Chapter 11. Respiratory System

Part 1 | Anatomy of the Respiratory Tract & Lungs

1 Learning Objectives

After studying this part you will be able to …

1. **Identify all structures of the upper and lower respiratory tracts,** listing their histological specialisations and functional roles.
2. **Describe the gross and microscopic anatomy of the lungs,** including lobes, segments, pleurae and the bronchial tree.
3. **Explain the mechanics of ventilation and gas exchange** in relation to airway and alveolar structure.
4. **Relate respiratory anatomy to common physiotherapy applications** such as airway-clearance techniques, breathing retraining and postural drainage.

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2 Upper vs. Lower Respiratory Tract

Level	Structures	Epithelial Lining	Primary Functions	PT Significance
Upper	• **Nose & Nasal cavity** • Paranasal sinuses • **Pharynx:** Nasopharynx, Oropharynx, Laryngopharynx • **Larynx** (to vocal folds)	Mostly **pseudostratified ciliated columnar** with goblet cells; oropharynx—stratified squamous	Filtration, humidification, warming; resonance & phonation	Teach nasal-breathing to enhance humidification; voice conservation post-laryngeal surgery
Lower	**Trachea → Primary bronchus → Bronchial tree → Alveoli**	Gradual transition: ciliated columnar → cuboidal → **simple squamous (Type I pneumocytes)**	Air conduction, mucociliary clearance, gas exchange	Manual percussion aligns with segmental bronchi; pursed-lip breathing targets small airways

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3 Airway Anatomy in Detail

3.1 Conducting Zone (Dead-Space Airway)

Generation	Key Features	Cartilage?	Smooth Muscle?
Trachea	~11 cm; C-shaped hyaline rings; carina at T4/5	✓ "C" rings	Few
Main (Primary) Bronchi	Right wider, shorter & more vertical (aspiration risk)	✓ Plates	↑
Lobar (Secondary) Bronchi	3 on right, 2 on left	✓ Plates	↑↑
Segmental (Tertiary) Bronchi	10 segments (R), 8–10 (L)	✓ Plates	↑↑
Bronchioles (< 1 mm)	No cartilage; clara/club cells secrete surfactant-like fluid	✗	✓✓
Terminal Bronchioles	End of conducting zone; last with cilia	✗	✓✓

3.2 Respiratory Zone

Structure	Function	Clinical Note
Respiratory bronchioles	Start of gas exchange; occasional alveoli in walls	Site of early emphysematous change
Alveolar ducts & sacs	Lined almost entirely by alveoli	Postural drainage positions target these segments

Structure	Function	Clinical Note
Alveoli (≈ 300 million)	Type I cells for diffusion; Type II produce surfactant; alveolar macrophages for defence	Surfactant deficiency → neonatal RDS; incentive spirometry prevents collapse

4 Gross Lung Anatomy

Aspect	Right Lung	Left Lung	Functional Angle
Lobes	3 – Superior, Middle, Inferior	2 – Superior, Inferior	Right middle lobe drains best in left side-lying
Fissures	Oblique + Horizontal	Oblique only	Auscultation landmarks for segmental percussion
Bronchopulmonary Segments	10	8–10	Surgical resection units; PT can isolate by positioning
Hilum Contents	Pulmonary artery (anterior), veins (inferior), main bronchus (posterior)	Artery superior to bronchus	Endotracheal suction depth awareness
Pleurae	**Visceral** (adheres to lung) + **Parietal** (thoracic cavity) with potential space	Pain from parietal only (phrenic/intercostal nerves)	Educate splinted breathing for pleuritic pain

Neurovascular Supply

- **Bronchial arteries** (systemic) nourish lung tissue; pulmonary arteries carry deoxygenated blood for gas exchange.
- **Parasympathetic (vagus) → bronchoconstriction / mucus ↑**; **Sympathetic → bronchodilation / mucus ↓** — basis for inhaler pharmacology.

