The respiratory formulation

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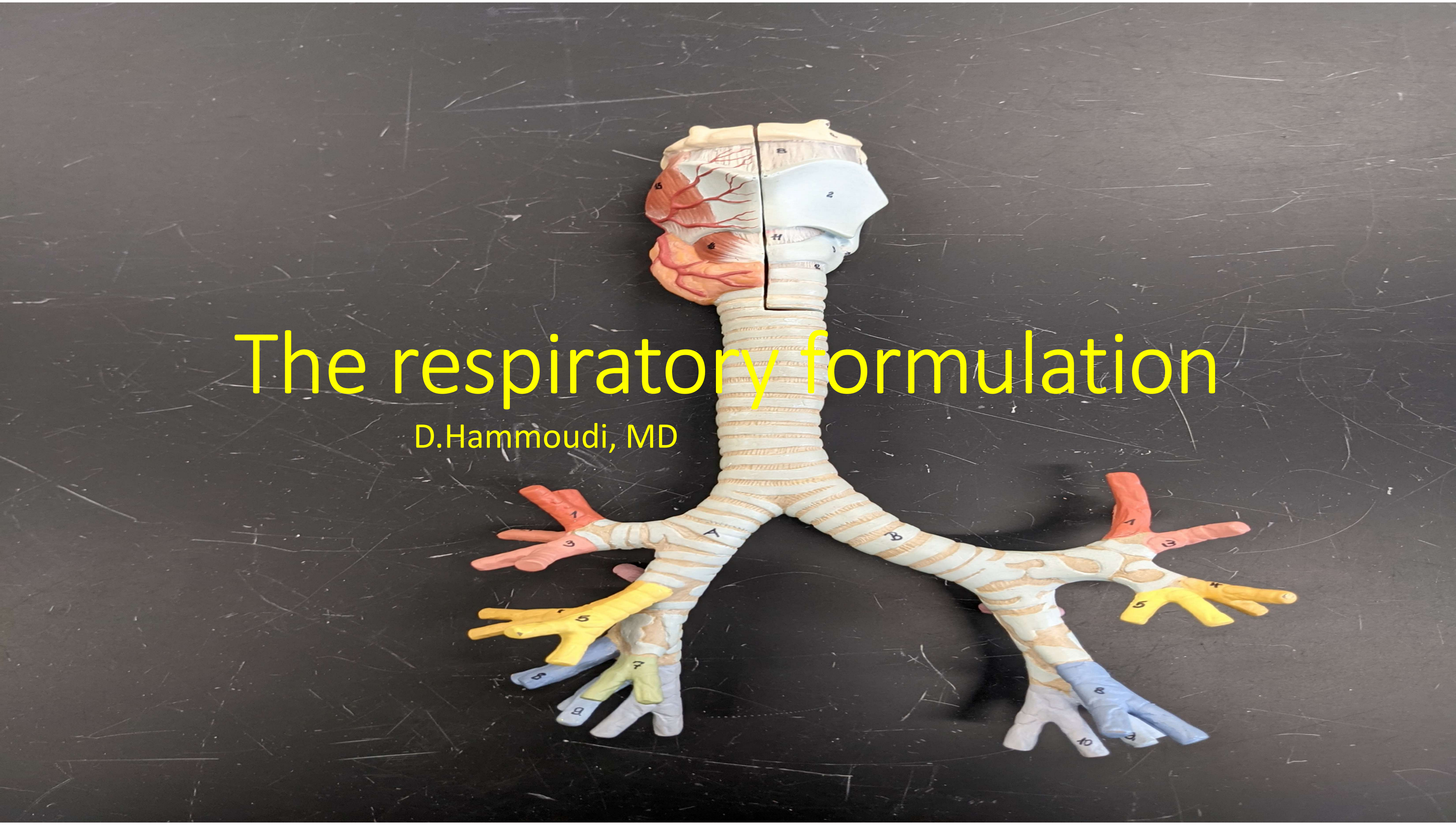

Boyle's Law:

For a fixed mass of gas at constant temperature, the pressure (P) and volume (V) are inversely proportional, such that $P \times V = k$, where k is a constant.

