Pulmonary ventilation-2

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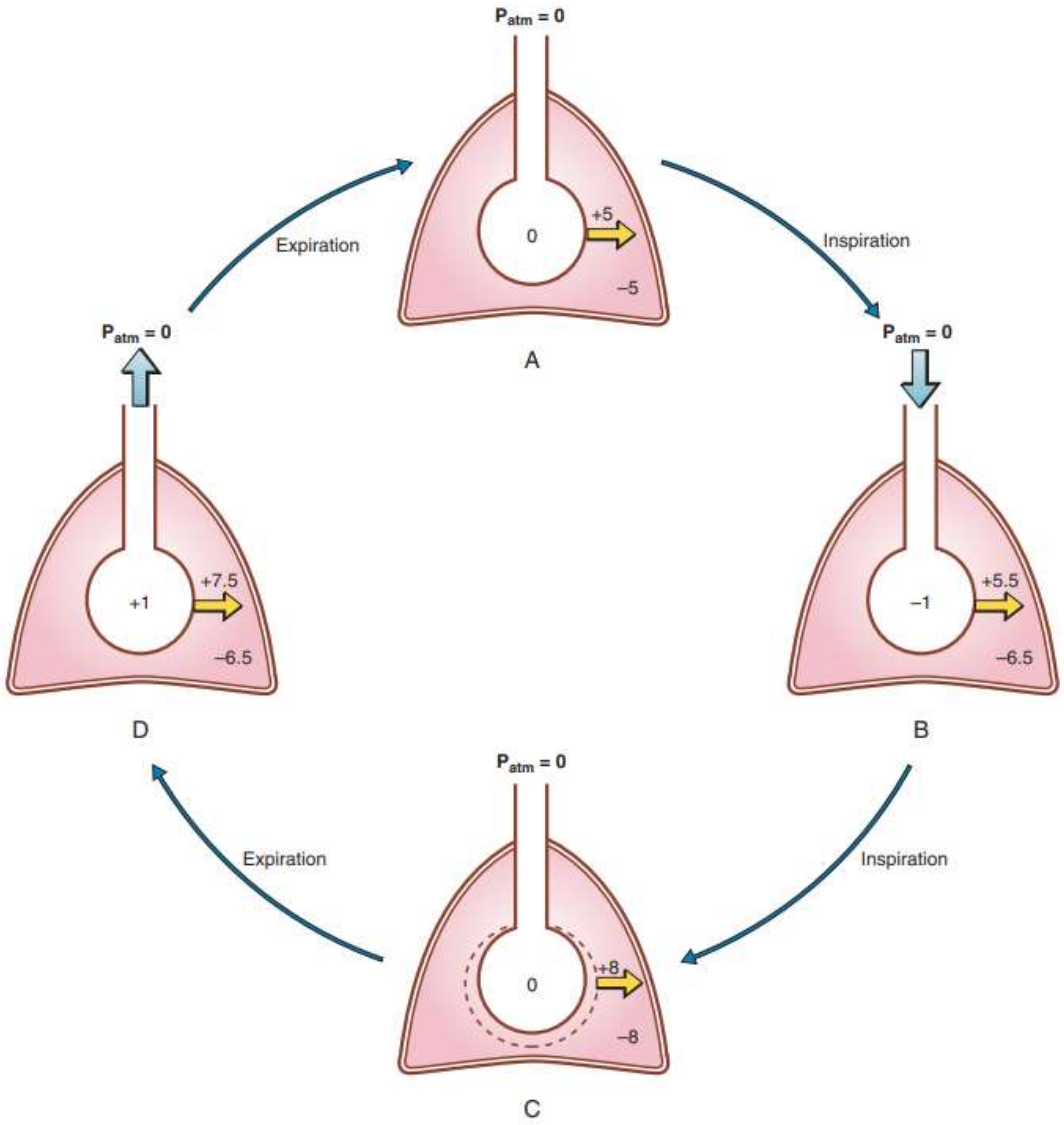
Breathing cycle

- Breathing cycle is divided into phases: rest (the period between breaths), inspiration, and expiration.



$P_{atm} = 0$
0
+5
−5
A
Inspiration
$P_{atm} = 0$
−1
+5.5
−6.5
B
Inspiration
$P_{atm} = 0$
0
+8
−8
C
Expiration
$P_{atm} = 0$
+1
+7.5
−6.5
D
Expiration

Airway resistance

- $$Q = P / R$$

$$R = \frac{8\eta l}{\pi r^4}$$

Airway resistance

- The medium-sized bronchi are the sites of highest airway resistance.

- Changes in **airway diameter** provide the major mechanism for altering resistance and air flow.