5 Mechanics of Ventilation (Quick Recap)

- **Inspiration:** Diaphragm (75 %) + external intercostals enlarge thoracic volume → intrapleural pressure falls from −2 to −6 mm Hg → lungs expand.
- **Expiration:** Passive recoil (quiet); abdominal & internal intercostals (forced).
- **Compliance (ΔV/ΔP)** highest at FRC; fibrosis ↓ compliance, emphysema ↑ compliance – exercise prescription differs.

6 Structure–Function–Clinical Correlations

Anatomy Feature	Physiological Benefit	PT Application
Mucociliary escalator (goblet + cilia)	Clears particles 5–10 µm	Flutter device & active cycle of breathing aid clearance
Right main bronchus vertical	Facilitates aspiration	Side-lying right 30° post feeding in neuro-patients
Segmental anatomy	Localises infection / collapse	Specific postural drainage + manual techniques
Type II pneumocytes	Surfactant reduces surface tension	Deep-breathing exercises recruit surfactant release
Pleural recesses	Costodiaphragmatic recess drains fluid	Thoracic expansion exercises promote re-expansion post-thoracentesis

7 Self-Check Quiz (with Answers)

1. **Which airway generation marks the end of cartilage and the start of substantial smooth muscle?**

Answer: Bronchioles (following segmental bronchi).

2. **Name the only pain-sensitive layer of the lung's pleural covering.**
   Answer: Parietal pleura.
3. **Why is the right lung more prone to aspiration pneumonia?**
   Answer: The **right main bronchus** is wider, shorter, and more vertical than the left, so aspirated material follows gravity into right lower lobe segments.
4. **Which cells produce pulmonary surfactant and what is one physiotherapy technique that can stimulate its distribution?**
   Answer: Type II pneumocytes; deep-breathing / incentive spirometry promotes surfactant spread.
5. **During quiet breathing, what percentage of the tidal volume is contributed by the diaphragm?**
   Answer: Approximately **75 %.**

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8 Suggested Lab / Practical Activities

Activity	Outcome
Airway Model Dissection	Trace trachea to alveoli; identify histological changes with hand-lenses.
Lung-Segment Positioning Drill	Students place peers in correct drainage postures for each segment.
Spirometry & Flow-Volume Loop Lab	Correlate obstructive vs restrictive patterns with anatomical sites.
Cilia Beat Experiment (video microscopy)	Visualise mucociliary action; discuss impact of smoking.

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9 Key Take-Home Points

- The respiratory tract transitions from **rigid, cartilage-supported conduits to delicate gas-exchange membranes;** each segment has distinct vulnerabilities and therapeutic targets.
- **Bronchopulmonary segments** permit selective physiotherapy techniques, surgical resections, and precise auscultation.
- **Understanding pleural anatomy** aids in managing pain, preventing atelectasis, and guiding breathing exercises.
- Physiotherapists leverage airway structure knowledge to design **airway-clearance, breathing retraining, and positioning protocols** tailored to pathology.

Part 2 | Mechanics of Breathing, Gas Exchange & Applied Physiology

1 • Learning Objectives

After completing this part you should be able to …

1. **List all primary and accessory muscles of inspiration and expiration,** their origins/insertions, nerve supply and kinesiologic actions.
2. **Explain the pressure-volume relationships** (Boyle's law) that drive airflow during quiet and forced ventilation.
3. **Define static and dynamic lung volumes and capacities,** and relate them to spirometric patterns in obstructive vs restrictive disease.
4. **Describe alveolar–capillary gas exchange** using Fick's law, including diffusion-limitation vs perfusion-limitation concepts.
5. **Outline oxygen and carbon-dioxide transport mechanisms** (Hb dissociation curve, Haldane & Bohr effects).
6. **Apply these principles clinically** to breathing retraining, airway-clearance, positioning and exercise prescription.