Physiologic dead space (VD): volume of inspired air that does not participate in gas exchange
VD is the sum of the anatomic dead space and the alveolar dead space

Anatomic dead space: the volume of air in the conducting zone, e.g., **mouth, trachea (approx. ⅓ of the resting tidal volume)**
Alveolar dead space: the sum of the volumes of alveoli that do not participate in gas exchange (mainly apex of the lungs); These alveoli are ventilated but not perfused

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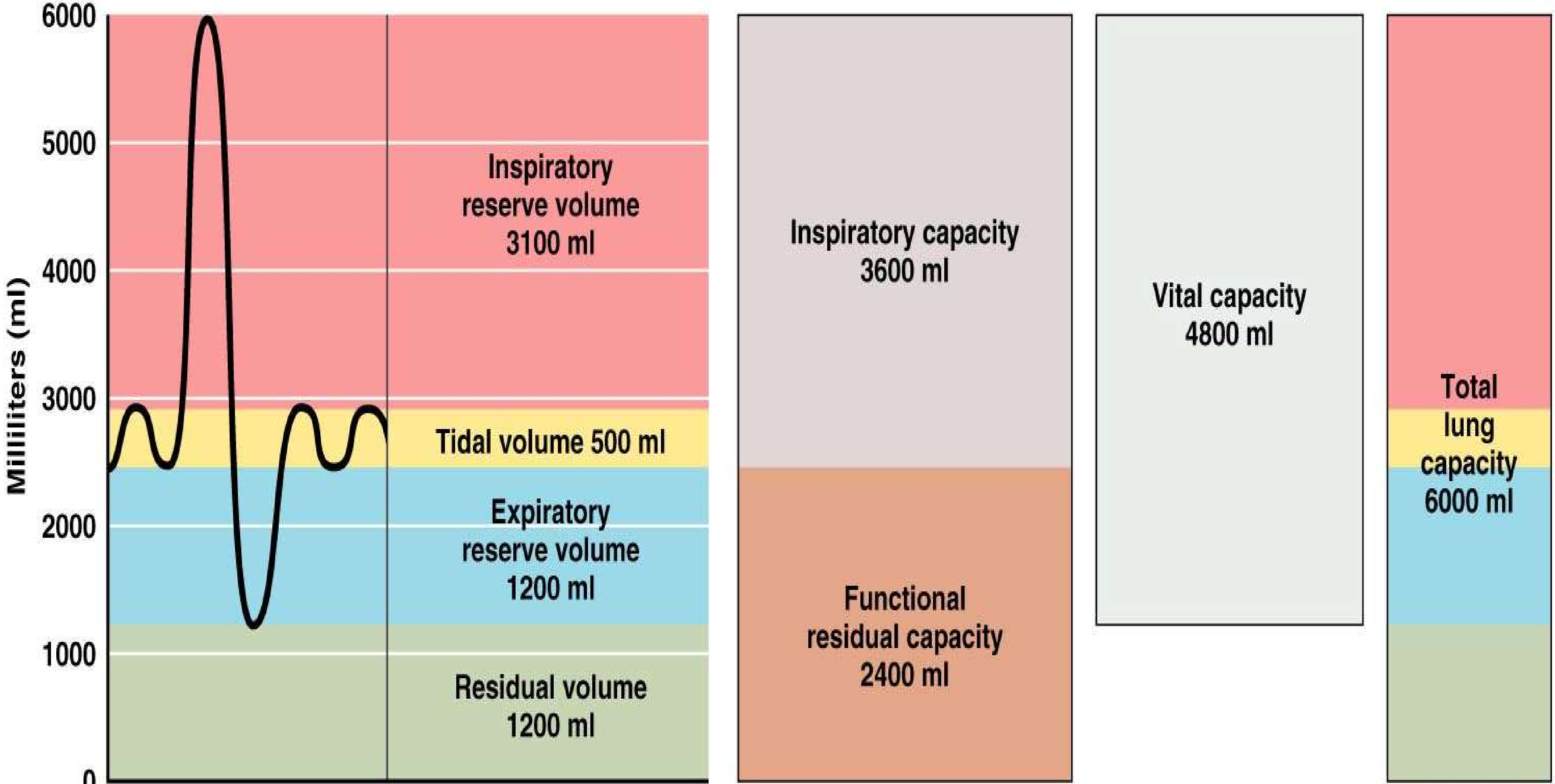
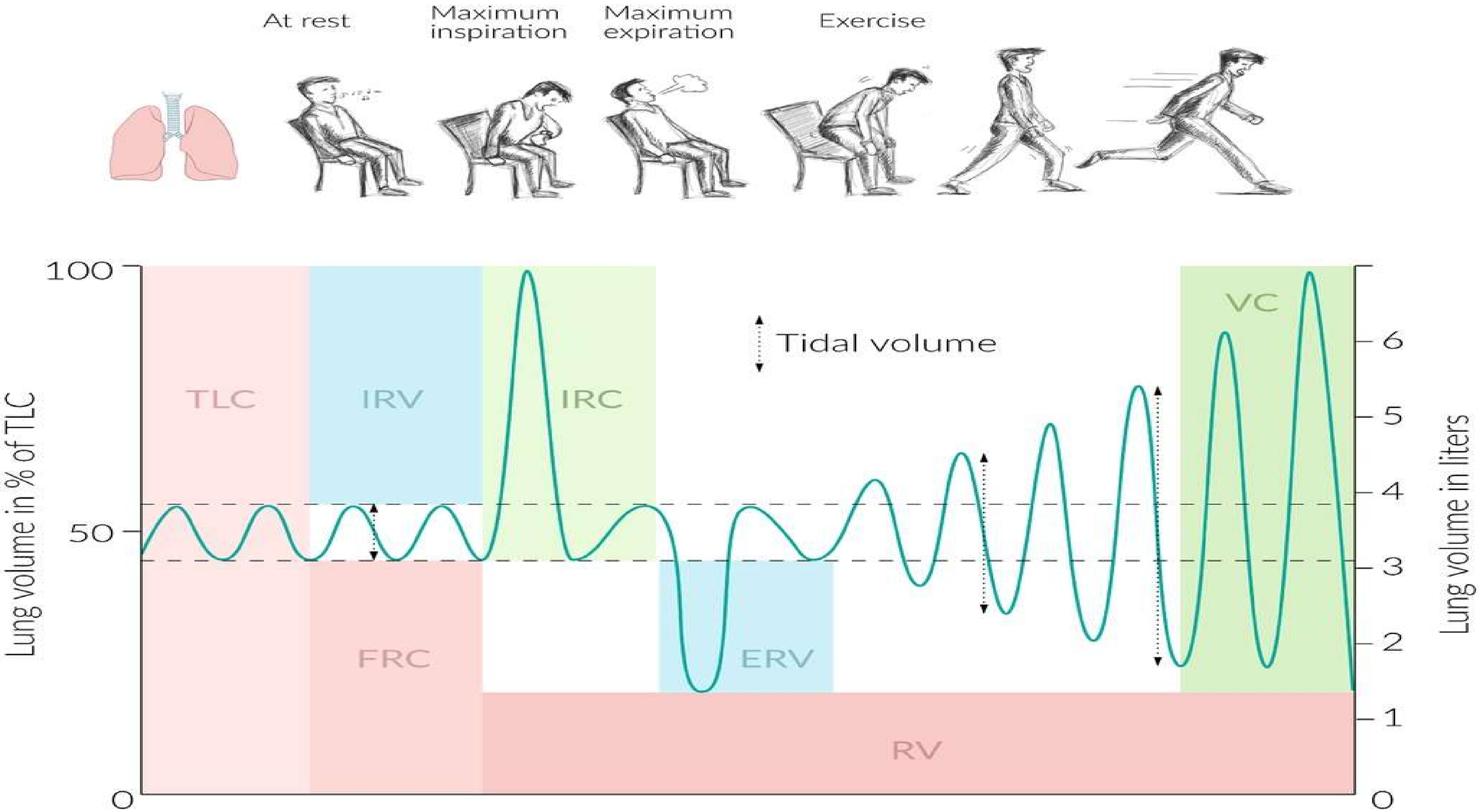
Bohr equation determines the physiologic dead space : **VD** = VT x ($PaCO_2$ - $PeCO_2$)/($PaCO_2$)
In a healthy lung, VD equals the anatomic dead space (normal value: approx. 150 mL/breath).