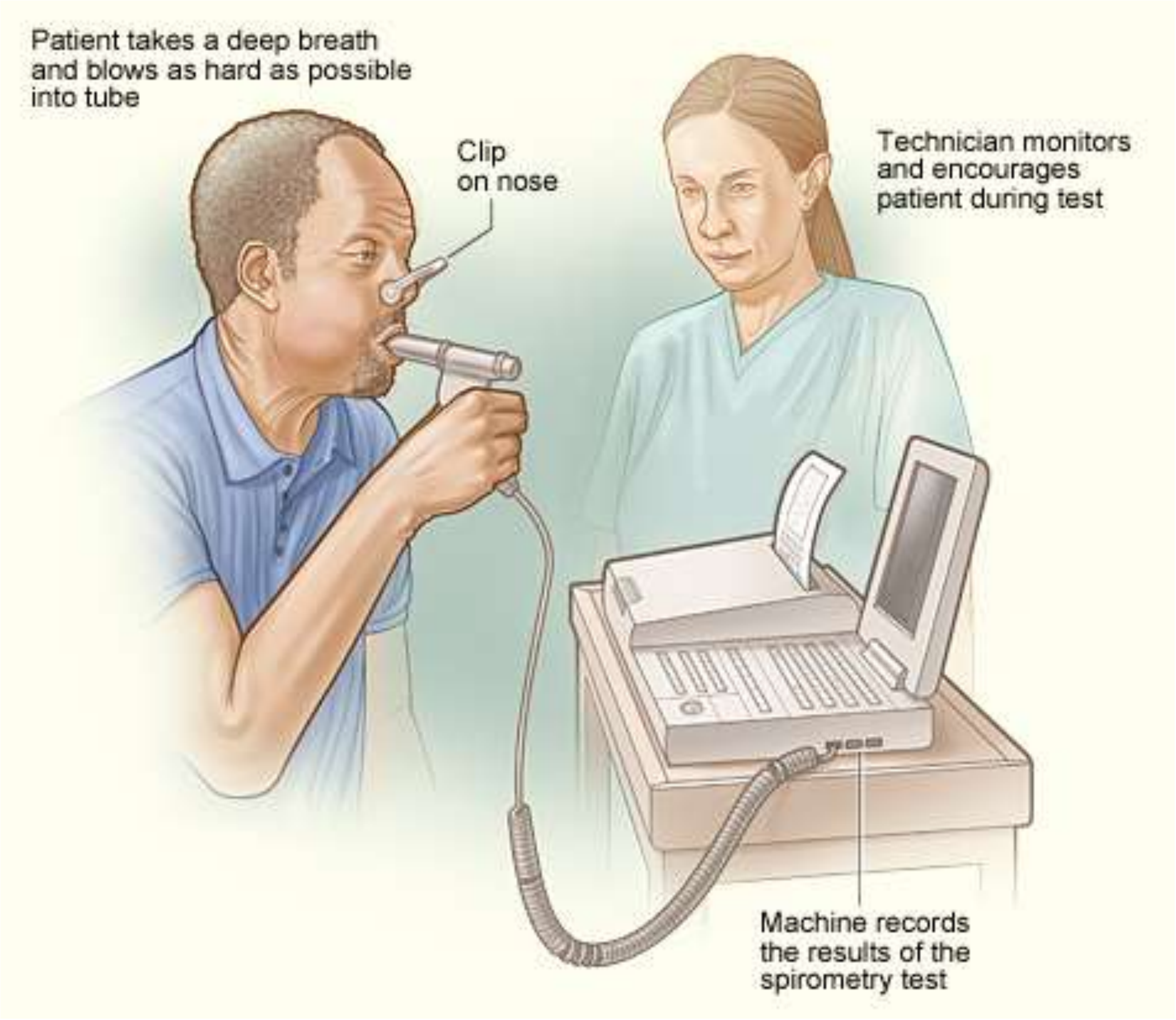
- **Viscosity** of inspired air (η) increases in gas viscosity (e.g., as occur during deep sea diving) produce increases in resistance.

Airway resistance

- **Autonomic nervous system**. Bronchial smooth muscle.

- **Lung volume**. Changes in lung volume alter airway resistance, whereby decreased lung volume causes increased airway resistance and increased lung volume causes decreased airway resistance.