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2 • Respiratory Muscles

Group	Muscles	Origin → Insertion	Innervation	Phase & Action	PT Relevance
Primary Inspiratory	**Diaphragm**	Sternum, lower 6 ribs, L1–L3 crura → central tendon	C3–5 phrenic	Quiet inspiration (75 % tidal volume) – dome descends 1.5 cm	Diaphragmatic breathing retrains efficient pattern; C-spine injury ≥ C3 threatens ventilation
	External intercostals	Inferior border rib n → superior border rib n+1	T1–T11 intercostals	Bucket-handle & pump-handle rib lift	Segmental expansion cue (“sniff test”)
Accessory Inspiratory (recruited during exertion/obstruction)	SCM, scalenes, upper trap, serratus anterior/posterior, pectoralis minor/major (fixed arms), erector spinae	Various	CN XI, C2–8	Elevate sternum/ribs, extend spine	Overactivity → apical breathing; manual facilitation in spinal cord lesions
Quiet Expiratory	— (passive elastic recoil)	—	—	—	Loss of recoil in emphysema prolongs expiration – pursed-lip breathing slows collapse
Forced Expiratory	Internal intercostals, **abdominals** (rectus, obliques, transversus), serratus posterior inferior		T6–L1 ventral rami	Compress thorax, ↑ intra-abdominal pressure	Huff & cough techniques require strong abs; abdominal binder in high SCI

3 • Ventilatory Mechanics

3.1 Pressure Dynamics (Quiet Breathing)

- **End-expiration:** Intra-alveolar (P_A) = atmospheric (P_B), trans-pulmonary (P_TP = P_A − P_pl) ≈ +4 cm H_2O holds lungs open.
- **Inspiration:** Diaphragm ↓ → intrapleural (P_pl) drops to ~ −6 cm H_2O → P_A falls ~ −2 cm H_2O → air flows in until P_A = P_B.
- **Expiration:** Relax → P_pl rises, elastic recoil ↑ P_A to +2 cm H_2O → air flows out.

3.2 Lung Volumes & Capacities

Static volume	Avg adult (m)	Description	Clinical Interpretation
Tidal Volume (VT)	500 mL	Quiet breath in/out	↓ in pain, neuromuscular weakness
Inspiratory Reserve (IRV)	3000 mL	Max extra inspiration	↓ in restrictive disease
Expiratory Reserve (ERV)	1100 mL	Max extra expiration	↓ in COPD (air-trapping)
Residual Volume (RV)	1200 mL	Air never exhaled	↑ in emphysema
Vital Capacity (VC = VT+IRV+ERV)	4600 mL	Max movable air	Measured in spirometry
Total Lung Capacity (TLC)	5800 mL	VC + RV	↑ in hyperinflation; ↓ fibrosis

- **FEV_1 / FVC ratio** < 70 % = obstruction; normal/high with ↓ volumes = restriction.

4 • Gas Exchange Physiology

4.1 Alveolar-Capillary Diffusion

Fick's Law: V˙gas=A·D·(P1−P2)/T\dot{V}_{gas}=A·D·(P_1−P_2)/TV˙gas=A·D·(P1−P2)/T

- A = 70 m²; T ≈ 0.5 µm; D depends on solubility (CO_2 × 20 > O_2).

O_2:

- Alveolar PO_2 ≈ 100 mm Hg → arterial 95 mm Hg.
  CO_2:
- Alveolar PCO_2 ≈ 40 mm Hg → venous 46 mm Hg.

Diffusion-limited (e.g., CO, fibrosis); **perfusion-limited** (O_2, CO_2). Exercise ↑ cardiac output → perfusion-limitation more prominent.

4.2 Ventilation–Perfusion (V/Q) Matching

- Ideal V/Q ≈ 0.8 (4 L air / 5 L blood min^{-1}).
- **Apices:** V/Q > 1 (dead-space like) – ↑ PAO_2, ↓ $PACO_2$.
- **Bases:** V/Q < 0.6 (shunt-like) – ↓ PAO_2, ↑ $PACO_2$.
- Therapeutic positioning (e.g., unilateral lung disease) places healthier lung **down** to optimise V/Q.

