BP203T · B.PHARM THEORY

BP203T Human Anatomy, Physiology and Pathophysiology II

Unit III — Respiratory & Urinary Systems

Pills & Python Notes

From-zero teaching standard: every technical term is defined before use.

Syllabus coverage: Unit III (12 hours).

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Chapter 1: Anatomy of the Respiratory System

Learning Objectives

After studying this chapter, you should be able to:

1. Define respiration and list the parts of the respiratory system in order.
2. Describe the structure of the nose, pharynx, larynx, trachea, bronchi and lungs so you can draw a labelled sketch.
3. Explain the functions of each part in very simple words.
4. Describe the structure of the lungs, the pleura, and the alveoli.
5. Draw and label a diagram of the respiratory tract and the alveolus.

1.1 What is respiration?

Concept. Respiration is the process by which the body takes in oxygen from the air and gives out carbon dioxide.

Simple explanation. Every cell in your body needs oxygen to produce energy — just like a fire needs air to burn. When cells use oxygen, they make carbon dioxide as waste. The respiratory system brings oxygen in and throws carbon dioxide out.

Example. When you run up stairs, you breathe faster. Your muscles are working harder, need more oxygen, and make more carbon dioxide — so your lungs work faster to match.

> **Analogy.** The respiratory system is like the ventilation system of a house: fresh air comes in through windows, stale air goes out. Lungs are the rooms where the exchange happens; the blood is like delivery boys carrying oxygen to every room (cell) of the body.

> **Key takeaway.** Respiration = taking in oxygen (O_2) + giving out carbon dioxide (CO_2). Without it, cells die within minutes.

1.2 Parts of the respiratory system in order

Air follows this path: **Nostrils → Nasal cavity → Pharynx (throat) → Larynx (voice box) → Trachea (windpipe) → Bronchi → Bronchioles → Alveoli (air sacs)**

The upper part (nose, pharynx, larynx) is called the **upper respiratory tract**. The lower part (trachea, bronchi, lungs) is the **lower respiratory tract**.

> **Terminology Alert**

> - **Respiration** = the whole process of gas exchange (breathing in/out + gas exchange in lungs + gas exchange in tissues + cellular use of oxygen).

> - **Breathing (pulmonary ventilation)** = only the physical act of air moving in and out of the lungs.

- **External respiration** = gas exchange between air and blood inside the lungs.

- **Internal respiration** = gas exchange between blood and tissue cells.

- **Cellular respiration** = cells using oxygen to make energy (ATP).

1.3 Nose and nasal cavity

Concept. The nose is the entry gate for air.

Simple explanation. Air enters through the two nostrils into the nasal cavity. Inside, the cavity is lined with a warm, moist membrane and tiny hairs (vibrissae) plus mucus. The air gets:

1. **Filtered** — hairs and mucus trap dust and germs.
2. **Warmed** — many blood vessels warm the cold air.
3. **Moistened** — mucus adds water vapour so the delicate lungs do not dry out.

The nasal cavity also has the **olfactory area** (smell receptors) at the top.

Example. On a cold morning in December, the air reaching your lungs is still warm — your nose heated it on the way.

Analogy. The nose is like a security checkpoint + air conditioner at the entrance of a building: it checks (filters), heats, and humidifies the air before letting it inside.

Key takeaway. The nose filters, warms and moistens incoming air, and gives us the sense of smell.

1.4 Pharynx (throat)

Concept. The pharynx is a common passage for both air and food.

Simple explanation. The pharynx is a muscular tube about 12–14 cm long behind the nose and mouth. Air passes down through it to the larynx; food also passes down through it to the oesophagus. A flap called the **epiglottis** closes over the windpipe when you swallow, so food goes to the stomach, not the lungs.

Example. When food "goes down the wrong pipe" and you cough violently — that is the body protecting the airway from food.

Analogy. The pharynx is like a railway junction where the food track and air track cross. The epiglottis is the signalman who sends food down the food track and air down the air track.

Key takeaway. Pharynx = shared passage of air and food; the epiglottis guards the airway during swallowing.

1.5 Larynx (voice box)

Concept. The larynx is a short tube of cartilage that produces voice and protects the airway.

Simple explanation. The larynx sits at the top of the windpipe. Inside it are the **vocal cords** — two folds that vibrate when air passes over them, producing sound. Its biggest cartilage (thyroid cartilage) is the "Adam's apple" seen in the neck. Besides voice, the larynx is a second guard: if anything other than air tries to enter, the vocal cords close and you cough.

> **Analogy.** Vocal cords are like the strings of a guitar — air is the finger that plucks them; tighter strings (cords) make a higher pitch.

> **Key takeaway.** Larynx = voice production + airway protection.

1.6 Trachea (windpipe)

Concept. The trachea is the main air tube leading to the lungs.

Simple explanation. The trachea is a tube about 10–12 cm long and 2 cm wide, running down the front of the neck into the chest. Its wall has **C-shaped rings of cartilage** (like the rings of a vacuum-cleaner hose) that keep it open all the time — air must flow freely, day and night. Inside, tiny hair-like structures called **cilia** sweep mucus with trapped dust upward toward the throat, where it is swallowed or coughed out.

> **Terminology Alert**

> - **Cartilage** = a firm but flexible tissue (like the tip of your nose or your ear). It is softer than bone.

> - **Cilia** = microscopic hair-like projections that beat in waves to move mucus.

> - **Mucus** = sticky fluid that traps dust and germs.

Example. Smokers' cilia get damaged, so mucus collects — that is why smokers develop a persistent morning cough trying to clear it.

> **Analogy.** The trachea is like a tunnel with steel ribs (cartilage rings) so it never collapses, and an escalator (cilia) that carries dust back up and out.

> **Key takeaway.** Trachea = open tube kept stiff by cartilage rings; cilia sweep trapped dust upward.

1.7 Bronchi and bronchioles

Concept. The trachea divides like an inverted tree, carrying air deeper into the lungs.

Simple explanation. At the level of the chest, the trachea splits into two **primary bronchi** — right and left, one for each lung. (The right bronchus is wider and more vertical; inhaled objects therefore more often enter the right lung.) Inside the lung, each bronchus divides again and again into smaller tubes called **secondary and tertiary bronchi**, then into tiny tubes called **bronchioles**. Bronchioles have smooth muscle in their walls — they can narrow (bronchoconstriction) or widen (bronchodilation) to control airflow.

Analogy. The bronchial tree is like an upside-down tree: the trachea is the trunk, bronchi are branches, bronchioles are twigs, and alveoli (next section) are the leaves.

Key takeaway. Trachea → 2 bronchi → many bronchioles. Bronchioles control airflow with smooth muscle.

1.8 Lungs

Concept. The lungs are two spongy organs where air meets blood.

Simple explanation. The lungs sit in the chest cavity (thorax), one on each side of the heart. Key facts:

- The **right lung** is bigger and has **3 lobes** (upper, middle, lower).
- The **left lung** is smaller (it shares space with the heart) and has **2 lobes** (upper, lower) with a notch called the **cardiac notch** where the heart rests.
- Each lobe is divided into smaller segments; each segment receives its own bronchus.
- Lungs are light and spongy — they float in water.
- The base of each lung rests on the **diaphragm** (the main breathing muscle).

How to sketch the lungs (step by step):

1. Draw two cone-shaped sponges side by side, pointed at top (apex), flat at bottom (base).
2. Make the right one slightly bigger with 3 sections; the left one with 2 sections and a small dent (cardiac notch) on its inner side.
3. Draw the windpipe coming down between them, splitting into two tubes (bronchi), one entering each lung.
4. Draw branches inside each lung getting smaller.
5. Label: apex, base, lobes, bronchus, diaphragm below.

Example. A healthy lung is pink and soft; a smoker's lung looks grey-black with tar deposits — doctors show this to explain why smoking harms.

Analogy. Lungs are like two sponges full of millions of tiny air pockets — squeeze them and air rushes out; release and air rushes in.

Key takeaway. Right lung = 3 lobes, left lung = 2 lobes (heart takes the space). Both are spongy and sit on the diaphragm.

1.9 Pleura

Concept. Each lung is wrapped in a double-layered slippery membrane called the pleura.

Simple explanation. The **pleura** has two layers: the inner (visceral) layer sticks to the lung surface; the outer (parietal) layer lines the chest wall. Between them is a thin space with a little lubricating **pleural fluid**. This fluid lets the lung slide smoothly against the chest wall during breathing, like oil between two sheets of glass. It also creates a slight suction that keeps the lung expanded against the chest wall.

Analogy. The pleura is like two sheets of cling film with a drop of water between them — they glide over each other but are hard to pull apart.

Key takeaway. Pleura = double slippery cover; fluid reduces friction and keeps lungs expanded.

1.10 Alveoli — where the real exchange happens

Concept. Alveoli are microscopic air sacs where oxygen enters the blood and carbon dioxide leaves it.

Simple explanation. At the end of the tiniest bronchioles are clusters of tiny sacs called **alveoli** (singular: alveolus). Each lung has about 300 million of them. Their walls are only **one cell thick**, and each is wrapped in a net of tiny blood vessels (**capillaries**). Because the wall is so thin and the total surface area so huge (roughly the size of a tennis court), gases pass through very easily:

- **Oxygen** moves from alveolar air → into blood.
- **Carbon dioxide** moves from blood → into alveolar air (to be breathed out).

Alveoli also contain **surfactant**, a soapy substance that stops the tiny sacs from collapsing when we breathe out.

How to sketch an alveolus:

1. Draw a bunch of grapes (a cluster of small circles) at the end of a thin tube (bronchiole).
2. Draw wavy lines (capillaries) hugging each "grape".
3. Draw arrows: O_2 arrow from the grape into the wavy line; CO_2 arrow from the wavy line into the grape.
4. Label: bronchiole, alveolus, capillary, O_2 in, CO_2 out, surfactant lining.

Terminology Alert

- **Alveolus** = tiny air sac (plural: alveoli).

- **Capillary** = the thinnest blood vessel, one cell thick.

- **Surfactant** = soapy fluid that keeps alveoli open.

Analogy. Alveoli are like millions of tiny balloons clustered at the ends of thin straws — each balloon is wrapped in a net of blood vessels, and gases swap through the thin rubber.

Key takeaway. Alveoli = 300 million thin-walled air sacs with huge surface area; this is where O_2 enters blood and CO_2 leaves.

1.11 Blood supply and muscles of respiration (brief)

- Lungs receive deoxygenated blood from the **pulmonary artery** (right ventricle of heart) and return oxygenated blood through **pulmonary veins** to the left atrium.
- The main breathing muscle is the **diaphragm** (dome-shaped muscle under the lungs). Helper muscles between the ribs (**intercostal muscles**) lift the ribs during deep breathing.

Summary table — parts of the respiratory system

Part	Main structure	Main function
Nose / nasal cavity	Hairs, mucus, blood vessels	Filters, warms, moistens air; smell
Pharynx	Muscular tube, epiglottis	Common passage; epiglottis guards airway
Larynx	Cartilage, vocal cords	Voice; airway protection
Trachea	C-shaped cartilage rings, cilia	Keeps airway open; sweeps dust up
Bronchi	Two main tubes (right wider)	Carry air into each lung
Bronchioles	Small tubes with smooth muscle	Control airflow (narrow/widen)
Alveoli	Thin-walled sacs + capillaries	Gas exchange (O_2 in, CO_2 out)
Pleura	Double membrane + fluid	Lubrication; keeps lung expanded
Diaphragm	Dome-shaped muscle	Main muscle of breathing

Pharmacy relevance

- **Inhalers and nebulisers** deliver drugs directly to the bronchioles and alveoli — e.g., asthma medicines. A pharmacist must teach correct inhaler technique, because the drug only works if it reaches deep into the airways.
- **Mucolytics and expectorants** (cough medicines) act on the mucus and cilia of the airways.
- Understanding the airway helps you explain why **smoking** damages cilia and alveoli.

India context

- India has a high burden of respiratory disease — tuberculosis, asthma, COPD and air-pollution-related illness are common reasons for hospital visits, especially in cities with poor air quality and in winter months in North India.
- Pharmacists in India frequently counsel on **inhaler technique** (metered-dose inhalers, rotahalers) and on completing the full course of TB medicines under the national programme.

Common confusions

1. **Trachea vs oesophagus** — the trachea (front) carries air; the oesophagus (behind) carries food. Do not mix them up.
2. **Bronchus vs bronchiole** — bronchus = larger tube with cartilage; bronchiole = tiny tube with smooth muscle, no cartilage.
3. **Right lung 3 lobes, left lung 2 lobes** — students often reverse this. Remember: the heart steals space on the left.
4. **Pleura vs pericardium** — pleura covers the lungs; pericardium covers the heart.
5. **Breathing vs respiration** — breathing is only air movement; respiration includes gas exchange and cellular use of oxygen.