Spirometer

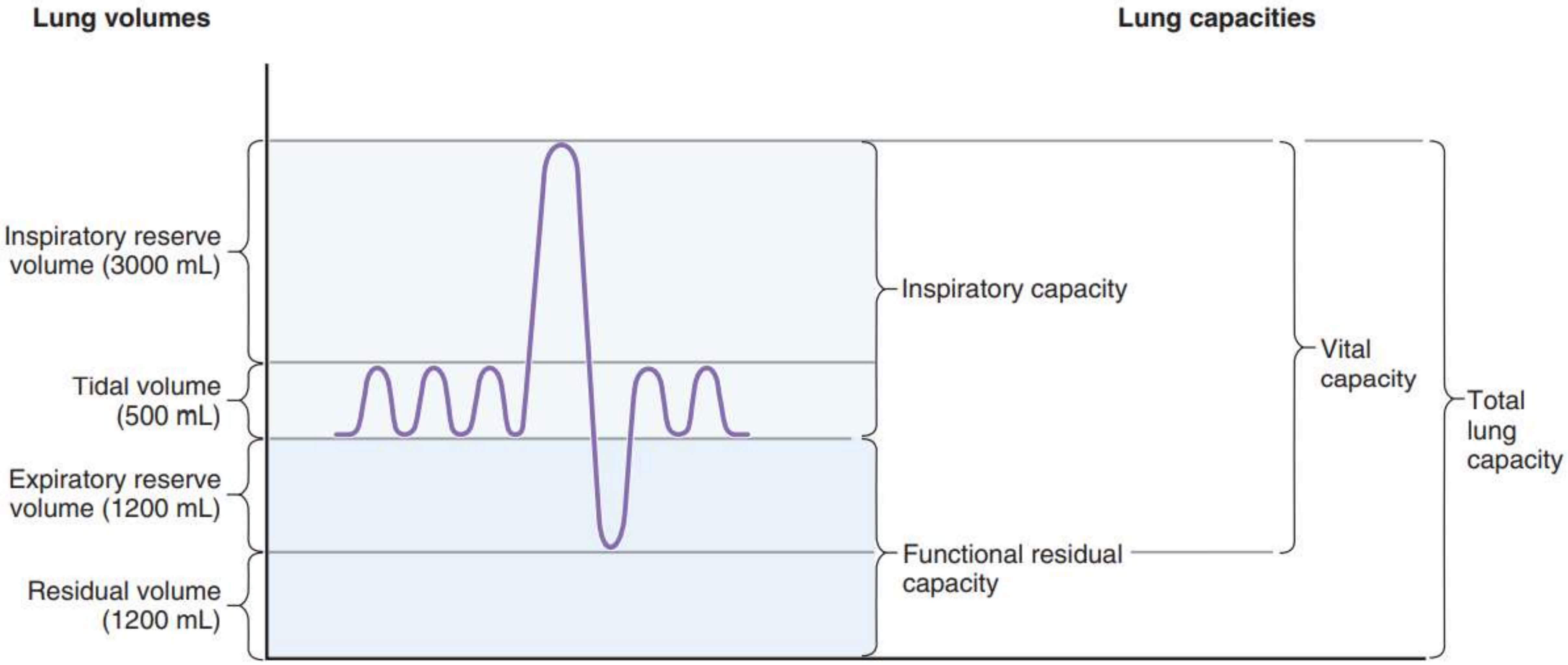

Patient takes a deep breath and blows as hard as possible into tube
Clip on nose
Technician monitors and encourages patient during test
Machine records the results of the spirometry test

Lung volumes

- First, the subject is asked to breathe quietly.

- Normal, quiet breathing involves inspiration and expiration of a **tidal volume (VT)**.

- Normal tidal volume is approximately 500 mL and includes the volume of air that fills the alveoli plus the volume of air that fills the airways.



Lung volumes
Lung capacities
Inspiratory reserve volume (3000 mL)
Tidal volume (500 mL)
Expiratory reserve volume (1200 mL)
Residual volume (1200 mL)
Inspiratory capacity
Functional residual capacity
Vital capacity
Total lung capacity

Lung volumes

- Next, the subject is asked to take a maximal inspiration, followed by a maximal expiration.

- The additional volume that can be inspired above tidal volume is the **inspiratory reserve volume**, which is approximately 3000 mL.

- The additional volume that can be expired below tidal volume is called the **expiratory reserve volume**, which is approximately 1200 mL.

Lung volumes

- The volume of gas remaining in the lungs after a maximal forced expiration is the **residual volume (RV),** which is approximately 1200 mL.

- It cannot be measured by spirometry.

Lung capacities

- Each lung capacity includes two or more lung volumes.

- **The inspiratory capacity (IC)** is composed of the tidal volume plus the inspiratory reserve volume and is approximately 3500 mL (500 mL + 3000 mL).

Lung capacities

- The **vital capacity (VC)** is composed of the IC plus the expiratory reserve volume, or approximately 4700 mL (3500 mL + 1200 mL).

- Vital capacity is the volume that can be expired after maximal inspiration.

- Its value increases with body size, male gender, and physical conditioning and decreases with age.