4.3 Oxygen & CO_2 Transport

Mode	%	Mechanism	Clinically Relevant Curve
O_2 bound to Hb	98.5 %	1.34 mL O_2 · g^{-1} Hb; SaO_2 curve (sigmoid)	**Bohr shift:** ↑ CO_2, ↑ H^+, ↑ temp, ↑ 2,3-DPG → curve right (unloading)
O_2 dissolved	1.5 %	0.003 mL · dL^{-1} · mm Hg^{-1}	Basis of P_aO_2 reading — hypoxemia if < 80 mm Hg
CO_2 dissolved	10 %	Direct plasma solution	Hyperventilation ↓ $PaCO_2$
Carbamino-Hb	20 %	Binds globin	**Haldane effect:** O_2 unloading ↑ CO_2 carriage
Bicarbonate (HCO_3^-)	70 %	Carbonic anhydrase in RBC	Respiratory acidosis/alkalosis management

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5 • Structure–Function–Clinical Correlations

Phenomenon	Anatomical Basis	Physiotherapy Note
Diaphragmatic descent increases vertical thoracic diameter	Central tendon anchored to pericardium → can affect venous return	Abdominal breathing aids venous return in HF
Bucket-handle rib motion widens transverse diameter	External intercostals pivot on costotransverse joints	Lateral costal expansion cue post-thoracotomy
Collateral ventilation (pores of Kohn) opens at deep breaths	Alveolar pores / canals of Lambert	Incentive spirometry prevents atelectasis
Dynamic airway compression during forced expiration	Intrapleural pressure exceeds airway pressure distal to equal-pressure point	COPD teach pursed-lip breathing to move EPP distally and keep airways splinted

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6 • Self-Check Quiz (Answers below)

1. **Which abdominal muscle is most active during a forceful cough?**
2. **Explain why FEV_1 is reduced more than FVC in obstructive disease.**
3. **What positional strategy improves oxygenation in unilateral pneumonia and why?**
4. **Describe the Bohr effect in simple terms.**
5. **During vigorous exercise, which variable—diffusing capacity or cardiac output—limits arterial O_2 content first in a healthy adult?**

Answers

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1. **Rectus abdominis** (with internal oblique) generates high intra-abdominal pressure.
2. **Airflow limitation** (small-airway collapse) prolongs expiration, so the volume exhaled in first second (FEV_1) drops disproportionately compared with total exhaled volume (FVC).
3. **"Good lung down"**—placing healthy lung in the dependent position maximises perfusion matching to better-ventilated alveoli through gravity-directed blood flow.
4. Rising **CO_2/H^+ shifts the haemoglobin-O_2 dissociation curve right**, enabling easier O_2 unloading to tissues.
5. **Cardiac output/perfusion** becomes limiting; diffusing capacity rises (recruitment) and usually exceeds demand in healthy lungs.

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7 • Suggested Practical / Lab Activities

Activity	Skill Gained
Surface EMG of respiratory muscles during quiet vs pursed-lip breathing	Muscle recruitment analysis
Spirometry workshop – perform, interpret FVC, FEV_1, MVV	Identify obstructive vs restrictive patterns
Incentive-spirometer & flow-volume loop simulation	Teach patient coaching cues
Blood-Gas Case Scenarios	Diagnose respiratory vs metabolic acidosis, devise breathing strategies

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8 • Key Take-Home Points

- **Diaphragm dominates quiet inspiration;** accessory muscles signal increased load or dysfunction.
- **Breathing mechanics hinge on pressure gradients** created by thoracic and abdominal muscle action plus lung compliance.
- **Gas exchange efficiency depends on intact alveolar-capillary membrane, optimal V/Q matching and Hb capacity.**
- Physiotherapists manipulate **positioning, breathing patterns, airway-clearance techniques and exercise intensity** to optimise these variables across a wide spectrum of cardiorespiratory conditions.