Common mistakes

- Drawing the trachea without cartilage rings, or the lungs without lobes.
- Saying oxygen is "produced" in the lungs — it is only **taken in** there; energy is produced in cells.
- Forgetting surfactant when asked why alveoli do not collapse.

Mnemonics

- Air pathway: **"Never Play Loud Trumpets Before Breakfast Again"** → **N**ostrils, **P**harynx, **L**arynx, **T**rachea, **B**ronchi, **B**ronchioles, **A**lveoli.
- Right lung lobes: **"Right is Right — 3"** (right lung has 3 lobes).

One-minute revision

Air enters through the nose (filtered, warmed, moistened) → pharynx (shared with food; epiglottis guards) → larynx (voice) → trachea (cartilage rings keep it open; cilia sweep dust) → two bronchi → bronchioles (smooth muscle controls airflow) → alveoli (300 million thin sacs where O_2 enters blood, CO_2 leaves). Lungs: right 3 lobes, left 2 lobes; wrapped in pleura; sit on the diaphragm.

Practice questions

MCQs

1. The C-shaped cartilage rings are found in the: a) Alveoli b) Trachea c) Bronchioles d) Pleura
2. Gas exchange in the lungs occurs in the: a) Bronchi b) Trachea c) Alveoli d) Larynx
3. The right lung has how many lobes? a) 2 b) 3 c) 4 d) 1
4. Surfactant in the alveoli: a) Kills germs b) Prevents alveolar collapse c) Carries oxygen d) Produces mucus
5. The epiglottis prevents: a) Air entering the lungs b) Food entering the windpipe c) Blood entering the heart d) Sound production

Short-answer (2–3 marks)

1. List the parts of the respiratory tract in the order air travels.
2. Describe the structure of the trachea and explain how it stays open.
3. What is the pleura? State its two functions.
4. Draw a labelled diagram of an alveolus with its capillary.

Long-answer (5 marks)

1. Describe the anatomy of the lungs with special reference to lobes, pleura and blood supply. Draw a labelled diagram of the respiratory system.

Application-based

1. A patient accidentally inhales a peanut. Which lung is it more likely to enter, and why?
2. Why does a pharmacist need to check a patient's inhaler technique?

Viva

1. Why are alveolar walls only one cell thick?
2. What would happen if the pleural fluid dried up?
3. Why does the left lung have only two lobes?

Answer key — MCQs: 1-b, 2-c, 3-b, 4-b, 5-b.

Chapter 2: Mechanism of Respiration and Its Regulation

Learning Objectives

After studying this chapter, you should be able to:

1. Explain how inspiration and expiration happen, step by step.
2. Describe the role of the diaphragm and intercostal muscles.
3. Explain the pressure changes that move air in and out.
4. Describe how the brain regulates breathing (respiratory centres, chemoreceptors).
5. Explain the Hering–Breuer reflex and the effect of emotions/exercise on breathing.

2.1 The basic principle — air follows pressure

Concept. Air always flows from an area of **high pressure** to an area of **low pressure**.

Simple explanation. Breathing works by changing the size of the chest cavity:

- When the chest cavity **expands**, pressure inside the lungs falls below outside air pressure → air rushes **in** (inspiration).
- When the chest cavity **shrinks**, pressure inside rises above outside → air is pushed **out** (expiration).

> **Analogy.** The lungs work like a syringe or a bellows: pull the plunger out (expand) and air is sucked in; push it in (shrink) and air is forced out.

> **Key takeaway.** Breathing = changing chest size → changing pressure → air flows in or out.

2.2 Inspiration (breathing in) — active process

Concept. Inspiration is an **active** process — muscles must work.

Step by step:

1. The **diaphragm contracts** and flattens (moves down).
2. The **external intercostal muscles** contract, lifting the ribs up and out.
3. The chest cavity becomes **bigger** in all directions.
4. Pressure inside the lungs (**intrapulmonary pressure**) falls below atmospheric pressure.
5. Air flows **into** the lungs.

Simple explanation. Think of the chest as a box. Inspiration makes the box bigger — the diaphragm pulls the floor down and the rib muscles lift the walls up and out. Bigger box = lower pressure = air sucked in.

> **Terminology Alert**

> - **Inspiration** = breathing in (do not confuse with the everyday meaning "a creative idea"!).

- **Diaphragm** = dome-shaped muscle separating chest from abdomen; the main breathing muscle.

- **Intercostal muscles** = muscles between the ribs ("inter" = between, "costal" = rib).

- **Intrapulmonary pressure** = pressure of air inside the lungs/alveoli.

Key takeaway. Inspiration: diaphragm flattens + ribs lift → chest expands → pressure falls → air enters. It needs muscular effort (active).

2.3 Expiration (breathing out) — normally passive

Concept. Quiet expiration is **passive** — muscles simply relax.

Step by step:

1. The diaphragm **relaxes** and domes back up.
2. The intercostal muscles **relax**; ribs move down and in.
3. The chest cavity becomes **smaller**.
4. The stretched elastic lungs **recoil** (spring back).
5. Intrapulmonary pressure rises above atmospheric pressure → air flows **out**.

Simple explanation. Let go of a stretched rubber band and it snaps back — the lungs do the same. No muscle work is needed for quiet breathing out; the elastic recoil of the lungs does it.

When is expiration active? During exercise, coughing, blowing, or playing a wind instrument, the **internal intercostal muscles** and **abdominal muscles** contract forcefully to push air out faster.

Terminology Alert

- **Expiration** = breathing out.

- **Elastic recoil** = the natural spring-back of stretched lung tissue.

Analogy. Quiet breathing is like a balloon: you blow it up with effort (inspiration), then just let go and it empties by itself (expiration).

Key takeaway. Quiet expiration is passive (muscles relax, lungs recoil). Forceful expiration uses abdominal and internal intercostal muscles.

2.4 Pressure changes — the core exam point

Phase	Diaphragm	Ribs	Chest volume	Lung pressure	Air flow
Inspiration	Contracts, flattens	Up and out	Increases	Falls below outside	In
Expiration (quiet)	Relaxes, domes up	Down and in	Decreases	Rises above outside	Out

One-line memory hook: "Volume up → pressure down → air in; volume down → pressure up → air out."

2.5 Regulation of respiration — the brain is in charge

Concept. Breathing is automatic — you do not have to think about it — because the brain controls it.

Simple explanation. In the lower brain (the **medulla oblongata** and **pons**), there are groups of nerve cells called **respiratory centres**:

- **Inspiratory centre (dorsal respiratory group, medulla):** sends signals to start inspiration. It is the basic rhythm generator — like a metronome setting the breathing rate.
- **Expiratory centre (ventral respiratory group, medulla):** mainly active during forceful breathing.
- **Pneumotaxic centre (pons):** fine-tunes the rhythm — it "switches off" inspiration so breathing stays smooth and regular.

These centres send messages through nerves (mainly the **phrenic nerve** to the diaphragm) telling the breathing muscles when to contract.

> **Analogy.** The respiratory centres are like the conductor of an orchestra — the diaphragm and rib muscles are the musicians who play exactly when the conductor signals.

> **Key takeaway.** The medulla sets the basic breathing rhythm; the pons smooths it; nerves carry orders to the breathing muscles.

2.6 Chemical control — chemoreceptors

Concept. The brain adjusts breathing based on the levels of carbon dioxide, oxygen and acid in the blood.

Simple explanation. Special sensors called **chemoreceptors** constantly taste the blood:

- **Central chemoreceptors** (in the brain) mainly sense **carbon dioxide** (via pH of the fluid around the brain). CO_2 is the **strongest stimulus** for breathing — even a small rise makes you breathe faster and deeper.
- **Peripheral chemoreceptors** (in the carotid bodies of the neck and aortic bodies near the heart) sense **low oxygen**, high CO_2 and high acid (low pH).

Example. Hold your breath: CO_2 builds up in your blood, chemoreceptors detect it, and soon you feel an irresistible urge to breathe — that is chemical control forcing you to exhale the CO_2.

Flowchart — how the body responds to high CO_2:

CO_2 rises in blood
↓
Chemoreceptors detect it
↓
Signal to respiratory centres (medulla)
↓
Stronger signals to diaphragm + intercostal muscles
↓
Faster, deeper breathing
↓
Extra CO_2 breathed out → blood CO_2 returns to normal

Terminology Alert

- **Chemoreceptor** = sensor that detects chemicals (CO_2, O_2, H^+) in blood.

- **Hypoxia** = low oxygen in tissues.

- **Hypercapnia** = high carbon dioxide in blood.

Key takeaway. CO_2 is the main controller of breathing. Chemoreceptors detect blood gases and tell the brain to speed up or slow down breathing.

2.7 Other factors affecting breathing

Factor	Effect on breathing	Simple reason
Exercise	Faster and deeper	Muscles make more CO_2, need more O_2
Fever	Faster	Higher body temperature speeds body processes
Emotions (fear, excitement)	Faster	Brain's emotional centres stimulate respiratory centres
Sleep	Slower and shallower	Body needs less oxygen at rest
Pain	May become rapid and shallow	Reflex response
High altitude	Faster and deeper	Less oxygen in air; body compensates
Voluntary control	Can hold or deepen breath briefly	Higher brain centres can override — but only for a short time

Example. Athletes "pant" after a sprint — their chemoreceptors detected the CO_2 their muscles produced, and breathing speeds up to clear it.

2.8 Hering–Breuer reflex

Concept. Over-inflation of the lungs automatically stops inspiration — a protective reflex.

Simple explanation. Stretch receptors in the walls of the bronchi and bronchioles sense when the lungs are inflated enough. They send a signal through the **vagus nerve** to the brain, which switches off inspiration and starts expiration. This prevents the lungs from over-stretching.

Analogy. It is like the automatic cut-off switch in an electric water pump — when the tank is full, the pump stops by itself.

Key takeaway. Hering–Breuer reflex = lung stretch sensors stop inspiration to prevent over-inflation.

Pharmacy relevance

- **Opioid painkillers and sedatives** depress the respiratory centres — this is why overdose can stop breathing, and why pharmacists must counsel on safe use.
- **Bronchodilators** (asthma/COPD medicines) relax the smooth muscle of bronchioles — you can now explain *where* and *how* they work.
- **Oxygen therapy** is guided by understanding chemoreceptor control — giving too much oxygen to some chronic lung patients can reduce their drive to breathe (their drive depends on low O_2).

India context

- Breathlessness is a very common complaint in Indian OPDs — from asthma and COPD to anaemia and heart disease. A pharmacist who understands breathing mechanics can counsel patients better on inhaler use and when to seek urgent care (e.g., severe breathlessness, bluish lips).
- During winter in North India, smog worsens breathing difficulty; pharmacists often advise masks and adherence to prescribed inhalers.

Common confusions

1. **Inspiration is active, quiet expiration is passive** — many students say both are active.
2. **CO_2, not O_2, is the main stimulus** for normal breathing — low oxygen matters mainly at high altitude or in disease.
3. **Medulla sets rhythm; pons fine-tunes** — do not swap their roles.
4. **Intrapulmonary vs intrapleural pressure** — intrapulmonary = inside the airways/alveoli; intrapleural = in the pleural space (always slightly negative, keeps lungs expanded).

Common mistakes

- Saying "the diaphragm pushes air out" — it is the *relaxation* of the diaphragm plus lung recoil that empties the lungs quietly.
- Saying oxygen shortage is what makes you breathe faster at rest — at rest it is CO_2 build-up.
- Confusing the Hering–Breuer reflex (stretch → stop inspiration) with chemoreceptor control (chemicals → adjust rate).

Mnemonics

- Inspiration muscles: **"DI"** — **D**iaphragm + external **I**ntercostals for **I**nspiration.
- Main breathing stimulus: **"CO_2 is the Boss"** — carbon dioxide controls the rate.

One-minute revision

Air flows from high to low pressure. Inspiration (active): diaphragm contracts and flattens, ribs lift up/out → chest expands → pressure falls → air in. Quiet expiration (passive): muscles relax, lungs recoil → pressure rises → air out. Brain control: medulla sets rhythm, pons smooths it, phrenic nerve drives the diaphragm. Chemoreceptors sense CO_2 (main stimulus), O_2 and pH, and adjust breathing. Hering–Breuer reflex stops over-inflation.