Lung capacities

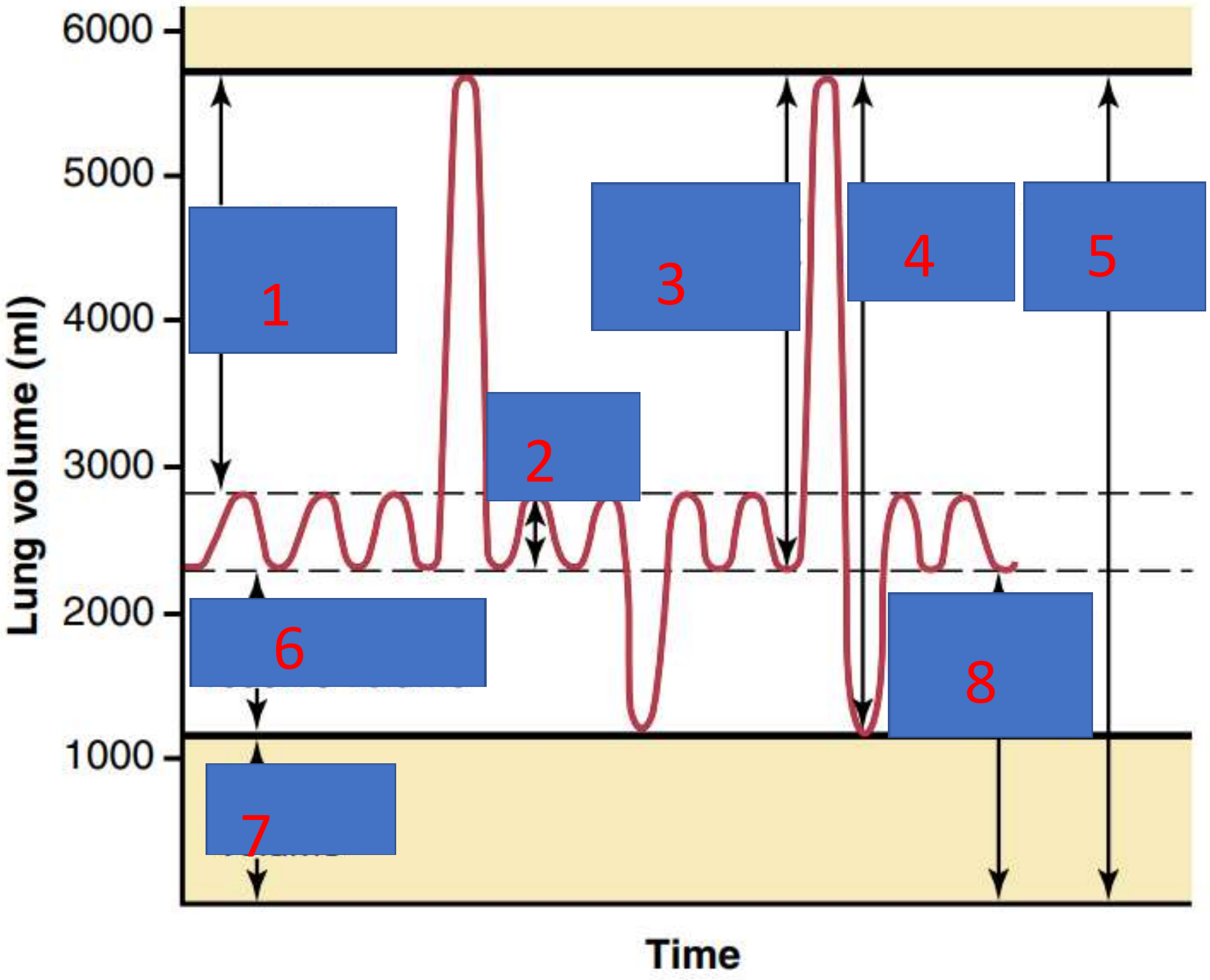
- The **functional residual capacity (FRC)** is composed of the expiratory reserve volume (ERV) plus the RV, or approximately 2400 mL (1200 mL +1200 mL).

- FRC is the volume remaining in the lungs after a normal tidal volume is expired and can be thought of as the **equilibrium volume of the lungs.**