Part 3 | Common Respiratory Disorders — Asthma, COPD & Pneumonia

1 Learning Objectives

By the end of this part you should be able to …

1. **Describe the pathophysiology, hallmark clinical signs, and diagnostic criteria** for bronchial asthma, chronic obstructive pulmonary disease (COPD), and pneumonia.
2. **Differentiate obstructive from restrictive spirometry patterns** and recognise red-flag features that warrant urgent referral.
3. **Outline evidence-based physiotherapy interventions**—airway-clearance, breathing retraining, exercise prescription, and patient education—for each disorder.
4. **Apply infection-control and safety precautions** relevant to acute respiratory infections.

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2 Disorder Snapshots

Feature	Asthma	COPD (Chronic Bronchitis &/or Emphysema)	Pneumonia

Feature	Asthma	COPD (Chronic Bronchitis &/or Emphysema)	Pneumonia
Core Pathology	Chronic airway inflammation → hyper-responsiveness, reversible bronchoconstriction	Progressive, largely irreversible airflow limitation; chronic inflammation + parenchymal destruction	Acute infection of distal airways & alveoli (bacterial, viral, fungal)
Key Triggers / Risks	Allergens, exercise, cold air, irritants, viral URTI	Tobacco smoke, biomass fuel, pollution, α-1 antitrypsin deficiency	Age < 5 /> 65, chronic disease, aspiration, immobility
Typical Symptoms	Episodic wheeze, cough (night/early AM), chest tightness, prolonged expiration	Chronic cough, sputum, exertional dyspnoea, wheeze, weight loss	Fever, productive cough, pleuritic pain, dyspnoea, fatigue
Spirometry	Obstructive; $FEV_1/FVC < 70$ % but **reversibility > 12 % & 200 mL** post-bronchodilator	Obstructive; $FEV_1/FVC < 70$ % with **< 12 % reversibility**	Often restrictive (↓ VC) + diffusion defect during acute phase
Radiology	Usually normal or hyper-inflated on attack	Hyper-inflation, flattened diaphragm, bullae	Lobar/segmental consolidation or interstitial pattern
Blood Gases	Mild hypoxemia during attack; $PaCO_2$ ↓ or normal	Chronic compensated hypercapnia; hypoxemia	Hypoxemia ± hypercapnia depending on severity
Clinical Red Flags	Silent chest, $SpO_2 < 90$ %, PEFR < 33 % predicted	Acute exacerbation with drowsiness, cyanosis, RR > 30	Rapid RR > 30, $SpO_2 < 92$ % on air, sepsis criteria

3 Physiotherapy Management Framework

Stage	Asthma	COPD	Pneumonia
Acute (exacerbation / hospitalization)	• High-Fowler position. • Teach **pursed-lip breathing** (PLB). • Gentle thoracic expansion with hold for collateral ventilation. • Short bouts of UL supported positioning (tripod).	• PLB + **paced breathing** with activity. • **Active Cycle of Breathing Technique (ACBT)** avoiding fatigue. • Early mobilisation (sit ↔ stand).	• Ensure adequate **oxygen therapy** & SpO_2 monitoring. • **Thoracic expansion exercises** to improve ventilation. • **Supported cough / huff** to clear secretions; splint incision if post-op. • Mobilise as tolerated to prevent deconditioning.
Sub-acute / Stable	• Identify triggers; breathing retraining (diaphragmatic, nasal). • Aerobic training 3–5 $d \cdot wk^{-1}$, 40–60 % HRR. • Inspiratory muscle training (IMT) if reduced PImax. • Patient education: inhaler technique, PEFR diary.	• **Pulmonary rehabilitation** 6–12 wk: endurance + strength (upper & lower limb), IMT. • Postural drainage & manual techniques for chronic bronchitis. • Energy-conservation and pacing strategies. • Education: smoking cessation, nutrition, vaccine update.	• Gradual re-conditioning post-infection; monitor for desaturation. • Segmental breathing + incentive spirometry to prevent atelectasis. • Airway-clearance if residual sputum. • Education on hydration and early mobilisation.
Long-term Goals	Symptom-free daily life; maintain airway health; prevent remodeling.	Slow decline of FEV_1; ↓ hospitalisations; enhance QOL.	Restore premorbid function; prevent recurrence / complications (VTE, de-conditioning).