Practice questions

MCQs

1. Quiet expiration is: a) Active b) Passive c) Both d) Neither
2. The main stimulus for normal breathing is: a) Low O_2 b) High CO_2 c) Low CO_2 d) High O_2
3. The inspiratory centre is located in the: a) Cerebrum b) Cerebellum c) Medulla oblongata d) Spinal cord
4. During inspiration, the diaphragm: a) Relaxes and domes up b) Contracts and flattens c) Does not move d) Pushes ribs in
5. The Hering–Breuer reflex prevents: a) Over-inflation of lungs b) CO_2 build-up c) Airway infection d) Voice loss

Short-answer (2–3 marks)

1. Explain the pressure changes during inspiration and expiration.
2. Why is quiet expiration called a passive process?
3. What are chemoreceptors? Name the two types and what they detect.
4. Write a short note on the Hering–Breuer reflex.

Long-answer (5 marks)

1. Describe the mechanism of respiration with the role of the diaphragm and intercostal muscles. Explain how respiration is regulated by nervous and chemical factors.

Application-based

1. Why does a person breathe faster and deeper after running 100 metres?
2. A patient on strong opioid painkillers is breathing very slowly. Explain the mechanism.

Viva

1. Which nerve carries signals to the diaphragm?
2. Can you hold your breath forever? Why not?
3. Why is the diaphragm called the main muscle of respiration?

Answer key — MCQs: 1-b, 2-b, 3-c, 4-b, 5-a.

Chapter 3: Lung Volumes and Capacities

Learning Objectives

After studying this chapter, you should be able to:

1. Define the four lung volumes (TV, IRV, ERV, RV) with typical values.
2. Define the four lung capacities (IC, FRC, VC, TLC) and show how each is calculated.
3. Draw a spirometry trace labelling all volumes and capacities.
4. Explain the clinical importance of vital capacity and residual volume.

3.1 Why measure lung volumes?

Concept. Lung volumes are the different amounts of air the lungs can hold during different types of breathing.

Simple explanation. Not all the air in your lungs moves with every breath. A normal quiet breath moves only a small amount; a deep breath moves much more; and some air always stays behind. Doctors measure these amounts with an instrument called a **spirometer** to check whether lungs are healthy.

> **Analogy.** Think of a water tank: the water you use daily (tidal volume), the extra you can draw in an emergency (reserve volumes), and the water that always remains at the bottom and cannot be drained (residual volume).

> **Key takeaway.** Measuring lung volumes tells us how well the lungs move air — reduced volumes signal lung disease.

3.2 The four lung volumes

> **Terminology Alert**

> - **Volume** = a single, non-overlapping amount of air.

> - **Capacity** = a combination of two or more volumes added together.

3.2.1 Tidal volume (TV) — about 500 mL

Concept. The amount of air breathed in or out in one normal, quiet breath.

Simple explanation. When you sit reading this, each breath moves about half a litre (500 mL) of air. That is the tidal volume — like the tide of the sea coming in and going out gently.

3.2.2 Inspiratory reserve volume (IRV) — about 3,000 mL

Concept. The extra air you can breathe **in** over and above a normal breath, by taking the deepest possible breath.

Example. Take a normal breath in — now, without breathing out, force in as much extra air as you can. That extra ~3 litres is the IRV.

3.2.3 Expiratory reserve volume (ERV) — about 1,100 mL

Concept. The extra air you can breathe **out** over and above a normal breath, by exhaling as forcefully as possible.

3.2.4 Residual volume (RV) — about 1,200 mL

Concept. The air that **always remains** in the lungs, even after the most forceful exhalation.

Simple explanation. You can never squeeze all the air out of your lungs — about 1.2 litres stays behind. This is good: it keeps the alveoli slightly open so gas exchange never stops completely, and it keeps the lungs from collapsing.

> **Analogy.** Residual volume is like the last bit of tea that always stays in the cup no matter how hard you tip it — it keeps the cup "wet" (the alveoli open).

> **Key takeaway.** TV (500) = normal breath; IRV (3,000) = extra in; ERV (1,100) = extra out; RV (1,200) = never leaves.

3.3 The four lung capacities

Capacities are sums of volumes:

Capacity	Formula	Typical value
Inspiratory capacity (IC)	TV + IRV	~3,500 mL
Functional residual capacity (FRC)	ERV + RV	~2,300 mL
Vital capacity (VC)	IRV + TV + ERV	~4,600 mL
Total lung capacity (TLC)	VC + RV (all four volumes)	~5,800 mL

Simple explanations:

- **Vital capacity** = the maximum air you can breathe out after the deepest breath in. It measures the useful working capacity of the lungs — reduced in lung diseases.
- **Total lung capacity** = the absolute maximum air the lungs can hold.
- **Functional residual capacity** = the air left in the lungs after a normal breath out — the "resting" air.

How to sketch the spirometry trace:

1. Draw a vertical scale of volume (0 to 6,000 mL).
2. Draw a wavy line in the middle showing 3–4 small waves — each small wave = tidal volume (500 mL).
3. From the top of a normal breath, draw one tall peak up = IRV; from the bottom of a normal breath, draw one deep dip down = ERV.
4. Below the lowest point, mark a block = RV (cannot be measured by spirometer — it never leaves).
5. Bracket TV+IRV and label IC; bracket ERV+RV and label FRC; bracket IRV+TV+ERV and label VC; bracket everything and label TLC.

> **Key takeaway.** Capacities = combinations of volumes. VC is the most clinically useful; RV keeps alveoli open.

Pharmacy relevance

- **Spirometry** results guide asthma/COPD treatment — pharmacists should understand terms like "reduced vital capacity" on prescriptions and test reports.
- **Incentive spirometers** (breathing exerciser devices sold in pharmacies) help post-surgery patients expand their lungs — pharmacists demonstrate their use.

India context

- Spirometry is now available in many Indian district hospitals and larger pharmacies' health camps; pharmacists assist in COPD screening camps where reduced VC/FEV_1 flags patients for referral.

Common confusions

1. **Volume vs capacity** — volume is single; capacity is a sum.
2. **VC vs TLC** — VC excludes residual volume; TLC includes everything.
3. **RV cannot be measured by a spirometer** — because it never comes out! It is measured by special gas-dilution methods.

Common mistakes

- Writing VC = TV + IRV only (forgetting ERV).
- Saying residual volume is "waste air" — it is essential to keep alveoli open.

Mnemonics

- Volumes: **"TIRE"** — **T**idal, **I**nspiratory reserve, **R**esidual, **E**xpiratory reserve.
- Capacities order of size: **FRC < IC < VC < TLC** — "Fun In Very Tall Cups".

One-minute revision

Four volumes: TV 500 mL (normal breath), IRV 3,000 mL (extra in), ERV 1,100 mL (extra out), RV 1,200 mL (always stays). Four capacities: IC = TV+IRV; FRC = ERV+RV; VC = IRV+TV+ERV (max useful breath); TLC = all four. RV keeps alveoli open and cannot be measured by simple spirometry.

Practice questions

MCQs

1. Tidal volume in a normal adult is about: a) 1200 mL b) 500 mL c) 3000 mL d) 4600 mL
2. Vital capacity = a) TV + IRV b) IRV + TV + ERV c) ERV + RV d) TV + RV
3. The air that remains in lungs after forceful expiration is: a) ERV b) IRV c) RV d) TV
4. Functional residual capacity = a) TV + IRV b) ERV + RV c) VC + RV d) IRV + ERV
5. Total lung capacity is about: a) 2300 mL b) 3500 mL c) 4600 mL d) 5800 mL

Short-answer (2–3 marks)

1. Define tidal volume, IRV, ERV and RV with typical values.
2. What is vital capacity? Why is it clinically important?
3. Draw a labelled spirometry trace showing all lung volumes.

Long-answer (5 marks)

1. Define lung volumes and capacities. Give the formula and typical value of each capacity, and draw a neat spirometry diagram.

Application-based

1. A patient's vital capacity is much lower than expected. What might this suggest, and what would you advise as a pharmacist?
2. Why can't residual volume be measured with an ordinary spirometer?

Viva

1. Which lung volume keeps alveoli from collapsing?
2. What is the difference between IRV and ERV?
3. Name the instrument used to measure lung volumes.

Answer key — MCQs: 1-b, 2-b, 3-c, 4-b, 5-d.

Chapter 4: Transport of Respiratory Gases

Learning Objectives

After studying this chapter, you should be able to:

1. Explain how oxygen is transported in blood (oxyhaemoglobin).
2. Describe the oxygen–haemoglobin dissociation curve and factors that shift it.
3. Explain the three ways carbon dioxide is transported.
4. Describe the chloride shift and the role of carbonic anhydrase.

4.1 The transport problem

Concept. Oxygen does not dissolve well in water (blood plasma), so the body needs a carrier.

Simple explanation. Only about 3% of oxygen travels dissolved in plasma — far too little for the body's needs. The red blood cells solve this with **haemoglobin (Hb)**, a protein that grabs oxygen in the lungs and releases it in the tissues.

> **Analogy.** Dissolved oxygen alone is like trying to supply a city with water using buckets; haemoglobin is like building pipelines — it carries ~97% of the oxygen.

> **Key takeaway.** Haemoglobin in red blood cells carries almost all oxygen; very little travels dissolved.

4.2 Oxygen transport — oxyhaemoglobin

Concept. In the lungs, haemoglobin binds oxygen to form **oxyhaemoglobin**; in the tissues, it releases oxygen.

Simple explanation. Each haemoglobin molecule has 4 iron-containing units (**haem** groups), and each can carry one O_2 — so one haemoglobin carries 4 oxygen molecules. In the lungs, where oxygen is plentiful, haemoglobin loads up (becomes bright red oxyhaemoglobin). In the tissues, where oxygen is low and CO_2/acid is high, haemoglobin unloads oxygen (becomes dark red deoxyhaemoglobin).

The oxygen–haemoglobin dissociation curve. This S-shaped (sigmoid) curve shows how much oxygen haemoglobin holds at different oxygen levels:

- At high O_2 (lungs): the curve is flat at the top — haemoglobin is almost fully loaded (about 97% saturated).
- At low O_2 (tissues): the curve drops steeply — haemoglobin readily gives up oxygen where it is needed most.

Factors that shift the curve to the RIGHT (haemoglobin releases O_2 more easily — good for active tissues):

- ↑ CO_2 (Bohr effect)
- ↓ pH (more acidic)
- ↑ temperature
- ↑ 2,3-BPG (a substance in RBCs, rises at high altitude)

Mnemonic for right shift: "CADET, face Right!" — **C**O_2, **A**cid (low pH), **D**PG (2,3-BPG), **E**xercise (heat), **T**emperature — shift right.

Example. During exercise, muscles produce CO_2, acid and heat — all shift the curve right, so haemoglobin dumps extra oxygen exactly where the working muscles need it.

Terminology Alert

- **Oxyhaemoglobin** = haemoglobin carrying oxygen (bright red).

- **Deoxyhaemoglobin** = haemoglobin after releasing oxygen (dark red).

- **Bohr effect** = CO_2/acid making haemoglobin release O_2 more easily.

- **Partial pressure** = the share of total air pressure contributed by one gas (e.g., pO_2, pCO_2).

Key takeaway. Haemoglobin loads O_2 in the lungs and unloads it in tissues; CO_2, acid, heat and exercise make unloading easier (right shift).

4.3 Carbon dioxide transport — three ways

Concept. CO_2 travels from tissues to lungs in three forms.

Simple explanation. Cells constantly make CO_2. It is carried to the lungs as:

1. **Bicarbonate ions (HCO_3^-) — about 70% (the main way).** Inside red blood cells, the enzyme **carbonic anhydrase** joins CO_2 + water → carbonic acid → bicarbonate + H^+. Bicarbonate travels in plasma to the lungs, where the reaction reverses and CO_2 is breathed out.
2. **Carbamino compounds — about 20–25%.** CO_2 binds directly to haemoglobin (not to the iron — to the protein part), forming carbaminohaemoglobin.
3. **Dissolved in plasma — about 7–10%.** A small amount simply dissolves.

Flowchart — the bicarbonate shuttle:

In TISSUES: $CO_2 + H_2O$ --carbonic anhydrase--> H_2CO_3 --> $H^+ + HCO_3^-$
(bicarbonate made, travels in plasma) (inside RBC) (carbonic acid)

In LUNGS: $H^+ + HCO_3^-$ --> H_2CO_3 --carbonic anhydrase--> $CO_2 + H_2O$
(reaction reverses) ↓
CO_2 breathed OUT

The chloride shift. When bicarbonate (HCO_3^-, negative) leaves the red blood cell into plasma, chloride ions (Cl^-, negative) move **into** the cell to keep the electrical balance. This swap is the **chloride shift**.