	Measurement	Adult male average value	Adult female average value	Description
Respiratory volumes	Tidal volume (TV)	500 ml	500 ml	Amount of air inhaled or exhaled with each breath under resting conditions
	Inspiratory reserve volume (IRV)	3100 ml	1900 ml	Amount of air that can be forcefully inhaled after a normal tidal volume inhalation
	Expiratory reserve volume (ERV)	1200 ml	700 ml	Amount of air that can be forcefully exhaled after a normal tidal volume exhalation
	Residual volume (RV)	1200 ml	1100 ml	Amount of air remaining in the lungs after a forced exhalation
Respiratory capacities	Total lung capacity (TLC)	6000 ml	4200 ml	Maximum amount of air contained in lungs after a maximum inspiratory effort: TLC = TV + IRV + ERV + RV
	Vital capacity (VC)	4800 ml	3100 ml	Maximum amount of air that can be expired after a maximum inspiratory effort: VC = TV + IRV + ERV (should be 80% TLC)
	Inspiratory capacity (IC)	3600 ml	2400 ml	Maximum amount of air that can be inspired after a normal expiration: IC = TV + IRV
	Functional residual capacity (FRC)	2400 ml	1800 ml	Volume of air remaining in the lungs after a normal tidal volume expiration: FRC = ERV + RV