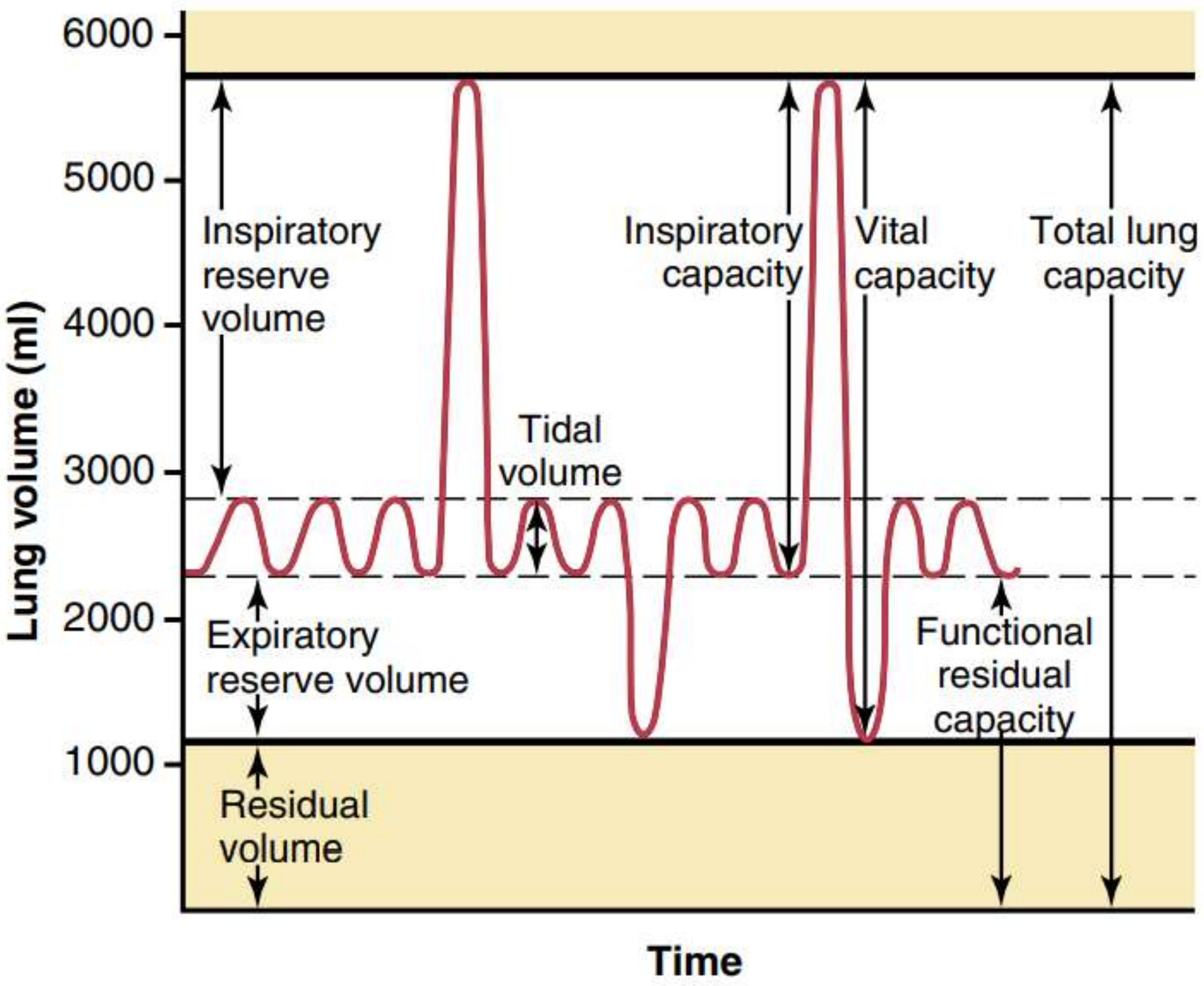
Lung capacities

- The **total lung capacity** (TLC) includes all of the lung volumes: It is the vital capacity plus the RV, or 5900 mL (4700 mL + 1200 mL).

- Because RV cannot be measured by spirometry, lung capacities that include the RV also cannot be measured by spirometry (FRC and TLC).