Analogy. The bicarbonate system is like a parcel service: CO_2 is packed into "bicarbonate parcels" inside RBCs, shipped through plasma, unpacked in the lungs, and the empty CO_2 is thrown out with the breath.

Key takeaway. Most CO_2 travels as bicarbonate made by carbonic anhydrase; the chloride shift keeps electrical balance.

4.4 Summary table — gas transport

Gas	Main form	%	Key points
O_2	Oxyhaemoglobin	~97%	4 O_2 per Hb; unloads in tissues; curve shifts right with CO_2/acid/heat
O_2	Dissolved in plasma	~3%	Too little alone
CO_2	Bicarbonate (HCO_3^-)	~70%	Made by carbonic anhydrase in RBC
CO_2	Carbaminohaemoglobin	~20–25%	Bound to Hb protein part
CO_2	Dissolved in plasma	~7–10%	Small amount

Pharmacy relevance

- **Carbonic anhydrase inhibitors** (e.g., acetazolamide) block this enzyme — used in glaucoma, altitude sickness and some epilepsy. Now you know the enzyme's normal job.
- **Anaemia** (low haemoglobin) reduces oxygen-carrying capacity — patients feel breathless and tired; pharmacists counsel on iron supplements and diet.
- **Pulse oximeters** (sold in pharmacies) measure oxygen saturation of haemoglobin — you can now explain what the SpO_2 reading means.

India context

- Anaemia is extremely common in India, especially among women — low haemoglobin directly reduces oxygen transport, which is why anaemic patients complain of fatigue and breathlessness on mild exertion.
- Pulse oximeters became household items during COVID-19; pharmacists explained SpO_2 readings to thousands of families.

Common confusions

1. **Oxyhaemoglobin vs carbaminohaemoglobin** — oxyhaemoglobin carries O_2 on the iron; carbaminohaemoglobin carries CO_2 on the protein part. Different gases, different binding sites.
2. **Bohr effect direction** — more CO_2/acid shifts the curve RIGHT (more unloading), not left.
3. **Carbonic anhydrase location** — mainly inside red blood cells, not free in plasma.

Common mistakes

- Saying "most CO_2 is carried by haemoglobin" — most CO_2 travels as bicarbonate; most O_2 is carried by haemoglobin.
- Saying oxygen dissolves easily in blood — it does not; that is why haemoglobin is needed.

Mnemonics

- CO_2 transport: **"70-20-7"** — 70% bicarbonate, ~20% carbamino, ~7% dissolved.
- Right shift: **"CADET, face Right!"**

One-minute revision

O_2: ~97% as oxyhaemoglobin (4 O_2 per Hb), ~3% dissolved. Tissues' CO_2, acid and heat shift the dissociation curve right → more O_2 released (Bohr effect). CO_2: ~70% as bicarbonate (carbonic anhydrase in RBC), ~20% as carbaminohaemoglobin, ~7% dissolved. Chloride shift balances charges when bicarbonate leaves the RBC.

Practice questions

MCQs

1. About what % of oxygen is carried as oxyhaemoglobin? a) 50% b) 70% c) 97% d) 25%
2. Most CO_2 is transported as: a) Dissolved gas b) Carbamino compounds c) Bicarbonate ions d) Carbonic acid
3. The enzyme carbonic anhydrase is found mainly in: a) Plasma b) Red blood cells c) Platelets d) Lungs
4. A right shift of the O_2–Hb curve is caused by: a) Low CO_2 b) High pH c) High CO_2 and low pH d) Low temperature
5. Chloride shift refers to: a) Cl^- entering RBC as HCO_3^- leaves b) Cl^- leaving RBC c) Na^+ entering RBC d) O_2 binding to Hb

Short-answer (2–3 marks)

1. Describe the three ways CO_2 is transported in blood.
2. What is the Bohr effect?
3. Explain the chloride shift.

Long-answer (5 marks)

1. Describe the transport of oxygen and carbon dioxide in blood. Draw the oxygen–haemoglobin dissociation curve and explain the factors affecting it.

Application-based

1. Why does an anaemic patient feel breathless on climbing stairs? Relate to oxygen transport.
2. During vigorous exercise, how does the body ensure active muscles get extra oxygen?

Viva

1. How many O_2 molecules can one haemoglobin carry?
2. Where does the bicarbonate reaction reverse?
3. What does a pulse oximeter actually measure?

Answer key — MCQs: 1-c, 2-c, 3-b, 4-c, 5-a.

Chapter 5: Artificial Respiration and Resuscitation Methods

Learning Objectives

After studying this chapter, you should be able to:

1. Define artificial respiration and list its indications.
2. Describe mouth-to-mouth breathing step by step.
3. Describe the steps of CPR (cardiopulmonary resuscitation) in general terms.
4. Explain the recovery position and when to use it.
5. State the pharmacist's role in emergencies.

5.1 What is artificial respiration?

Concept. Artificial respiration = manually helping or replacing a person's breathing when they cannot breathe adequately on their own.

Simple explanation. If someone stops breathing — due to drowning, electric shock, choking, drug overdose, or heart attack — their brain starts dying within 4–6 minutes without oxygen. Artificial respiration buys time by forcing air into their lungs until natural breathing returns or medical help arrives.

Example. A person pulled from a village pond, unconscious and not breathing — immediate mouth-to-mouth breathing can keep oxygen going to the brain until the ambulance arrives.

> **Key takeaway.** Artificial respiration = breathing for someone who cannot breathe; its purpose is to keep the brain alive until help comes.

5.2 Mouth-to-mouth (rescue) breathing

Steps:

1. Lay the person flat on their back on a firm surface.
2. **Open the airway** — tilt the head back and lift the chin (this lifts the tongue away from the back of the throat).
3. Pinch the nose shut.
4. Take a normal breath, seal your mouth over the person's mouth, and blow steadily for about 1 second — enough to make the chest rise.
5. Remove your mouth and let the chest fall (air comes out on its own).
6. Repeat about one breath every few seconds, watching for chest rise each time.

Why it works: Your exhaled air still contains about 16% oxygen — enough to keep the victim's blood oxygenated.

> **Analogy.** You become a human bellows — your lungs pump air into their lungs.

> **Key takeaway.** Head tilt–chin lift opens the airway; seal, blow, watch the chest rise, repeat.

5.3 CPR — cardiopulmonary resuscitation

Concept. CPR combines chest compressions (to pump blood) with rescue breaths (to supply oxygen) when the heart has stopped.

Simple explanation. When the heart stops, blood stops moving. Chest compressions manually squeeze the heart between the breastbone and the spine, pushing blood to the brain and heart. Rescue breaths supply the oxygen. The standard approach taught to the public is:

1. Check response and call for emergency help first.
2. Place the heel of your hand on the centre of the chest; push hard and fast, allowing full chest recoil between pushes.
3. Give rescue breaths (about 2 breaths after every 30 compressions for a trained rescuer).
4. Continue until the person revives or trained medical help takes over.

Note for students: Exact compression rates and depths follow current resuscitation council guidelines, which are updated periodically — always learn the latest guideline version in certified first-aid/CPR training. Do not memorise fixed numbers from textbooks for real-life use.

Analogy. In CPR your hands become the heart (compressions) and your mouth becomes the lungs (breaths).

Key takeaway. CPR = chest compressions + rescue breaths to keep blood and oxygen moving when the heart stops. Get trained — technique matters.

5.4 Other resuscitation methods and positions

Method	What it is	When used
Recovery position	Laying an unconscious but breathing person on their side	Prevents the tongue blocking the airway and lets vomit drain out
Oxygen therapy	Giving extra oxygen via mask or nasal tube	Breathlessness, low blood oxygen
Mechanical ventilator	Machine that breathes for the patient	ICU patients who cannot breathe adequately
Defibrillation	Electric shock to restart a normal heart rhythm	Certain cardiac arrests (done by trained staff with a defibrillator/AED)

Key takeaway. Recovery position for unconscious-but-breathing; ventilators and defibrillators for hospital settings.

Pharmacy relevance

- Pharmacists are often the **first health professional** people approach in an emergency — knowing basic life support can save a life before the ambulance arrives.
- Pharmacists stock and explain **emergency medicines** (e.g., adrenaline auto-injectors for severe allergy) and first-aid supplies.
- **Naloxone** (opioid overdose antidote) is a rescue medicine — artificial respiration keeps the patient alive while it takes effect.

India context

- Drowning (ponds, rivers, monsoon flooding) and road accidents are common emergencies in India where bystander CPR is rarely performed — training more pharmacists and students in CPR directly saves lives.
- The national emergency number **112** (and 108 ambulance services in many states) should be called immediately in any collapse.

Common confusions

1. **Artificial respiration vs ventilator** — artificial respiration is the manual emergency technique; a ventilator is a machine for longer-term hospital support.
2. **Recovery position vs CPR** — recovery position is for unconscious but BREATHING persons; CPR is for NOT breathing / no pulse.
3. **Your exhaled air still has oxygen (~16%)** — it is not "waste air"; it is enough for rescue breathing.

Common mistakes

- Blowing too hard/fast into the victim's mouth (causes air in the stomach) — gentle breaths that raise the chest are enough.
- Stopping CPR too early — continue until help arrives or the person clearly revives.
- Forgetting to open the airway first — blowing into a blocked airway achieves nothing.

Mnemonics

- Emergency order: **"DRS-ABC"** — **D**anger (check scene safe), **R**esponse (shake and shout), **S**hout for help, **A**irway, **B**reathing, **C**irculation (compressions).

One-minute revision

Artificial respiration breathes for someone who cannot. Mouth-to-mouth: head tilt–chin lift, pinch nose, seal and blow, watch chest rise. CPR = compressions + breaths when the heart stops; call 112/108 first. Recovery position (on the side) for unconscious but breathing persons. Exact CPR numbers follow current guidelines — learn them in certified training.

Practice questions

MCQs

1. The first step in rescue breathing is: a) Chest compressions b) Opening the airway (head tilt–chin lift) c) Giving water d) Checking BP
2. CPR is needed when: a) Person is sleeping b) Heart has stopped / person not breathing c) Person has fever d) Person is anxious
3. The recovery position is used for a person who is: a) Unconscious but breathing b) In cardiac arrest c) Choking d) Having a seizure only
4. Exhaled air used in rescue breathing contains about: a) 21% O_2 b) 16% O_2 c) 5% O_2 d) 0% O_2
5. In an emergency in India, the national helpline is: a) 100 only b) 112 c) 911 d) 999

Short-answer (2–3 marks)

1. Describe the steps of mouth-to-mouth breathing.
2. What is the recovery position and why is it used?
3. Differentiate between artificial respiration and mechanical ventilation.

Long-answer (5 marks)

1. What is artificial respiration? Describe the methods of resuscitation, including CPR steps and the recovery position.

Application-based

1. You see an unconscious person on the roadside who is breathing. What do you do?
2. As a pharmacist, how would you respond to an opioid overdose in your pharmacy?

Viva

1. Why must the airway be opened before rescue breaths?
2. Why do we continue CPR until medical help arrives?
3. What is an AED?

Answer key — MCQs: 1-b, 2-b, 3-a, 4-b, 5-b.

Chapter 6: Pathophysiology of Asthma, COPD and Tuberculosis

Learning Objectives

After studying this chapter, you should be able to:

1. Define asthma, COPD and tuberculosis in simple words.
2. Explain the pathophysiology (what goes wrong) in each disease.
3. Compare the three diseases in a table.
4. List general clinical features of each (recognise and refer).
5. Explain pharmacy relevance: inhaler counselling, adherence, DOTS.

6.1 What is pathophysiology?

Concept. Pathophysiology = the study of **what goes wrong** in the body during disease ("pathos" = disease, "physiology" = function).

Simple explanation. Anatomy tells you the normal structure; physiology tells you the normal function; pathophysiology tells you how the function breaks down in disease — and that breakdown explains the symptoms the patient feels.

> **Key takeaway.** Pathophysiology links the disease process → to the symptoms → to the treatment logic.

6.2 Asthma

Definition. Asthma is a chronic condition in which the airways become **inflamed and hyper-reactive** — they narrow suddenly (bronchospasm), making breathing difficult. The narrowing is largely **reversible** (with treatment or on its own).

What goes wrong (pathophysiology), step by step:

1. **Trigger** — dust, pollen, smoke, cold air, exercise, or infection irritates the airways.
2. **Inflammation** — the airway lining swells and produces extra mucus.
3. **Bronchospasm** — the smooth muscle around bronchioles contracts, narrowing the tubes.
4. **Airflow obstruction** — air struggles to get in and especially **out**; the patient wheezes.
5. **Reversibility** — with reliever medicine (bronchodilator) the muscle relaxes and breathing improves.

