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Respiratory Physiology

Anatomy & Physiology

Mechanism of breathing, lung volumes and capacities, gaseous exchange, transport of oxygen and carbon dioxide, regulation of respiration and respiratory functions.

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Functions and the sequence of respiration

Respiratory physiology links movement of air with transfer of gases between atmosphere, blood and tissues. Ventilation is bulk air movement into and out of the lungs. External respiration is exchange between alveoli and pulmonary blood; internal respiration is exchange between systemic blood and tissues. Cellular respiration uses oxygen to support ATP production and produces carbon dioxide. These processes are connected but are not interchangeable terms.

The respiratory system also contributes to acid-base regulation, voice, smell, warming and humidification of inspired air, and defence against inhaled particles. Mucus, ciliary activity, cough and alveolar macrophages help protect the exchange surface. Effective respiration requires a patent airway, ventilatory movement, an adequate alveolar membrane and sufficient pulmonary perfusion.

Mechanics of breathing

During quiet inspiration, the diaphragm contracts and descends while external intercostal activity expands the thorax. Thoracic expansion makes intrapleural pressure more negative and increases lung volume. Alveolar pressure falls below atmospheric pressure, so air enters. Quiet expiration is mainly passive elastic recoil: inspiratory muscles relax, alveolar pressure rises above atmospheric pressure and air leaves. Forced expiration recruits abdominal muscles and internal intercostals.

Compliance describes how readily lung volume changes for a pressure change. Airway resistance describes opposition to airflow and rises as airway calibre narrows. Type II alveolar cells produce surfactant, which reduces surface tension and helps stabilize alveoli. Pleural coupling keeps lung movement linked to chest-wall movement; loss of the usual pleural pressure relationship can impair expansion. Increased work of breathing may precede a marked change in measured oxygen saturation.

Lung volumes, capacities and ventilation

Measure	Meaning or relationship	Interpretation
Tidal volume	Air moved in a usual quiet breath	Varies with body size and breathing pattern
Inspiratory and expiratory reserve volumes	Additional air inhaled or exhaled beyond a usual breath	Reflect available volume reserves
Residual volume	Air remaining after maximal expiration	Not measured by simple spirometry alone
Vital capacity	Inspiratory reserve + tidal volume + expiratory reserve	Maximum movable breath volume
Total lung capacity	Vital capacity + residual volume	Includes the air that cannot be exhaled
Minute ventilation	Tidal volume x respiratory rate	Includes dead-space ventilation

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Alveolar ventilation	(Tidal volume - dead-space volume) x rate	Air reaching exchanging alveoli per minute

Anatomical dead space is conducting-airway volume that does not perform gas exchange. Physiological dead space also includes ventilated alveoli with ineffective perfusion. Rapid shallow breathing may maintain minute ventilation while reducing alveolar ventilation. Use measured or predicted values appropriate to age, height, sex-related reference equations and the testing service; textbook volume examples do not define every person's normal lungs.

Gas exchange and ventilation-perfusion matching

Oxygen and carbon dioxide diffuse down their own partial-pressure gradients across the alveolar-capillary barrier. Diffusion improves with a larger area and greater gradient, and worsens when the barrier becomes thicker. External exchange loads oxygen and removes carbon dioxide; tissue exchange unloads oxygen while loading carbon dioxide. Partial pressure refers to the pressure contributed by one gas in a mixture.

Ventilation and perfusion must reach the same functional lung units. Low ventilation relative to blood flow limits oxygenation; absent ventilation with continued flow is a shunt-like situation. Ventilation without useful blood flow increases dead space. Alveolar fluid, collapsed regions or impaired circulation can disrupt matching. A normal respiratory rate does not establish normal gas exchange, and pulse oximetry cannot identify all causes of respiratory dysfunction.

Transport of oxygen and carbon dioxide

Most oxygen is transported bound reversibly to haemoglobin, with a small dissolved fraction determining oxygen partial pressure. Oxygen saturation, partial pressure and oxygen content describe different properties. Content depends heavily on haemoglobin concentration, so anaemia may reduce oxygen delivery despite an apparently satisfactory saturation. Increased carbon dioxide, acidity and temperature favour oxygen unloading in active tissues through a rightward shift of the haemoglobin dissociation curve.