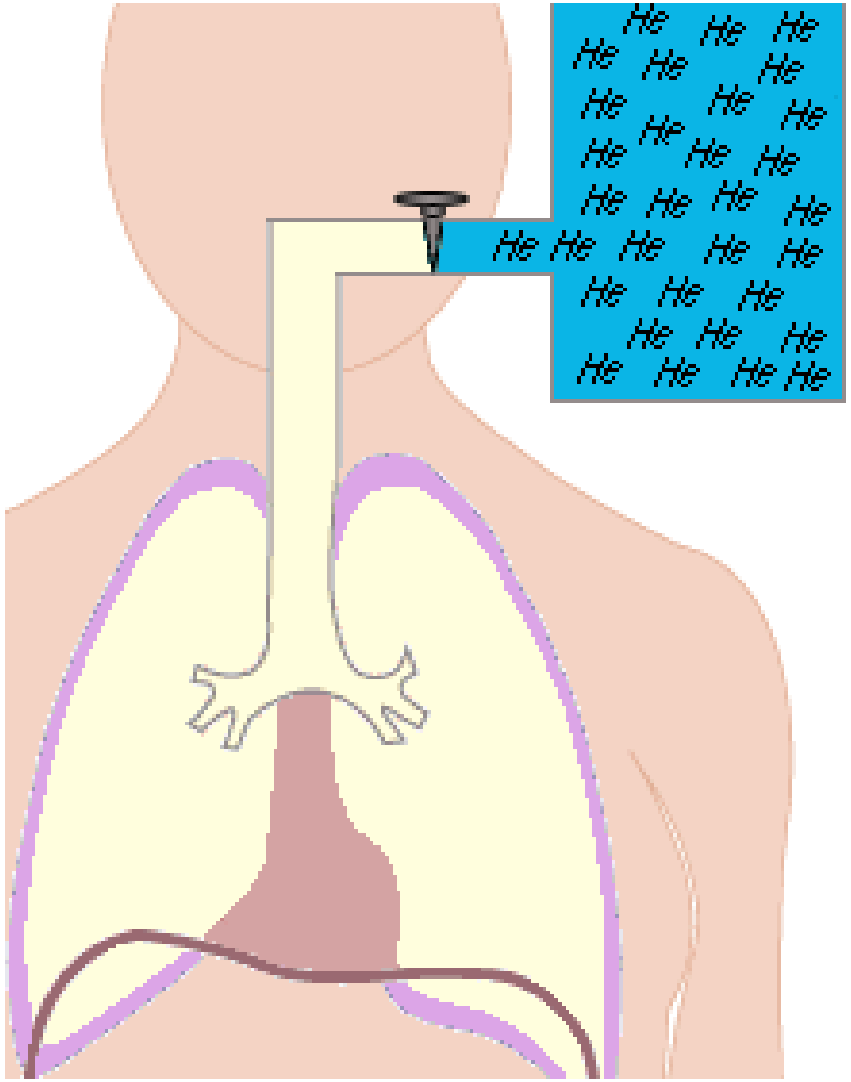


6000
5000
4000
3000
2000
1000
Lung volume (ml)
Time
1
2
3
4
5
6
7
8

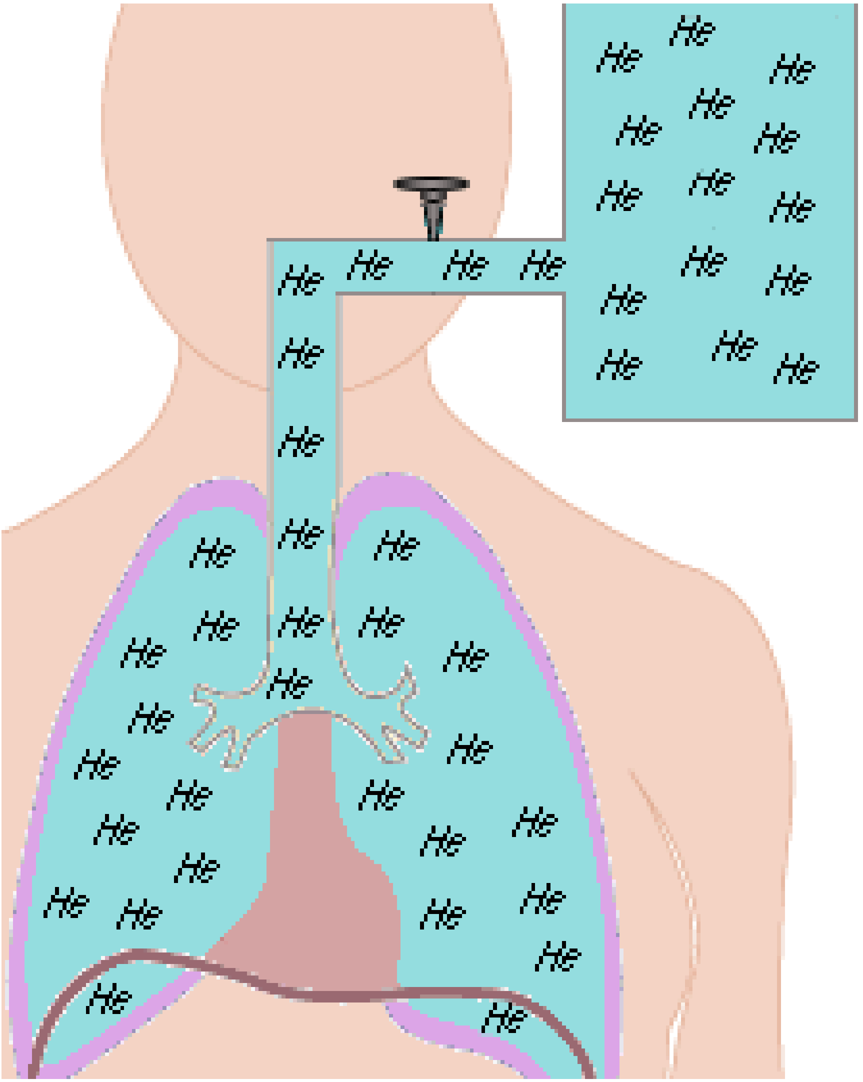

6000
5000
4000
3000
2000
1000
Lung volume (ml)
Inspiratory reserve volume
Tidal volume
Expiratory reserve volume
Residual volume
Inspiratory capacity
Vital capacity
Total lung capacity
Functional residual capacity
Time

Methods to measure FRC

- In the **helium dilution method**, the subject breathes a known amount of helium, which has been added to the spirometer.
- Because helium is insoluble in blood, after a few breaths the helium concentration in the lungs becomes equal to that in the spirometer, which can be measured.
- The amount of helium that was added to the spirometer and its concentration in the lungs are used to “back-calculate” the lung volume.
- If this measurement is made after a normal tidal volume is expired, the lung volume being calculated is the FRC.