Flowchart:

Trigger (dust/smoke/pollen)
↓
Airway inflammation + mucus
↓
Bronchial smooth muscle contracts (bronchospasm)
↓
Airways narrow → wheezing, breathlessness, cough, chest tightness
↓
Reliever medicine relaxes muscle → airways open (REVERSIBLE)

General clinical features: recurrent wheezing (whistling sound while breathing out), breathlessness, chest tightness, cough — often worse at night or early morning. Severe attacks are emergencies.

> **Analogy.** Asthma is like a road that suddenly narrows because of an accident (spasm) plus parked trucks (mucus/swelling) — traffic (air) jams, but once cleared, the road opens fully again.

> **Key takeaway.** Asthma = inflamed, twitchy airways that narrow suddenly but open up again — wheeze + breathlessness, reversible.

6.3 COPD (Chronic Obstructive Pulmonary Disease)

Definition. COPD is a long-term, **largely irreversible** narrowing of the airways and destruction of lung tissue, usually caused by **smoking** or long-term air pollution/biomass smoke exposure. It has two main forms that usually occur together:

- **Chronic bronchitis** — long-standing inflammation of the bronchi with persistent productive cough (cough with mucus) for months, year after year.
- **Emphysema** — destruction of alveolar walls; the tiny air sacs merge into large, floppy spaces with less surface area for gas exchange.

What goes wrong (pathophysiology):

1. **Chronic irritation** (cigarette smoke, indoor chulha smoke, air pollution) damages airways and alveoli over years.
2. **Chronic bronchitis part:** airway lining thickens, glands enlarge, excess mucus → narrowed airways → persistent cough with sputum.
3. **Emphysema part:** alveolar walls break down → fewer, bigger air sacs → less surface area → less oxygen enters blood; lungs lose elasticity → air gets **trapped** (hard to breathe out).
4. The obstruction is **largely irreversible** — medicines relieve symptoms but cannot restore destroyed alveoli.

General clinical features: long-standing breathlessness (first on exertion, later even at rest), chronic cough with sputum, wheezing, frequent chest infections. Advanced patients may have bluish lips (low oxygen) and weight loss.

> **Analogy.** COPD lungs are like an old sponge whose holes have merged into big useless cavities and whose walls have stiffened — it can neither soak up nor squeeze out properly, and no repair can restore it.

> **Key takeaway.** COPD = chronic, mostly irreversible airway narrowing + alveolar destruction, usually from smoking — persistent cough, progressive breathlessness.

6.4 Tuberculosis (TB)

Definition. Tuberculosis is an **infectious disease** caused by the bacterium *Mycobacterium tuberculosis*, most commonly affecting the **lungs** (pulmonary TB). It spreads through the air when an infected person coughs or sneezes.

What goes wrong (pathophysiology):

1. **Inhalation** — droplet nuclei carrying the bacteria are breathed in and reach the alveoli.
2. **Immune response** — immune cells surround the bacteria, forming small nodules called **tubercles** (hence "tuberculosis") — often the infection is contained here (latent TB, no symptoms).
3. **Active disease** — if immunity weakens, bacteria multiply; tubercles grow, merge, and break down (**caseation** — cheese-like dead tissue), forming **cavities** in the lung.
4. **Spread** — cavities connect to airways → bacteria coughed out → infect others; bacteria can also spread through blood to other organs.

General clinical features: persistent cough (often more than 2–3 weeks, sometimes with blood), evening fever, night sweats, weight loss and loss of appetite, fatigue, chest pain.

> **Analogy.** TB is like a slow-burning fire walled off by the body's fire brigade (immune cells) — as long as the wall holds, there is no damage; if the wall breaks, the fire spreads and hollows out the building (lung cavities).

> **Key takeaway.** TB = airborne bacterial infection forming tubercles and cavities in lungs — chronic cough, evening fever, weight loss; curable with full course of medicines.

6.5 Comparison table — asthma vs COPD vs TB

Feature	Asthma	COPD	Tuberculosis
Nature	Inflammatory, hyper-reactive airways	Chronic obstructive, destructive	Infectious (bacterial)
Cause	Allergy/irritant triggers	Smoking, pollution, biomass smoke	*Mycobacterium tuberculosis* (airborne)
Reversibility	Largely **reversible**	Largely **irreversible**	Curable with full treatment
Main pathology	Bronchospasm + inflammation + mucus	Chronic bronchitis + emphysema	Tubercles, caseation, cavities
Typical pattern	Episodic attacks	Progressive, persistent	Chronic, slowly progressive
Key symptom	Wheezing, worse at night	Chronic cough with sputum, progressive breathlessness	Cough >2–3 weeks, evening fever, weight loss
Contagious?	No	No	**Yes** (pulmonary TB, airborne)

Pharmacy relevance

- **Inhaler technique counselling** is the pharmacist's top job in asthma/COPD — most patients use inhalers wrongly. Check: shake, exhale fully, seal lips, inhale slowly and deeply, hold breath ~10 seconds, rinse mouth after steroid inhalers.
- **Adherence:** asthma preventer inhalers must be used daily even when the patient feels fine; stopping early is a common cause of attacks.
- **TB – DOTS/NTEP:** TB medicines must be taken for the full prescribed course (months). Stopping early breeds **drug-resistant TB**. Pharmacists motivate completion, watch for side effects, and refer suspects (chronic cough) for testing.
- **Smoking cessation** counselling is the single most powerful intervention in COPD.

India context

- India has the world's largest TB burden — the **National TB Elimination Programme (NTEP)** provides free diagnosis and treatment, with **Nikshay** portal tracking. Pharmacists are formally engaged as treatment supporters and referral points.
- **Biomass/chulha smoke** is a major COPD cause among rural Indian women who never smoked — Ujjwala LPG connections have helped reduce this.
- Winter smog in North Indian cities sharply worsens asthma and COPD; pharmacists advise adherence, masks, and avoiding outdoor exertion on severe-smog days.

Common confusions

1. **Asthma vs COPD** — asthma: episodic + reversible + often younger/allergic; COPD: persistent + irreversible + usually older/smoker.
2. **TB is infectious; asthma and COPD are not** — do not isolate asthma/COPD patients, but do counsel TB patients on cough hygiene.
3. **"Cured" vs "controlled"** — asthma is controlled, not cured; TB is curable with complete treatment.

Common mistakes

- Saying COPD is reversible like asthma.
- Saying TB spreads by sharing food/water — it spreads through **air** (droplets).
- Stopping TB medicines when feeling better — the most dangerous mistake; causes drug resistance.

Mnemonics

- Asthma features: **"Wheeze-ABC"** — **W**heezing, **B**reathlessness, **C**hest tightness, **C**ough at night.
- TB symptoms: **"Fever, Cough, Weight — FCW"** — evening **F**ever, **C**hronic cough, **W**eight loss (+ night sweats).

One-minute revision

Asthma = reversible bronchospasm + inflammation → episodic wheeze, worse at night. COPD = chronic bronchitis + emphysema from smoking → persistent cough, progressive breathlessness, irreversible. TB = airborne *Mycobacterium tuberculosis* → tubercles, cavities → chronic cough, evening fever, night sweats, weight loss; curable only with the FULL course (DOTS/NTEP). Pharmacist: inhaler technique, adherence, smoking cessation, TB referral and treatment support.

Practice questions

MCQs

1. The reversible airway disease is: a) COPD b) Asthma c) Emphysema d) Pneumonia
2. Emphysema mainly involves destruction of: a) Bronchi b) Alveolar walls c) Pleura d) Trachea
3. TB is caused by: a) A virus b) *Mycobacterium tuberculosis* c) A fungus d) Smoking
4. TB spreads mainly through: a) Contaminated water b) Airborne droplets c) Mosquitoes d) Touch
5. Chronic bronchitis is defined by persistent productive cough lasting: a) Days b) Months, year after year c) Hours d) Minutes

Short-answer (2–3 marks)

1. Describe the pathophysiology of asthma with a flowchart.
2. Differentiate between chronic bronchitis and emphysema.
3. Explain how tubercles and cavities form in TB.
4. Compare asthma and COPD (any four points).

Long-answer (5 marks)

1. Describe the pathophysiology, clinical features and pharmacy relevance of asthma, COPD and tuberculosis. Add a comparison table.

Application-based

1. A patient with asthma uses the reliever inhaler daily but never the preventer. What counselling would you give?
2. A customer reports cough for one month with evening fever and weight loss. What do you suspect and what is your next step as a pharmacist?
3. Why is completing the full TB course critical? What happens if stopped early?

Viva

1. Why is asthma called reversible while COPD is not?
2. What is caseation in TB?
3. Name the national programme for TB elimination in India.

Answer key — MCQs: 1-b, 2-b, 3-b, 4-b, 5-b.

Chapter 7: Anatomy of the Urinary Tract — Kidney and Nephrons

Learning Objectives

After studying this chapter, you should be able to:

1. List the parts of the urinary system in order.
2. Describe the external and internal structure of the kidney so you can draw it.
3. Describe the structure of a nephron and its parts, with a labelled sketch.
4. Explain the functions of each nephron segment in simple words.
5. State the blood supply of the kidney.

7.1 What does the urinary system do?

Concept. The urinary system removes waste and extra water from the blood as urine, while keeping useful substances.

Simple explanation. Blood constantly collects waste (like urea from protein breakdown) and extra water/salts. The kidneys filter the blood — keeping what the body needs, throwing out the rest as urine. The rest of the urinary tract (ureters, bladder, urethra) simply stores and carries urine out.

> **Analogy.** The urinary system is like a water-purification plant: the kidneys are the filters, ureters are pipes, the bladder is the storage tank, and the urethra is the outlet tap.

> **Key takeaway.** Kidneys filter blood → make urine; ureters carry, bladder stores, urethra expels it.

7.2 Parts of the urinary system in order

Kidneys (2) → Ureters (2) → Urinary bladder (1) → Urethra (1)

- **Kidneys:** bean-shaped organs, about 11 cm long, lying at the back of the abdomen on either side of the spine (**retroperitoneal** — behind the abdominal cavity lining). The right kidney sits slightly lower (the liver is above it).
- **Ureters:** two thin muscular tubes (~25 cm) carrying urine from each kidney to the bladder by wave-like contractions (**peristalsis**).
- **Urinary bladder:** a muscular sac in the pelvis that stores urine (capacity roughly 400–600 mL).
- **Urethra:** the tube carrying urine from the bladder to the outside. It is much shorter in females (~4 cm) than in males (~20 cm, also carries semen) — which is why urinary infections are more common in females (bacteria travel a shorter distance).

> **Terminology Alert**

> - **Retroperitoneal** = behind the peritoneum (the lining of the abdominal cavity).

> - **Peristalsis** = wave-like muscle contractions that push contents forward.

- **Renal** = relating to the kidney (from Latin *renes*).

- **Micturition** = the act of passing urine.

7.3 Internal structure of the kidney

How to sketch a kidney (longitudinal section):

1. Draw a bean shape. Mark the inner curved dent — the **hilum**, where blood vessels, nerves and the ureter enter/leave.
2. Inside, draw an outer dark band — the **cortex** (outer region).
3. Inside the cortex, draw 5–8 striped triangular pyramids — the **medulla** (inner region), each pyramid's tip (**papilla**) pointing toward the centre.
4. Draw small cup shapes around the papillae — **minor calyces**; several join into 2–3 **major calyces**; these join into a funnel — the **renal pelvis**, which narrows into the **ureter**.
5. Label: cortex, medulla (pyramid), papilla, minor/major calyx, renal pelvis, ureter, hilum, renal artery/vein.

Simple explanation of each part:

- **Cortex** — outer zone; contains most of the filtering units (glomeruli).
- **Medulla** — inner zone of pyramids; contains the loops of Henle and collecting ducts that concentrate urine.
- **Calyces and renal pelvis** — collect urine from the pyramids and funnel it into the ureter.

Analogy. The kidney is like a bean-shaped factory: the cortex is the workshop floor full of filter machines (nephrons), the medulla pyramids are the packing lines, and the pelvis is the dispatch funnel sending finished product (urine) out through the ureter.

Key takeaway. Cortex (filters) → medulla pyramids (concentrate) → calyces → renal pelvis → ureter.

7.4 The nephron — the functional unit of the kidney

Concept. The **nephron** is the microscopic structural and functional unit of the kidney — each kidney has about **1 million** of them. Every drop of urine is made by nephrons.

