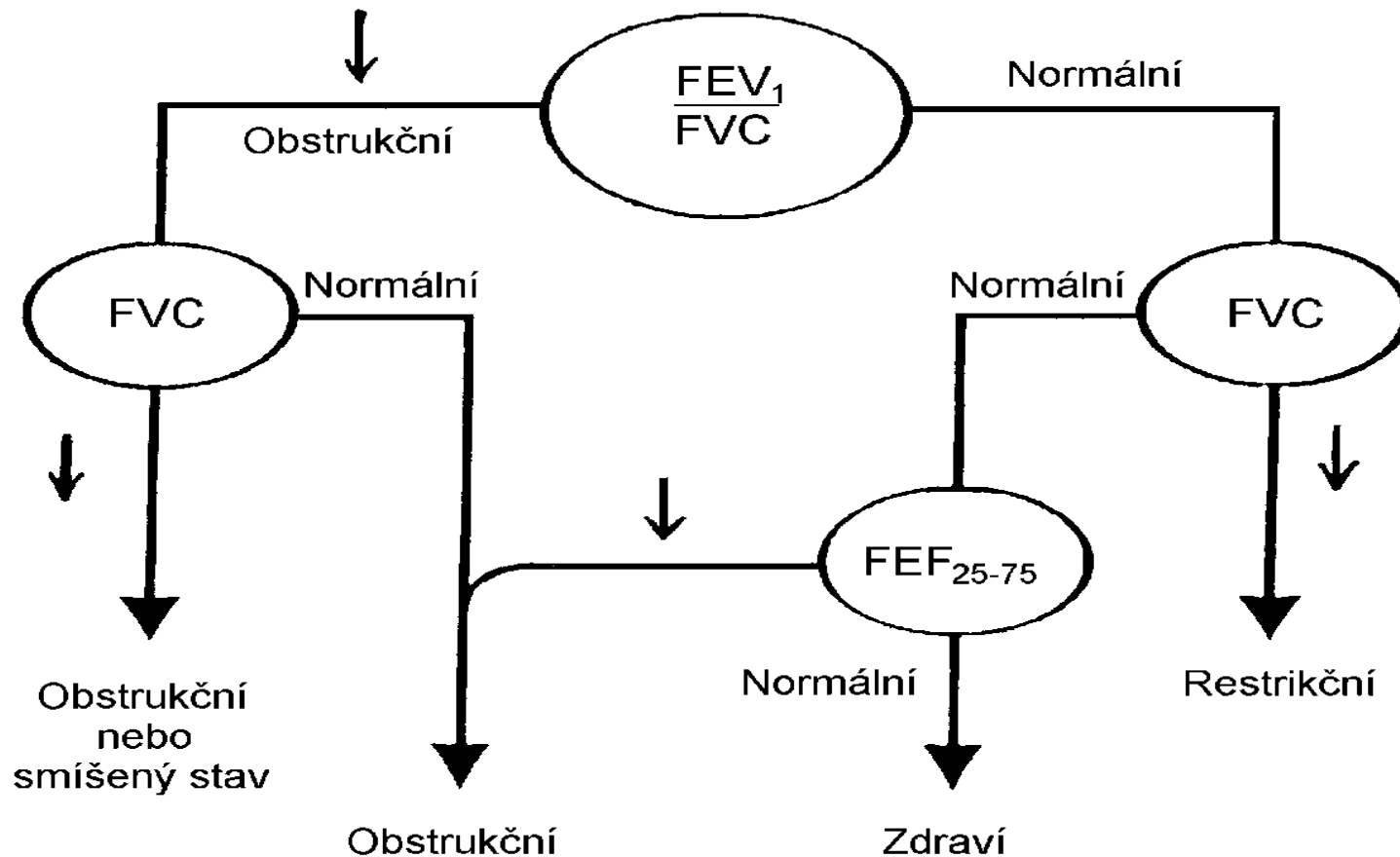
FEV1	> 80% predicted	normal
	65 - 80%	mild
	50 - 65%	moderate
	< 50%	severe