At beginning of gas dilution test



After several minutes

Dead space

- The volume of the airways and lungs that does not participate in gas exchange.

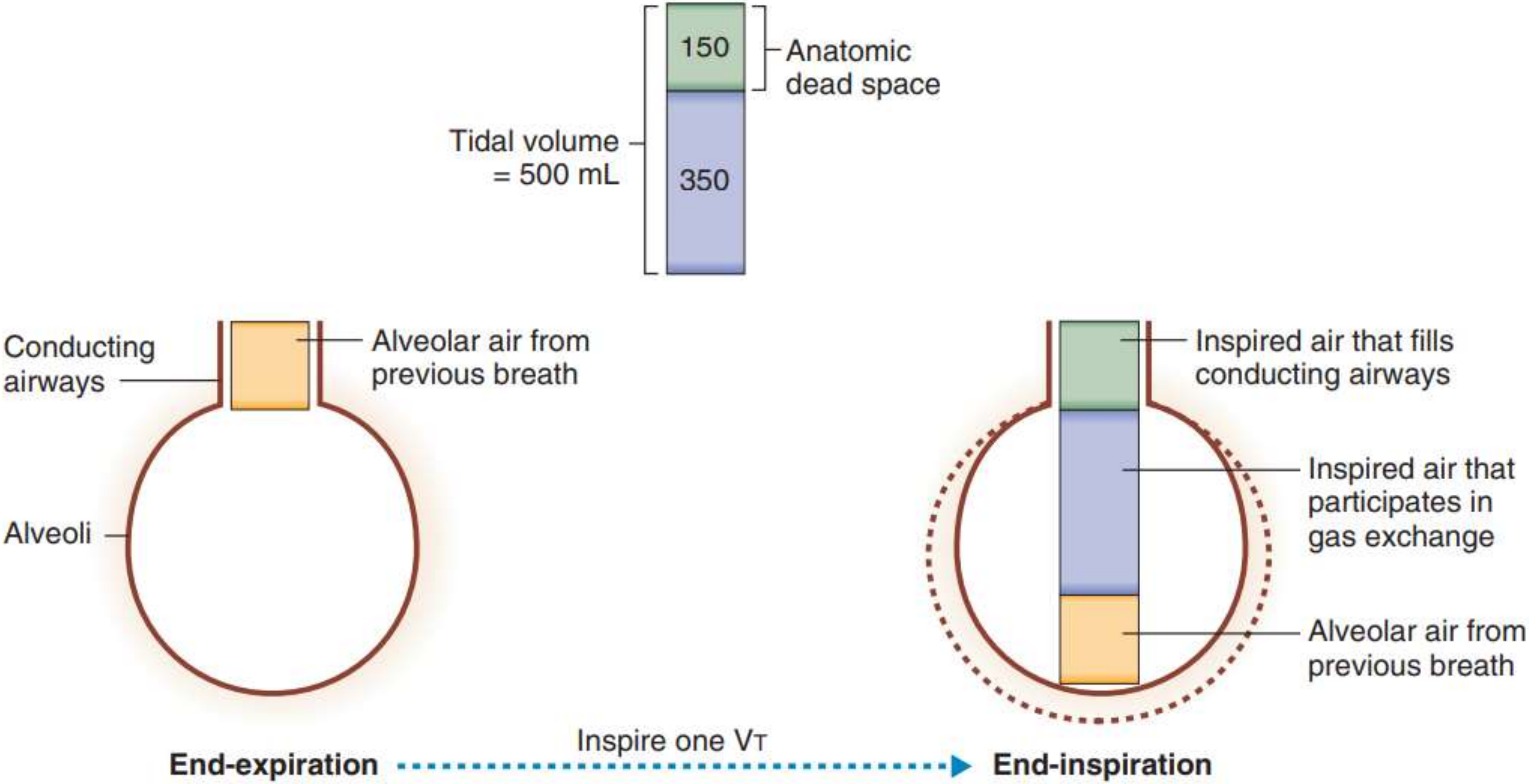
- Dead space is a general term that refers to both the anatomic dead space of the conducting airways and a functional, or physiologic, dead space.

Anatomic dead space

- The anatomic dead space is the volume of the conducting airways including the nose (and/or mouth), trachea, bronchi, and bronchioles.

- The volume of the conducting airways is approximately 150 mL.

- The first air expired is dead space air that has not undergone gas exchange. To sample alveolar air, one must sample end-expiratory air.