Parts of a nephron, in order:

1. **Glomerulus** — a tuft (ball) of tiny blood capillaries where filtration begins. Blood enters through the **afferent arteriole** and leaves through the **efferent arteriole**.
2. **Bowman's capsule** — a cup-shaped sac wrapping the glomerulus; it collects the filtered fluid. (Glomerulus + Bowman's capsule = **renal corpuscle**.)
3. **Proximal convoluted tubule (PCT)** — twisted tube after the capsule; reabsorbs most useful substances.
4. **Loop of Henle** — a U-shaped hairpin loop dipping into the medulla (descending limb + ascending limb); concentrates urine.
5. **Distal convoluted tubule (DCT)** — twisted tube after the loop; fine-tunes salt and water under hormone control.
6. **Collecting duct** — straight tube receiving fluid from many nephrons; final concentration of urine (under ADH hormone); empties into the papilla → calyx.

How to sketch a nephron:

1. Draw a small ball of squiggles (glomerulus) inside a cup (Bowman's capsule) at the top — in the cortex region.
2. From the cup, draw a wiggly tube (PCT).
3. Draw a long U-turn dipping down into the medulla and back up (loop of Henle).
4. Draw another wiggly tube (DCT) near the top.
5. Draw a straight vertical tube (collecting duct) going down through the medulla.
6. Add two tiny vessels: one entering the ball (afferent arteriole), one leaving (efferent arteriole).
7. Label all six parts + cortex/medulla zones.

Table — what each nephron part does:

Part	Main job (simple words)
Glomerulus	Filters blood — water, salts, glucose, urea pass into the capsule; cells and big proteins stay in blood
Bowman's capsule	Collects the filtered fluid (filtrate)
PCT	Reabsorbs ~65–70% of useful stuff: all glucose, most water, salts, amino acids
Loop of Henle (descending)	Water leaves (reabsorbed) → filtrate concentrates
Loop of Henle (ascending)	Salt leaves (reabsorbed); water cannot follow → filtrate dilutes
DCT	Fine-tuning of Na^+, K^+, Ca^{2+} under hormones (aldosterone, PTH)
Collecting duct	Final water control under ADH — decides how concentrated the urine is

Terminology Alert

- **Filtrate** = the fluid filtered from blood into Bowman's capsule (like "filtered tea" before processing).

- **Reabsorption** = taking useful substances BACK from the tubule into blood.

- **Secretion** = adding waste substances FROM blood INTO the tubule (extra dumping).

- **Afferent** = carrying toward (afferent arteriole → into glomerulus); **efferent** = carrying away.

Analogy. A nephron is like a recycling plant on a river: the glomerulus is a sieve that dumps river water plus everything small into a channel; along the channel, workers (tubule cells) pick out all the valuables (glucose, water, salts) and return them to the river, while adding extra rubbish (secretion); what finally flows out is concentrated waste — urine.

Key takeaway. Nephron = glomerulus (filter) → capsule (collect) → PCT (reabsorb most) → loop of Henle (concentrate) → DCT (fine-tune) → collecting duct (final water control).

7.5 Blood supply of the kidney

- Each kidney receives blood from a **renal artery** (branch of the abdominal aorta) — about 20–25% of the heart's output goes to the kidneys, showing how important filtration is.
- Blood leaves via the **renal vein** to the inferior vena cava.
- Inside: renal artery → afferent arteriole → **glomerulus** (filtration) → efferent arteriole → **peritubular capillaries** (around tubules, for reabsorption) → renal vein.

> **Key takeaway.** Kidneys get a huge blood supply (one-fifth of cardiac output) because continuous filtration is their core job.

Pharmacy relevance

- **Diuretics** (water tablets) act on specific nephron segments — e.g., loop diuretics on the loop of Henle, thiazides on the DCT. Knowing the segments explains their names and actions.
- **Kidney function tests** (urea, creatinine) reflect glomerular filtration — pharmacists adjust drug doses in kidney disease.
- Many drugs are **excreted by the kidney** — understanding filtration/secretion explains drug interactions and why kidney patients need dose changes.

India context

- Kidney stones are common in India's hot, dry regions (Rajasthan, Gujarat) where low water intake concentrates urine — pharmacists counsel on hydration.
- The shorter female urethra explains why UTIs are frequently seen in Indian women; pharmacists advise on hygiene and completing prescribed courses.

Common confusions

1. **Ureter vs urethra** — ureter: kidney → bladder; urethra: bladder → outside. (Ureter has an "R" like "kidney to bladder Run".)
2. **Reabsorption vs secretion** — reabsorption: tubule → blood (saving); secretion: blood → tubule (dumping).
3. **Glomerulus vs Bowman's capsule** — glomerulus = blood capillaries (the sieve); capsule = the cup collecting filtrate.
4. **Cortex vs medulla** — cortex outer (filters), medulla inner (pyramids concentrate).

Common mistakes

- Drawing the nephron without the loop dipping into the medulla.
- Saying urine is formed only by filtration — it is filtration + reabsorption + secretion.
- Mixing up afferent (in) and efferent (out) arterioles.

Mnemonics

- Nephron order: **"Great People Love Doing Chores"** — **G**lomerulus, **P**CT, **L**oop of Henle, **D**CT, **C**ollecting duct. (Bowman's capsule hugs the glomerulus.)
- Urine path: **"KUBU"** — **K**idney → **U**reter → **B**ladder → **U**rethra.

One-minute revision

Urinary tract: kidneys (filter, retroperitoneal, ~1 million nephrons each) → ureters (peristalsis) → bladder (stores) → urethra (female shorter → more UTIs). Kidney interior: cortex (glomeruli) → medulla pyramids → calyces → renal pelvis → ureter. Nephron: glomerulus + Bowman's capsule (filter) → PCT (reabsorb ~2/3) → loop of Henle (concentrate) → DCT (fine-tune) → collecting duct (ADH water control). Renal artery brings ~20–25% of cardiac output.

Practice questions

MCQs

1. The functional unit of the kidney is the: a) Glomerulus b) Nephron c) Pyramid d) Calyx
2. Filtration of blood occurs in the: a) PCT b) Loop of Henle c) Glomerulus d) Collecting duct
3. Most glucose and amino acids are reabsorbed in the: a) DCT b) PCT c) Collecting duct d) Pelvis
4. Urine flows: kidney → ___ → bladder → urethra. The blank is: a) Urethra b) Ureter c) Calyx d) Nephron
5. ADH acts mainly on the: a) Glomerulus b) PCT c) Collecting duct d) Loop of Henle

Short-answer (2–3 marks)

1. Draw a labelled diagram of the longitudinal section of the kidney.
2. Draw and label a nephron. State the function of each part.
3. Why are UTIs more common in females?
4. Differentiate between reabsorption and secretion.

Long-answer (5 marks)

1. Describe the anatomy of the kidney with special reference to the nephron. Draw labelled diagrams of the kidney section and a nephron.

Application-based

1. A drug label says "loop diuretic". Which nephron part does it act on, and what would be its effect on urine?
2. Why do doctors advise kidney-stone patients in Rajasthan to drink more water?

Viva

1. How many nephrons are there in each kidney?
2. Which arteriole enters the glomerulus — afferent or efferent?
3. What is the renal pelvis?

Answer key — MCQs: 1-b, 2-c, 3-b, 4-b, 5-c.

Chapter 8: Functions of the Kidney and Physiology of Urine Formation

Learning Objectives

After studying this chapter, you should be able to:

1. List the functions of the kidney.
2. Describe the three steps of urine formation: filtration, reabsorption, secretion.
3. Explain GFR and the factors affecting it.
4. Describe the role of ADH and aldosterone in urine concentration.
5. Explain why glucose normally does not appear in urine.

8.1 Functions of the kidney — the body's multitasker

Concept. The kidney does far more than make urine.

Simple explanation — the kidney's job list:

1. **Excretion** — removes waste: urea (from protein), creatinine (from muscles), excess salts, drugs and toxins.
2. **Water balance** — keeps body water constant; makes concentrated urine when dehydrated, dilute urine when over-hydrated.
3. **Electrolyte balance** — controls sodium, potassium, calcium, phosphate levels.
4. **Acid–base balance** — keeps blood pH steady (more in Chapter 9).
5. **Blood pressure control** — via the RAAS system (Chapter 9).
6. **RBC production** — secretes **erythropoietin**, a hormone that tells bone marrow to make red blood cells.
7. **Vitamin D activation** — converts vitamin D to its active form for calcium absorption and bone health.

> **Analogy.** The kidney is like a smart municipal corporation: it runs waste disposal (excretion), water supply (water balance), quality control (electrolytes, pH), pressure regulation (BP), and even orders new delivery trucks (RBCs via erythropoietin).

> **Key takeaway.** Kidney = excretion + water/electrolyte/pH balance + BP control + erythropoietin + vitamin D activation.

8.2 Urine formation — three steps

Concept. Urine is made in three steps: **filtration** → **reabsorption** → **secretion**.

Step 1 — Glomerular filtration (in the glomerulus):

- High blood pressure in the glomerular capillaries forces water and small substances (salts, glucose, amino acids, urea, creatinine) through the filter into Bowman's capsule.
- Cells and large proteins are **too big** and stay in blood.
- About **180 litres** of filtrate is formed daily — an enormous amount!

Step 2 — Tubular reabsorption (PCT, loop, DCT, collecting duct):

- Useful substances are taken BACK into blood: **all** glucose and amino acids (in PCT), most water (~99%), sodium, and other needed salts.
- This is why such a huge filtrate (180 L) becomes only ~1.5 L of urine.

Step 3 — Tubular secretion (mainly PCT and DCT):

- Extra waste (H^+, K^+, some drugs, creatinine) is dumped FROM blood INTO the tubule — a second chance to remove what filtration missed.

Flowchart — from blood to urine:

GLOMERULUS: blood filtered → 180 L/day filtrate
(water + salts + glucose + urea + everything small)
↓
PCT: reabsorb ALL glucose, amino acids, ~65% water/salts
↓
LOOP OF HENLE: concentrate — water out (descending), salt out (ascending)
↓
DCT: fine-tune $Na^+/K^+/Ca^{2+}$ (aldosterone acts here)
↓
COLLECTING DUCT: ADH decides final water → concentrated or dilute urine
↓
~1.5 L/day URINE → calyx → pelvis → ureter → bladder

Example. After drinking 2 litres of water at a wedding, your urine becomes pale and copious — ADH is low, so the collecting duct lets water pass out. On a hot day with little water, urine becomes dark yellow and scanty — ADH is high, water is saved.

Terminology Alert

- **GFR (Glomerular Filtration Rate)** = volume of filtrate formed by both kidneys per minute (~125 mL/min in a healthy adult). It is the best measure of kidney function.

- **ADH (antidiuretic hormone)** = "water-saving" hormone from the pituitary; makes collecting ducts permeable to water.

- **Aldosterone** = hormone from the adrenal gland; makes DCT/collecting duct reabsorb Na^+ (and water follows) while secreting K^+.

Key takeaway. Filtration dumps everything small (180 L/day) → reabsorption saves the useful (~99% water, all glucose) → secretion adds extra waste → ~1.5 L urine out.

8.3 Why glucose is normally absent from urine

Concept. All filtered glucose is reabsorbed in the PCT — so normal urine has no glucose.

Simple explanation. The PCT has "pumps" that pull every glucose molecule back into blood. But the pumps have a limit (**transport maximum**). In diabetes, blood glucose is so high that filtered glucose exceeds the pumps' capacity — the extra spills into urine (**glycosuria**). That is why urine testing for sugar was the old diabetes test.

> **Analogy.** The PCT is like a checkout counter that can scan only 100 items per minute — if 150 items arrive (high blood sugar), 50 slip through unscanned into urine.

> **Key takeaway.** Normal: 100% of glucose reabsorbed. Diabetes: filter load exceeds capacity → glucose in urine.

8.4 Countercurrent mechanism (brief, exam-favourite)

Concept. The loop of Henle builds a salty gradient in the medulla that lets the kidney make concentrated urine.

Simple explanation. The descending limb lets water out; the ascending limb pumps salt out but is waterproof. This makes the medulla very salty at the bottom. When ADH opens water channels in the collecting duct, water rushes out toward the salty medulla — producing small volumes of concentrated urine. Without this gradient, we could not survive with limited water.

> **Key takeaway.** Loop of Henle → salty medulla → ADH lets water follow the salt → concentrated urine, water saved.

Pharmacy relevance

- **Diuretics:** thiazides (DCT), loop diuretics (ascending loop of Henle), potassium-sparing (collecting duct) — the nephron map from Chapter 7 explains every diuretic class.
- **GFR and drug dosing:** many drugs (e.g., certain antibiotics) are cleared by the kidney — doses are reduced when GFR falls.
- **Erythropoietin** injections treat anaemia of chronic kidney disease — now you know the kidney normally makes it.