	Meas	Pred	%Pred
FVC	2.63	3.11	84
FEV1	1.58	2.28	69
FEV1/FVC	60	73	
FEF25-75	0.59	2.56	23
PEF	4.90	5.78	85

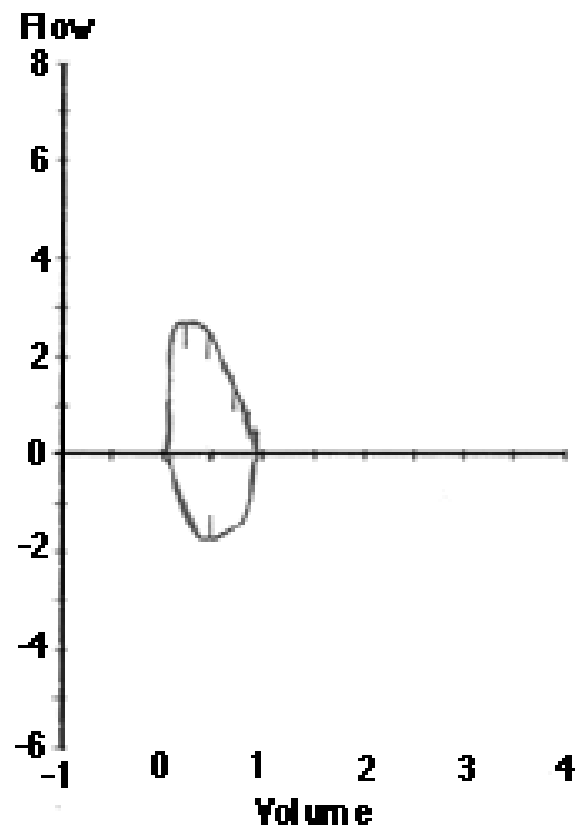
Restrictive diseases

	Meas	Pred	%Pred
FVC	0.96	2.75	35
FEV1	0.94	1.90	49
FEV1/FVC	98	69	
FEF25-75	2.25	2.11	107
PEF	2.98	5.40	55

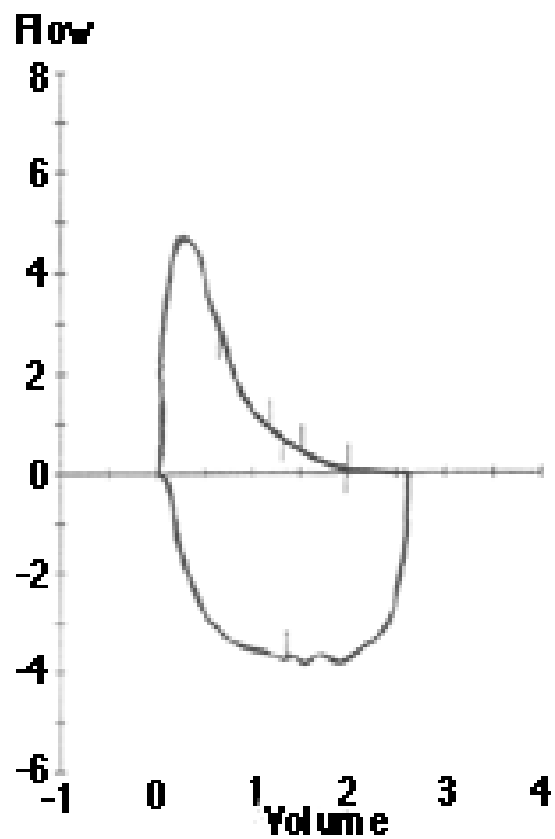
Algorithm for spirometry interpretation



Restriction



Obstruction



Peak flow meter

- Peak flow meter is a small device that monitors the flow of air through the bronchi and helps to detect any obstruction in the airway.
- Peak flow meter measures the ability or peak expiratory flow or peak expiratory flow rate (PEFR or PEF).
- PEF is higher in the physiological condition of the patient, at lower values infer constriction.
- From changes in the measured values, we can determine the patient's condition, or appropriate therapy.