150
350
Anatomic
dead space
Tidal volume
= 500 mL
Conducting
airways
Alveolar air from
previous breath
Alveoli
Inspired air that fills
conducting airways
Inspired air that
participates in
gas exchange
Alveolar air from
previous breath
Inspire one VT
End-expiration
End-inspiration

Physiologic dead space

- The physiologic dead space is the total volume of the lungs that does not participate in gas exchange.

- Physiologic dead space includes the anatomic dead space of the conducting airways plus a functional dead space in the alveoli.

- The ventilated alveoli that do not participate in gas exchange.

Physiologic dead space

- Usually due to ventilation-perfusion defect (mismatch), in which ventilated alveoli are not perfused by pulmonary capillary blood.

- In normal persons, the physiologic dead space is nearly equal to the anatomic dead space.

- In certain pathologic situations, however, the physiologic dead space can become larger than the anatomic dead space.

Volume of physiologic dead space

- It is estimated based on the measurement of the partial pressure of CO_2 (PCO_2) of mixed expired air (P_ECO_2) and the following three assumptions:

- (1) All of the CO_2 in expired air comes from exchange of CO_2 in functioning (ventilated and perfused) alveoli
- (2) there is essentially no CO_2 in inspired air
- (3) the physiologic dead space neither exchanges nor contributes any CO_2.

Volume of physiologic dead space

- If physiologic dead space is zero, then P_{ECO_2} will be equal to alveolar P_{CO_2} (P_{ACO_2}).

- However, if a physiologic dead space is present, then P_{ECO_2} will be "diluted" by dead space air and P_{ECO_2} will be less than P_{ACO_2} by a dilution factor.

- Therefore, by comparing P_{ECO_2} with P_{ACO_2}, the dilution factor (i.e., volume of the physiologic dead space) can be measured.

Volume of physiologic dead space

- A potential problem in measuring physiologic dead space is that alveolar air cannot be sampled directly.

- This problem can be overcome, however, because alveolar air normally equilibrates with pulmonary capillary blood (which becomes systemic arterial blood).

- Thus, the PCO2 of systemic arterial blood (PaCO2) is equal to the PCO2 of alveolar air (PACO2).

$$V_D = V_T \times \frac{Pa_{CO_2} - PE_{CO_2}}{Pa_{CO_2}}$$

V_D = Physiologic dead space (mL)

V_T = Tidal volume (mL)

Pa_{CO_2} = P_{CO_2} of arterial blood (mm Hg)

PE_{CO_2} = P_{CO_2} of mixed expired air (mm Hg)

Ventilation rates

- The volume of air moved into and out of the lungs per unit time.
- **Minute ventilation** = VT × Breaths/min
- **Alveolar ventilation** is minute ventilation corrected for the physiologic dead space.

Alveolar ventilation

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$$\dot{V}_A = (V_T - V_D) \times \text{Breaths/min}$$

where

$\dot{V}_A$ = Alveolar ventilation (mL/min)

V_T = Tidal volume (mL)

V_D = Physiologic dead space (mL)

SAMPLE PROBLEM. A man who has a tidal volume of 550 mL is breathing at a rate of 14 breaths/min. The P_{CO_2} in his arterial blood is 40 mm Hg, and the P_{CO_2} in his expired air is 30 mm Hg. *What is his minute ventilation? What is his alveolar ventilation? What percentage of each tidal volume reaches functioning alveoli? What percentage of each tidal volume is dead space?*

SOLUTION. Minute ventilation is tidal volume times breaths per minute, or:

$$\begin{aligned}\text{Minute ventilation} &= 550\text{ mL} \times 14\text{ breaths/min} \\ &= 7700\text{ mL/min}\end{aligned}$$

Alveolar ventilation is minute ventilation corrected for the physiologic dead space, which must be calculated. This problem illustrates the usual method of assessing physiologic dead space, which represents structures that are ventilated but are not exchanging CO_2.

$$\begin{aligned}V_D &= V_T \times \frac{Pa_{CO_2} - PE_{CO_2}}{Pa_{CO_2}} \\ &= 550\text{ mL} \times \frac{40\text{ mm Hg} - 30\text{ mm Hg}}{40\text{ mm Hg}} \\ &= 550\text{ mL} \times 0.25 \\ &= 138\text{ mL}\end{aligned}$$

Thus alveolar ventilation ($\dot{V}_A$) is

$$\begin{aligned}\dot{V}_A &= (V_T - V_D) \times \text{Breaths/min} \\ &= (550\text{ mL} - 138\text{ mL}) \times 14\text{ breaths/min} \\ &= 412\text{ mL} \times 14\text{ breaths/min} \\ &= 5768\text{ mL/min}\end{aligned}$$

If tidal volume is 550 mL and physiologic dead space is 138 mL, then the volume of fresh air reaching functioning alveoli on each breath is 412 mL, or 75% of each tidal volume. Dead space is, accordingly, 25% of each tidal volume.

Thank you