(b) Summary of respiratory volumes and capacities for males and females



(a) Spirographic record for a male



At rest
Maximum inspiration
Maximum expiration
Exercise
100
50
0
Lung volume in % of TLC
TLC
IRV
IRC
FRC
ERV
RV
VC
Tidal volume
6
5
4
3
2
1
0
Lung volume in liters

Lung volume	Definition	Normal range
Total lung capacity (TC, TLC)	•Volume of air in the lungs after maximal inhalation **TC = VC + RV**	•6–6.5 L
Vital capacity (VC)	•Difference in lung volume between maximal exhalation and maximal inhalation **VC = TV + IRV + ERV**	•4.5–5 L
Residual volume (RV)	•Volume of air that remains in the lungs after a maximal exhalation	•1–1.5 L
Tidal volume (TV)	•Volume of air that is inhaled and exhaled in a normal breath at rest	•~ 500 mL or 7 mL/kg
Inspiratory reserve volume (IRV)	•Maximum volume of air that can still be forcibly inhaled following the inhalation of a normal TV	•3–3.5 L
Inspiratory capacity (IC)	•Maximum volume of air that can be inhaled after the exhalation of a normal TV **IRC = IRV + TV**	•3.5–4 L
Expiratory reserve volume (ERV)	•Maximum volume of air that can still be forcibly exhaled after the exhalation of a normal TV	•1.5 L
Expiratory capacity (EC)	•Maximum volume of air that can be exhaled after the inspiration of a normal TV **ERC = ERV + TV**	•2 L
Functional residual capacity (FRC)	•Volume of air that remains in the lungs after the exhalation of a normal TV **FRC = RV + ERV**	•2.5–3 L

CALCULATION POSSIBILITIES USING THE FORMULAS

- IC= IRV+TV INSPIRATORY CAPACITY = INSPIRATORY RESERVE VOLUME + TIDAL VOLUME = 3100+500= 3600 ml
- IC= TLC – FRC

- FRC = ERV + RV FUNCTIONAL RESIDUAL CAPACITY = EXPIRATORY RESERVE VOLUME + RESIDUAL VOLUME= 1200+1200=2400 ml
- FRC = TLC - IC

- VC= IRV+TV+ERV VITAL CAPACITY= INSP RESERVE VOLUME+ TIDAL VOLUME + EXPIRATORY RESERVE VOLUME = 3100+ 500+ 1200 = 4800 ml

- VC= IC + ERV
- VC = TLC – RV

- TLC= IRV+TV+ERV+RV = 3100+500+1200+1200= 6000 ml TLC = TOTAL LUNG CAPACITY
- TLC= IC + FRC = 3600 + 2400 = 6000 ml
- TLC= VC + RV = 4800 + 1200 = 6000 ml

•**Flow = volume / time.**

•**Volume = flow × time.**

•**Pressure = flow × resistance.**

•**Resistance = change in pressure / flow.**

•**Compliance = volume / change in pressure.**

•**Work of breathing = pressure × volume.**

Lung compliance

•**Definition**: the ability of the lungs to distend under pressure

•**Measurement**: change in volume of the lung per unit change in pressure ($C = \Delta V/\Delta P$)

AVR = frequency x (TV – dead space) = Aveolar ventilation rate

VE = TV x RR Minute ventilation = total volume of gas entering lungs per min

the amount of air breathed per minute, which equals about 6 liters (about 2 liters stay in the anatomic dead space consisting of the upper airway and the mouth, and 4 liters participate in gas exchange in the millions of alveoli constituting alveolar ventilation).

Minute ventilation = **tidal volume x respiratory rate** (normal is 4-6 L/min)

Tidal volume = alveolar space + dead space.

Overview of normal and pathologic ventilation			
Parameter	**Normal**	**Decreased**	**Increased**
Respiratory rate (RR)	12–20/min	Bradypnea (< 12/min)	Tachypnea (> 20/min)
Tidal volume (VT OR TV)	0.5 L/breath	Hypopnea	Hyperpnea
Minute ventilation (VE)	7.5 L/min	Hypoventilation	Hyperventilation

If alveolar ventilation increases (i.e., hyperventilation), more CO_2 is exhaled and the $PaCO_2$ decreases.