Most carbon dioxide is carried as bicarbonate, with smaller amounts bound to proteins or dissolved. In erythrocytes, carbonic anhydrase accelerates conversion between carbon dioxide and carbonic acid; dissociation produces hydrogen ions and bicarbonate. Haemoglobin buffers many of the hydrogen ions. These reactions reverse in the lungs, enabling carbon dioxide exhalation and linking ventilation with pH control.

Control, nursing applications and examination structure

Medullary networks generate the breathing rhythm, with pontine and higher-centre influences modifying the pattern. Central chemoreceptors respond mainly to cerebrospinal-fluid hydrogen-ion changes produced by carbon dioxide. Peripheral chemoreceptors respond to arterial oxygen, carbon dioxide and pH changes. Raised carbon dioxide normally stimulates ventilation; low oxygen becomes a particularly strong peripheral stimulus at sufficiently reduced arterial oxygen pressure.

Assess rate, depth, pattern, effort, symmetry, sounds, mental state and measured oxygenation together. New exhaustion, reduced consciousness or severe work of breathing requires rapid escalation. Interpret blood gases with oxygen delivery conditions and the clinical picture. For exams, explain pressure changes before airflow, use formulas with units, then organize gas exchange, transport and regulation separately. Link hypoventilation with carbon dioxide retention and hyperventilation with excessive carbon dioxide loss rather than equating either term simply with a slow or fast rate.

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Quick Revision

- Ventilation, pulmonary gas exchange, tissue exchange and cellular respiration are distinct processes.
- Air moves because alveolar and atmospheric pressures differ.
- Surfactant reduces alveolar surface tension.
- Alveolar ventilation excludes dead-space volume.
- Oxygen content depends on haemoglobin as well as saturation.
- Chemoreceptor responses connect ventilation with blood gases and pH.

Important Examination Questions

1. Explain quiet inspiration and expiration using pressure and volume changes.
2. Define lung volumes and capacities and calculate alveolar ventilation.
3. Describe gas diffusion and ventilation-perfusion mismatch.
4. Compare transport of oxygen with transport of carbon dioxide.
5. Explain neural and chemical regulation of breathing and nursing assessment implications.

References and further reading

Newly written physiology study notes. Read the supporting textbook sections for diagrams, mechanisms and further explanation.

- OpenStax Anatomy and Physiology 2e: The Lungs (https://openstax.org/books/anatomy-and-physiology-2e/pages/22-2-the-lungs)
- OpenStax Anatomy and Physiology 2e: The Process of Breathing (https://openstax.org/books/anatomy-and-physiology-2e/pages/22-3-the-process-of-breathing)
- OpenStax Anatomy and Physiology 2e: Gas Exchange (https://openstax.org/books/anatomy-and-physiology-2e/pages/22-4-gas-exchange)
- OpenStax Anatomy and Physiology 2e: Transport of Gases (https://openstax.org/books/anatomy-and-physiology-2e/pages/22-5-transport-of-gases)
- OpenStax Anatomy and Physiology 2e: Modifications in Respiratory Functions (https://openstax.org/books/anatomy-and-physiology-2e/pages/22-6-modifications-in-respiratory-functions)
- OpenStax Anatomy and Physiology 2e: Acid-Base Balance (https://openstax.org/books/anatomy-and-physiology-2e/pages/26-4-acid-base-balance)

Practice questions

Choose one best answer. The answer key and explanations follow the questions.

1. Which expression gives alveolar ventilation?

A. Tidal volume x heart rate
B. Residual volume x respiratory rate
C. (Tidal volume - dead-space volume) x rate
D. Vital capacity respiratory rate

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2. Which alveolar cells produce surfactant?

A. Type II alveolar cells

B. Erythrocytes

C. Type I alveolar cells exclusively

D. Platelets

3. In which form is most carbon dioxide transported?

A. Free gas bubbles

B. Bicarbonate

C. Bound to albumin only

D. Dissolved oxygen

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Answer key and explanations

1. C - (Tidal volume - dead-space volume) x rate

The air remaining in dead space is excluded from each breath before multiplying by rate.

2. A - Type II alveolar cells

Surfactant from type II cells lowers surface tension.

3. B - Bicarbonate

Conversion into bicarbonate provides the principal transport form of carbon dioxide.

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