India context

- **Diabetes is widespread in India** — glycosuria and frequent urination are often the first clues; pharmacists refer such customers for blood-sugar testing.
- Heat and dehydration are common — pharmacists counsel on oral rehydration and water intake to protect kidney function.

Common confusions

1. **Filtration vs reabsorption vs secretion** — filtration: blood → capsule (dumping); reabsorption: tubule → blood (saving); secretion: blood → tubule (extra dumping).
2. **ADH vs aldosterone** — ADH saves **water** (collecting duct); aldosterone saves **sodium** (DCT/collecting duct), water follows.
3. **180 L filtrate vs 1.5 L urine** — students think kidneys "make" 180 L of urine; almost all is reabsorbed.

Common mistakes

- Saying glucose is "filtered out as waste" — it is filtered then fully reabsorbed; only excess appears in urine.
- Saying the loop of Henle "makes urine" — it concentrates the filtrate; urine is the final product of all segments.

Mnemonics

- Urine formation: **"FRS"** — **F**iltration, **R**eabsorption, **S**ecretion.
- Kidney jobs: **"WATER-BP"** — **W**aste excretion, w**A**ter balance, elec**T**rolytes, **E**rythropoietin, **R**egulate pH, **B**P control, vitamin D.

One-minute revision

Kidney functions: excretion, water/electrolyte/acid–base balance, BP control, erythropoietin, vitamin D. Urine formation: glomerular filtration (180 L/day, cells/proteins stay back) → tubular reabsorption (all glucose, ~99% water saved) → tubular secretion (extra H^+/K^+/drugs dumped) → ~1.5 L urine. GFR ~125 mL/min measures kidney function. ADH saves water; aldosterone saves sodium. Loop of Henle's salty gradient concentrates urine.

Practice questions

MCQs

1. The three steps of urine formation in order are: a) Secretion, filtration, reabsorption b) Filtration, reabsorption, secretion c) Reabsorption, secretion, filtration d) Filtration, secretion, reabsorption
2. About how much filtrate is formed daily? a) 1.5 L b) 18 L c) 180 L d) 1800 L
3. All filtered glucose is normally reabsorbed in the: a) DCT b) PCT c) Loop of Henle d) Collecting duct
4. ADH mainly causes: a) Sodium loss b) Water reabsorption c) Glucose excretion d) Protein filtration
5. Erythropoietin stimulates production of: a) WBCs b) RBCs c) Platelets d) Plasma proteins

Short-answer (2–3 marks)

1. List any six functions of the kidney.
2. What is GFR? State its normal value and significance.
3. Explain why glucose is absent from normal urine.
4. Differentiate between ADH and aldosterone.

Long-answer (5 marks)

1. Describe the physiology of urine formation with a flowchart. Add a note on the countercurrent mechanism.

Application-based

1. A diabetic patient's urine test shows glucose. Explain the mechanism.
2. Why do doctors reduce the dose of certain antibiotics in kidney-failure patients?

Viva

1. Which substances are NOT filtered at the glomerulus?
2. What happens to urine volume when ADH is high?
3. Name the hormone that regulates sodium reabsorption.

Answer key — MCQs: 1-b, 2-c, 3-b, 4-b, 5-b.

Chapter 9: Micturition Reflex, Acid–Base Balance and RAAS

Learning Objectives

After studying this chapter, you should be able to:

1. Describe the micturition reflex step by step.
2. Explain voluntary control of urination.
3. Describe the kidney's role in acid–base balance (bicarbonate, H^+, ammonia).
4. Draw the RAAS cascade and explain its role in BP and sodium balance.
5. Relate RAAS to antihypertensive drug classes.

9.1 Micturition reflex — how the bladder empties

Concept. Micturition (urination) is a **reflex** — the bladder empties itself automatically when full — but it is under **voluntary control** in adults.

Step by step:

1. **Bladder fills** — as urine collects (~300–400 mL), the bladder wall stretches.
2. **Stretch receptors** in the bladder wall detect the stretch and send signals through pelvic nerves to the **spinal cord** (sacral region) and brain.
3. **Reflex arc** — the spinal cord sends back a signal through **parasympathetic nerves**: the bladder muscle (**detrusor**) contracts, and the **internal urethral sphincter** relaxes.
4. **Urine flows out** — if the brain permits, the **external sphincter** (voluntary, skeletal muscle) relaxes too, and urination occurs.

Voluntary control: In adults, the brain can override the reflex — keeping the external sphincter closed until a suitable time and place (learned during toilet training in childhood). In infants, the reflex is purely automatic (which is why babies wet themselves).

Terminology Alert

- **Detrusor** = the smooth muscle of the bladder wall ("detrude" = push out).

- **Sphincter** = a ring-like muscle guarding an opening. Internal sphincter = involuntary (smooth muscle); external sphincter = voluntary (skeletal muscle).

- **Reflex arc** = automatic loop: sensor → spinal cord → muscle, without needing conscious thought.

Flowchart:

Bladder fills → wall stretches
↓
Stretch receptors → signal to spinal cord (sacral) + brain
↓
Parasympathetic signal back:
• Detrusor contracts • Internal sphincter relaxes
↓
Brain decides: suitable place?
YES → external sphincter relaxes → URINATION
NO → external sphincter stays shut → wait

Analogy. The bladder is like a water tank with a float sensor: when the float rises high enough, an alarm rings (urge to urinate); the tank drains automatically unless you hold the manual valve (external sphincter) shut.

Key takeaway. Stretch → spinal reflex (detrusor contracts, internal sphincter opens) → brain gives final permission via the voluntary external sphincter.

9.2 Role of kidneys in acid–base balance

Concept. Blood pH must stay near 7.4 — even small changes are dangerous. The kidneys are the long-term pH controllers.

Simple explanation. The body constantly produces acids (CO_2 from breathing, acids from food and metabolism). Two systems handle them:

- **Lungs** act fast (minutes): breathe out CO_2 to reduce acid.
- **Kidneys** act slowly but powerfully (hours–days): they **reabsorb bicarbonate (HCO_3^-, the base)** and **secrete hydrogen ions (H^+, the acid)** into urine.

Three kidney mechanisms:

1. **Bicarbonate reabsorption** — the kidney reclaims almost all filtered bicarbonate back into blood (mainly in PCT). Bicarbonate is the body's main base buffer — losing it would make blood acidic.
2. **H^+ secretion** — tubule cells pump excess H^+ into the urine (PCT, DCT, collecting duct), getting rid of acid directly.
3. **Ammonia (NH_3) buffer** — tubule cells make ammonia, which grabs H^+ to form **ammonium (NH_4^+)** that is excreted. This carries away acid without making urine dangerously acidic.

Simple summary: Kidneys keep pH normal by **saving base (bicarbonate)** and **throwing out acid (H^+)**.

Example. In uncontrolled diabetes or severe diarrhoea, the body becomes acidic — the kidneys compensate by excreting more H^+ and making more bicarbonate, over hours to days.

Terminology Alert

- **pH 7.4** = slightly alkaline; the normal pH of blood.

- **Acidosis** = blood too acidic (pH low); **alkalosis** = blood too alkaline (pH high).

Key takeaway. Kidneys defend blood pH by reabsorbing bicarbonate (base) and secreting H^+ (acid), helped by the ammonia buffer.

9.3 RAAS — Renin-Angiotensin-Aldosterone System

Concept. RAAS is the kidney's hormonal system for raising blood pressure and saving sodium/water when BP or blood volume falls.

Simple explanation. When blood pressure drops (e.g., dehydration, blood loss, low salt), special kidney cells (**juxtaglomerular cells**) release an enzyme called **renin**. Renin starts a chain reaction:

The RAAS cascade — draw this as a flowchart:

Low BP / low blood volume / low Na^+
↓
Kidney releases RENIN
↓
Renin converts ANGIOTENSINOGEN (from liver)
→ into ANGIOTENSIN I
↓
ACE (angiotensin-converting enzyme, in lungs)
converts Angiotensin I → ANGIOTENSIN II
↓
ANGIOTENSIN II does THREE things:
1. Constricts blood vessels → BP rises
2. Stimulates ALDOSTERONE release (adrenal gland)
→ kidney reabsorbs Na^+ (water follows) → blood volume rises → BP rises
3. Stimulates ADH + thirst → more water intake/retention
↓
BP and blood volume restored → renin release switches OFF

What each player does (simple words):

Player	Made in	Job
Renin	Kidney (juxtaglomerular cells)	Starts the cascade when BP is low
Angiotensinogen	Liver	Raw material
Angiotensin I	Blood (from renin action)	Intermediate
ACE	Lungs (blood vessels)	Converts I → II
Angiotensin II	Blood	Constricts vessels; releases aldosterone
Aldosterone	Adrenal gland	Kidney saves Na^+ (and water), loses K^+

Analogy. RAAS is like a building's emergency water system: low tank level (low BP) triggers the pump starter (renin) → pipes narrow to keep pressure up (angiotensin II) → valves recycle water back into the tank (aldosterone saving Na^+/water) → tank refills, system switches off.

Key takeaway. Low BP → renin → angiotensin II (vessel constriction + aldosterone → Na^+/water saved) → BP restored. ACE sits in the middle of the chain.

Pharmacy relevance — the biggest exam link

- **ACE inhibitors** (names ending in **-pril**: enalapril, lisinopril) block ACE → less angiotensin II → vessels relax, BP falls. First-line hypertension drugs.
- **ARBs** (names ending in **-sartan**: losartan, telmisartan) block angiotensin II receptors — same pathway, different step.
- **Aldosterone antagonists** (spironolactone) block aldosterone → less Na^+/water retention; also **potassium-sparing** (aldosterone normally wastes K^+).
- **Direct renin inhibitors** (aliskiren) block the very first step.
- Knowing RAAS explains **why** these drug classes lower BP and why ACE inhibitors can raise potassium and cause dry cough (ACE also breaks down bradykinin — build-up causes cough).

India context

- Hypertension is extremely common in India and often uncontrolled — RAAS-blocking drugs (telmisartan, losartan, enalapril) are among the most prescribed medicines in Indian pharmacies.
- Pharmacists counsel hypertensive patients on salt restriction (less salt → less RAAS activation) and adherence.

Common confusions

1. **Angiotensin I vs II** — I is inactive; ACE converts it to active II. Drugs block ACE or II's receptor.
2. **Aldosterone vs ADH** — aldosterone saves **sodium** (water follows); ADH saves **water** directly.
3. **Renin is an enzyme, not a hormone** — it starts the chain but does not travel to a distant target itself.
4. **Micturition: internal sphincter involuntary, external voluntary** — do not swap them.

Common mistakes

- Saying "renin raises BP directly" — renin only starts the cascade; angiotensin II and aldosterone do the work.
- Saying the kidney "makes urine acidic to balance pH" without mentioning bicarbonate reabsorption — both halves matter.
- Forgetting that the brain can override the micturition reflex (voluntary control).

Mnemonics

- RAAS order: **"Real Actors Always Act"** — **R**enin → **A**ngiotensin I → **A**CE → **A**ngiotensin II → aldosterone. Or: **"Renin Raises Angiotensin, Aldosterone Saves salt"**.
- Drug classes on RAAS: **"-pril blocks ACE, -sartan blocks the receptor"**.

One-minute revision

Micturition: bladder stretch → spinal reflex → detrusor contracts + internal sphincter relaxes → brain permits → external (voluntary) sphincter relaxes → urine out. Kidneys keep blood pH ~7.4 by reabsorbing bicarbonate and secreting H^+ (ammonia buffer helps). RAAS: low BP → kidney releases renin → angiotensin I → (ACE in lungs) → angiotensin II → vessel constriction + aldosterone (Na^+/water saved, K^+ lost) → BP restored. Drug targets: ACE inhibitors (-pril), ARBs (-sartan), aldosterone blockers, renin inhibitors.

Practice questions

MCQs

1. The micturition reflex centre is in the: a) Brain only b) Sacral spinal cord c) Kidney d) Bladder wall
2. The detrusor muscle is: a) Bladder wall muscle b) Urethral sphincter c) Kidney muscle d) Ureter muscle
3. Renin is secreted by: a) Liver b) Adrenal gland c) Juxtaglomerular cells of kidney d) Lungs
4. ACE converts: a) Renin to angiotensin b) Angiotensin I to II c) Aldosterone to renin d) ADH to aldosterone
5. Aldosterone causes the kidney to: a) Lose Na^+ b) Reabsorb Na^+ and secrete K^+ c) Excrete water only d) Filter more glucose

Short-answer (2–3 marks)

1. Describe the micturition reflex with a flowchart.
2. How do the kidneys maintain blood pH?
3. Draw the RAAS cascade.
4. Name two drug classes acting on RAAS with one example each.