4 Key Physiological Concepts for PT Intervention

1. **Dynamic Hyperinflation (COPD):**
   Air-trapping ↑ end-expiratory lung volume → flattened diaphragm & ↓ inspiratory capacity.
   PLB & interval training allow longer expiratory time & ↓ hyperinflation.
2. **Asthmatic Airway Resistance:**
   Bronchospasm + mucus plugs narrow radius (Poiseuille: $R \propto 1/r^4$).

Bronchodilator use + warm-up can attenuate exercise-induced bronchoconstriction.

3. **V/Q Mismatch in Pneumonia:**
   Consolidated alveoli perfused but not ventilated → shunt.
   *Position with affected lung **uppermost** to improve overall V/Q.*
4. **Oxygen–Hb Dissociation (Acute Exacerbation):**
   ↑ CO_2 + ↓ pH shift curve right (Bohr), aiding O_2 unloading but risking hypoxemia.
   Controlled O_2 (target 88–92 %) in COPD prevents CO_2 narcosis.

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5 Red-Flag Decision Tree for the Physio

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pgsqlCopyEditSevere SOB + SpO₂ < 88 % on air?
           │
           ├── YES → Immediate O₂, medical review.
           │
           └── NO
                │
     Productive cough + fever + HR > 125?
                │
                ├── YES → Rule out pneumonia / sepsis.
                └── NO
                     │
          PEFR < 33 % predicted (Asthma only)?
                     │
                     ├── YES → ER referral for status asthmaticus.
                     └── Continue with cautious treatment & monitor.
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6 Self-Check Quiz (answers below)

1. **What spirometric criterion distinguishes reversible airway obstruction in asthma from COPD?**
2. **Why might administering high-flow oxygen (FiO_2 > 0.4) to a patient with chronic hypercapnic COPD precipitate CO_2 retention?**
3. **State two breathing-control strategies useful during an acute asthmatic attack.**
4. **Which lung segments are most prone to aspiration pneumonia when a supine patient aspirates, and how would you position them for drainage?**
5. **List three absolute contraindications to chest percussion.**

Answers

1. A **post-bronchodilator increase in FEV_1 ≥ 12 % and ≥ 200 mL** denotes reversibility typical of asthma.
2. High FiO_2 suppresses the **hypoxic respiratory drive** and worsens V/Q mismatch by reversing hypoxic pulmonary vasoconstriction, leading to **CO_2 narcosis**.
3. **Pursed-lip breathing, forward-leaning with arm support ("tripod"),** controlled diaphragmatic breathing.
4. **Posterior segments of upper lobes and superior segments of lower lobes**; position patient in **prone with head-down 15–30°** to drain these areas.
5. **Undrained pneumothorax, severe osteoporosis, rib fracture, unstable haemodynamics,** or **recent thoracic surgery incision** without clearance.

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7 Key Take-Home Points

- **Asthma is reversible; COPD is progressive and largely irreversible; pneumonia is infectious.** Each requires distinct but overlapping PT strategies.

- **Accurate assessment (vitals, spirometry, auscultation)** enables safe progression of therapy and early recognition of exacerbations.
- **Breathing retraining, airway-clearance, targeted positioning, and exercise** are cornerstone interventions—tailored to pathophysiology and patient tolerance.
- Red-flag knowledge and timely referral are critical for patient safety.