If alveolar ventilation decreases (i.e. hypoventilation), $PaCO_2$ increases.

Partial pressure during the respiratory cycle (% of total gas composition)			
Gases	**In inspired air** [2]	**In alveoli**	**In expired air**
N_2	593 mmHg (≈ 79%)	573 mmHg (≈ 75%)	593 mmHg (≈ 79%)
O_2	160 mmHg (≈ 21%)	104 mmHg (≈ 14%)	116 mmHg (≈ 16%)
H_2O	3.0 mmHg (≈ 0.5%)	47 mmHg (≈ 6%)	47 mmHg (≈ 6%)
CO_2	0.3 mmHg (≈ 0.04%)	40 mmHg (≈ 5%)	28.5 mmHg (≈ 4%)
Total of all gases	760 mmHg (= 100%)		

Partial pressure of O_2 and CO_2 across the blood-air barrier		
	In the alveoli	**In the pulmonary capillaries**
Partial pressure of O_2	104 mm Hg	40 mm Hg
Partial pressure of CO_2	40 mm Hg	45 mm

- **Mean pulmonary arterial pressure** (mPAP): normal 10–14 mmHg
- **Pulmonary capillary pressure**: ~ 8 mmHg

Pulmonary vascular resistance (PVR): the resistance offered by the pulmonary circulatory system that must be overcome to create blood flow

PVR = Ppulm artery - PL atrium/CO

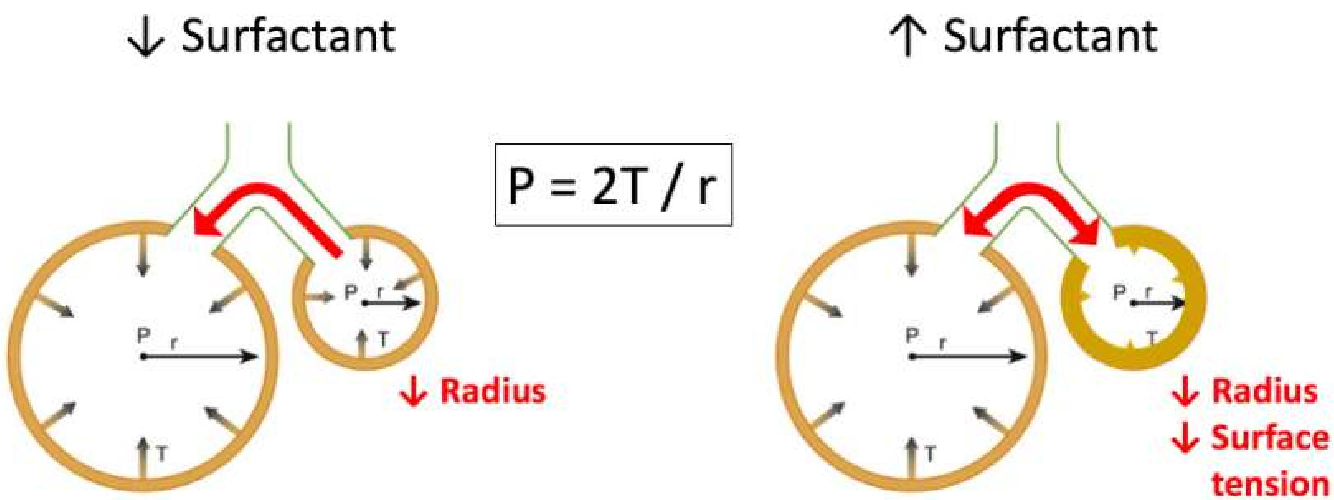
Ppulm artery = pulmonary artery pressure
PL atrium = left atrial pressure (pulmonary capillary wedge pressure)
CO= cardiac output

Ventilation-perfusion ratio (V/Q ratio): the volumetric ratio of air that reaches the alveoli (ventilation) to alveolar blood supply (perfusion) per minute

- **Ideal V/Q ratio= 1**
- **Average V/Q ratio = 0.8**
- **At the apex = 3 (V > Q)**
- **At the base = 0.6 (Q > V)**

In an upright position, the lung bases are better ventilated and perfused than the apices (apex of the lung)

Laplace law


↓ Surfactant
↑ Surfactant
P = 2T / r
P
r
T
↓ Radius
↓ Radius
↓ Surface tension