Long-answer (5 marks)

1. Describe the micturition reflex and the role of kidneys in acid–base balance. Draw and explain the RAAS cascade with its pharmacological importance.

Application-based

1. Why do ACE inhibitors (e.g., enalapril) lower blood pressure? Explain using RAAS.
2. A patient on spironolactone is warned about high potassium foods. Why?

Viva

1. Which sphincter is voluntary in urination?
2. What is the normal pH of blood?
3. Where is ACE mainly found?

Answer key — MCQs: 1-b, 2-a, 3-c, 4-b, 5-b.

Chapter 10: Pathophysiology of Renal Failure and Urinary Tract Infections

Learning Objectives

After studying this chapter, you should be able to:

1. Define acute and chronic renal failure in simple words.
2. Classify acute renal failure (pre-renal, intra-renal, post-renal) with examples.
3. Describe what goes wrong in chronic renal failure and its general features.
4. Explain urinary tract infections — causes, types, general features.
5. State pharmacy relevance: drug dosing in kidney disease, UTI counselling, referral.

10.1 What is renal failure?

Concept. Renal failure = the kidneys can no longer filter blood and balance water/salts adequately.

Simple explanation. When kidneys fail, waste (urea, creatinine) builds up in blood, water and salts go out of balance, and acid accumulates. There are two very different forms:

- **Acute renal failure (ARF)** — sudden loss of kidney function over hours to days. Often **reversible** if the cause is treated quickly.
- **Chronic renal failure / chronic kidney disease (CKD)** — slow, progressive, **irreversible** loss over months to years, often from diabetes or long-standing hypertension.

> **Analogy.** ARF is like a factory suddenly shut by a power cut — restore power and it restarts. CKD is like a factory whose machines have slowly rusted away over years — it cannot be rebuilt.

> **Key takeaway.** Acute = sudden, often reversible. Chronic = gradual, irreversible.

10.2 Acute renal failure — three types by cause

Type	Where is the problem?	Examples	Simple logic
Pre-renal	BEFORE the kidney — not enough blood reaching it	Severe dehydration, blood loss, heart failure, very low BP	"No water reaching the filter"
Intra-renal	WITHIN the kidney — kidney tissue damaged	Toxins/drugs, severe infection, glomerular disease, blocked small vessels	"The filter itself is broken"
Post-renal	AFTER the kidney — urine cannot drain out	Kidney stones blocking ureter, enlarged prostate blocking urethra, tumours	"The outlet pipe is blocked"

What goes wrong (general): GFR falls sharply → urine output drops (**oliguria** — very little urine) or stops (**anuria**) → urea/creatinine rise in blood → potassium rises (dangerous for the heart) → fluid overload, swelling, breathlessness → blood becomes acidic.

> **Terminology Alert**

- **Oliguria** = very low urine output.

- **Anuria** = almost no urine output.

- **Azotaemia** = build-up of nitrogen waste (urea) in blood.

- **Uraemia** = the clinical syndrome of kidney failure (waste build-up causing symptoms).

Key takeaway. ARF: find WHERE the problem is (before / within / after the kidney) — pre-renal is the most common and often reversible with fluids.

10.3 Chronic renal failure (CKD)

Concept. Progressive, irreversible loss of nephrons over months–years; remaining nephrons overwork until they too fail.

Common causes: long-standing **diabetes** (diabetic nephropathy — the leading cause), long-standing **hypertension**, chronic glomerular disease, polycystic kidney disease.

What goes wrong (general, as nephrons are lost):

1. Waste accumulates — urea, creatinine rise; patient feels nauseous, itchy, fatigued.
2. Water/salt imbalance — swelling (oedema), high BP worsens.
3. Potassium rises — risk of heart rhythm problems.
4. Acid builds up — kidneys cannot excrete H^+ or make bicarbonate.
5. Anaemia — less **erythropoietin** → fewer RBCs → fatigue, pallor.
6. Bone problems — vitamin D not activated → calcium/phosphate imbalance → weak bones.
7. In advanced stages, **dialysis** (artificial filtering of blood) or **kidney transplant** is needed to survive.

General clinical features: fatigue, loss of appetite, nausea, itching, swelling of feet/face, reduced urine, breathlessness, pale skin (anaemia).

Analogy. CKD is like a team where players keep retiring one by one — the remaining players cover extra ground until they collapse too; eventually you need substitute players from outside (dialysis machine).

Key takeaway. CKD = slow irreversible nephron loss (diabetes/hypertension top causes) → waste build-up, anaemia (no erythropoietin), bone disease, eventually dialysis/transplant.

10.4 Urinary tract infections (UTIs)

Definition. Infection of any part of the urinary tract by microorganisms — most commonly **bacteria** (especially *E. coli* from the gut) entering through the urethra.

Types by location:

- **Lower UTI — cystitis** (bladder infection): burning during urination, frequent urge, cloudy/foul-smelling urine, lower abdominal discomfort.
- **Upper UTI — pyelonephritis** (kidney infection): fever, back/flank pain, nausea — more serious; needs prompt treatment.

Why it happens:

- Bacteria (usually from the anal region) travel **up the urethra** — shorter female urethra = higher risk.
- Incomplete bladder emptying, holding urine too long, poor hygiene, kidney stones, enlarged prostate (in men), diabetes (sugar in urine feeds bacteria), urinary catheters.

General clinical features: burning/pain on urination (**dysuria**), frequent urge with little urine, cloudy or strong-smelling urine, lower belly pain; with fever and back pain — suspect kidney involvement → refer urgently.

Terminology Alert

- **Cystitis** = bladder inflammation/infection.

- **Pyelonephritis** = kidney infection ("pyelo" = pelvis of kidney).

- **Dysuria** = painful/burning urination.

- **Bacteriuria** = bacteria in urine.

Prevention (pharmacist counselling points): drink adequate water, do not hold urine long, maintain personal hygiene (wipe front to back), urinate after intercourse, complete the full prescribed antibiotic course.

Key takeaway. UTIs = usually *E. coli* ascending the urethra; cystitis (bladder) is common, pyelonephritis (kidney, with fever/back pain) is serious — complete the full medicine course.

10.5 Comparison table — ARF vs CKD

Feature	Acute renal failure	Chronic renal failure
Onset	Hours to days	Months to years
Reversibility	Often reversible	Irreversible, progressive
Common causes	Dehydration, blood loss, toxins, obstruction	Diabetes, hypertension
Urine output	Often very low (oliguria)	May be normal until late
Anaemia/bone disease	Not prominent early	Prominent (low erythropoietin, vitamin D)
Treatment focus	Treat the cause urgently	Slow progression; dialysis/transplant in end stage

Pharmacy relevance

- **Drug dosing in kidney disease:** many drugs and their doses must be reduced when kidneys fail (they accumulate → toxicity). Pharmacists check creatinine/urea reports and flag dosing.
- **Nephrotoxic drugs:** some medicines (certain painkillers/NSAIDs, some antibiotics) can harm kidneys — pharmacists counsel on safe use, hydration, and avoiding self-medication.
- **UTI counselling:** encourage fluids, hygiene, and FULL antibiotic course completion; refer urgently if fever + back pain (possible pyelonephritis) or in pregnancy.
- **Dialysis patients:** take medicines at the right time around dialysis; pharmacists coordinate with the dialysis schedule.

India context

- **Diabetes + hypertension** drive most CKD in India — controlling sugar and BP is the main prevention, and pharmacists reinforce adherence at every refill.
- UTIs are among the most common reasons for antibiotic prescriptions in India — pharmacists discourage incomplete courses and self-medication, which breed resistance.
- Dehydration-related kidney injury is seen in Indian summers among outdoor workers — pharmacists promote oral rehydration.

Common confusions

1. **ARF vs CKD** — sudden/reversible vs gradual/irreversible. Do not mix them.
2. **Cystitis vs pyelonephritis** — bladder (lower, less serious) vs kidney (upper, fever + back pain, urgent).
3. **Azotaemia vs uraemia** — azotaemia = lab finding (waste in blood); uraemia = the clinical illness from it.
4. **Pre/intra/post-renal** — before the kidney / in the kidney / after the kidney.

Common mistakes

- Saying "kidney failure means no urine at all" — many patients still pass urine; the problem is inadequate filtration.
- Saying UTIs come from "dirty water" — most come from the patient's own gut bacteria ascending the urethra.
- Advising extra water to "flush" a suspected kidney infection with fever and back pain instead of urgent referral.

Mnemonics

- ARF causes: **"BWT — Before, Within, aFter (ouT)"** — **B**efore (pre-renal: blood supply), **W**ithin (intra-renal: tissue), **T** (post-renal: ou**T**flow blocked).
- CKD causes: **"Diabetes & Hypertension Destroy Kidneys"** — the two leading causes.

One-minute revision

ARF = sudden (hours–days), often reversible; causes classified pre-renal (poor blood supply), intra-renal (tissue damage), post-renal (blocked outflow) — waste builds up, urine falls, K^+ rises. CKD = slow irreversible nephron loss, mainly from diabetes and hypertension → uraemia, anaemia (no erythropoietin), bone disease → dialysis/transplant. UTI = usually *E. coli* up the urethra; cystitis (burning, frequency) vs pyelonephritis (fever, back pain — urgent). Pharmacist: dose adjustment in kidney disease, avoid nephrotoxins, UTI counselling + full course, urgent referral red flags.

Practice questions

MCQs

1. Acute renal failure is best described as: a) Gradual irreversible loss b) Sudden, often reversible loss of function c) Bladder infection d) Kidney stone
2. Pre-renal failure is caused by: a) Ureter stone b) Severe dehydration reducing blood flow to kidney c) Glomerular damage d) Prostate enlargement
3. The leading causes of chronic kidney disease are: a) TB and malaria b) Diabetes and hypertension c) Asthma and COPD d) Anaemia and jaundice
4. Pyelonephritis is infection of the: a) Bladder b) Kidney c) Urethra d) Ureter only
5. UTIs are more common in females mainly because: a) Weaker immunity b) Shorter urethra c) Larger bladder d) More water intake

Short-answer (2–3 marks)

1. Classify acute renal failure with one example of each type.
2. Differentiate between acute and chronic renal failure.
3. What is the difference between cystitis and pyelonephritis?
4. List the general clinical features of chronic renal failure.

Long-answer (5 marks)

1. Define renal failure. Describe the types of acute renal failure and the pathophysiology and clinical features of chronic renal failure. Add a note on urinary tract infections.

Application-based

1. A patient with chronic kidney disease is prescribed a normal dose of an antibiotic cleared by the kidney. What is the risk, and what should the pharmacist do?
2. A woman reports burning urination and frequency for 2 days, no fever. Another reports the same plus high fever and back pain. How does your advice differ?
3. Why should NSAID painkillers be used cautiously in elderly patients with kidney problems?

Viva

1. What is oliguria?
2. Why does CKD cause anaemia?
3. What is the most common organism causing UTI?

Answer key — MCQs: 1-b, 2-b, 3-b, 4-b, 5-b.

UNIT III INFOGRAPHIC — RESPIRATORY & URINARY SYSTEMS AT A GLANCE

System	Core structure	Core process	High-yield disease link
Respiratory tract	Nose → pharynx → larynx → trachea → bronchi → bronchioles → alveoli	O_2 enters blood and CO_2 leaves at the alveoli	Asthma = reversible airway narrowing; COPD = persistent obstruction; TB = infectious granulomatous lung disease
Breathing mechanics	Diaphragm + intercostal muscles	Volume up → pressure down → air in; volume down → pressure up → air out	Respiratory-centre depression can slow or stop breathing
Gas transport	Haemoglobin + bicarbonate system	O_2 mainly as oxyhaemoglobin; CO_2 mainly as bicarbonate	Anaemia reduces oxygen-carrying capacity
Urinary tract	Kidneys → ureters → bladder → urethra	Filtration → reabsorption → secretion → urine	ARF is sudden and often reversible; CKD is gradual and irreversible
Nephron	Glomerulus + renal tubule + collecting duct	Forms urine and controls water, salts and acid-base balance	Loss of nephrons causes waste, fluid, electrolyte and acid accumulation
RAAS	Renin → angiotensin II → aldosterone	Raises BP by vasoconstriction + salt/water retention	Overactive RAAS contributes to hypertension and CKD progression

High-yield chain: Air reaches alveoli → gases exchange with blood → blood delivers oxygen to tissues → kidneys filter the blood → nephrons adjust water, salts and acid → urine carries wastes out.

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