

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.
- 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.

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

3 Airway Anatomy in Detail

3.1 Conducting Zone (Dead-Space Airway)

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

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

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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		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?

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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.

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- 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.
- During quiet breathing, what percentage of the tidal volume is contributed by the diaphragm?
 Answer: Approximately 75 %.

8 Suggested Lab / Practical Activities

Activity Outcome

Airway Model DissectionTrace trachea to alveoli; identify histological changes with hand-lenses.Lung-Segment Positioning DrillStudents place peers in correct drainage postures for each segment.Spirometry & Flow-Volume Loop LabCorrelate obstructive vs restrictive patterns with anatomical sites.

Cilia Beat Experiment (video microscopy) Visualise mucociliary action; discuss impact of smoking.

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.

2 • Respiratory Muscles

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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)	_	- 6	-	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, 1 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_pI) ≈ +4 cm H₂O holds lungs open.
- Inspiration: Diaphragm \downarrow \rightarrow intrapleural (P_pl) drops to \sim -6 cm H₂O \rightarrow P_A falls \sim -2 cm H₂O \rightarrow air flows in until P A = P B.
- Expiration: Relax → P_pl rises, elastic recoil ↑ P_A to +2 cm H₂O → 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; \downarrow fibrosis

• FEV1 / FVC ratio < 70 % = obstruction; normal/high with \downarrow volumes = restriction.

4 • Gas Exchange Physiology

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4.1 Alveolar-Capillary Diffusion

Fick's Law: V° gas= $A \cdot D \cdot (P1-P2)/T \cdot dot\{V\}_{gas}=A \cdot D \cdot (P_1-P_2)/T \cdot gas=A \cdot D \cdot (P1-P2)/T$

• A = 70 m²; T \approx 0.5 μ m; D depends on solubility (CO₂ × 20 > O₂).

O2:

- Alveolar PO₂ ≈ 100 mm Hg → arterial 95 mm Hg.
- Alveolar PCO₂ ≈ 40 mm Hg → venous 46 mm Hg.

Diffusion-limited (e.g., CO, fibrosis); **perfusion-limited** (O_2 , CO_2). Exercise \uparrow cardiac output \rightarrow 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) ↑ PAO₂, ↓ PACO₂.
- Bases: V/Q < 0.6 (shunt-like) \downarrow PAO₂, \uparrow PACO₂.
- Therapeutic positioning (e.g., unilateral lung disease) places healthier lung **down** to optimise V/Q.

4.3 Oxygen & CO2 Transport

Mode	%	Mechanism	Clinically Relevant Curve
O ₂ bound to Hb	98.5 %	$^{\circ}$ 1.34 mL $O_2 \cdot g^{-1}$ Hb; Sa O_2 curve $^{\circ}$ (sigmoid)	Bohr shift: \uparrow CO ₂ , \uparrow H ⁺ , \uparrow temp, \uparrow 2,3-DPG \rightarrow curve right (unloading)
O ₂ dissolved	1.5 %	$0.003~\mathrm{mL\cdot dL^{-1}\cdot mm~Hg^{-1}}$	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: O₂ unloading ↑ CO₂ carriage
Bicarbonate (HCO ₃ -	70 %	Carbonic anhydrase in RBC	Respiratory acidosis/alkalosis management

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

6 • Self-Check Quiz (Answers below)

- 1. Which abdominal muscle is most active during a forceful cough?
- 2. Explain why FEV1 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 O₂ 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 (FEV₁) drops disproportionately compared with total exhaled volume (FVC).
- 3. **"Good lung down"**—placing healthy lung in the dependent position maximises perfusion matching to betterventilated alveoli through gravity-directed blood flow.
- 4. Rising CO₂/H+ shifts the haemoglobin-O₂ dissociation curve right, enabling easier O₂ unloading to tissues.
- 5. **Cardiac output/perfusion** becomes limiting; diffusing capacity rises (recruitment) and usually exceeds demand in healthy lungs.

7 • Suggested Practical / Lab Activities

Activity

Surface EMG of respiratory muscles during quiet vs pursed-lip breathing

Spirometry workshop – perform, interpret FVC, FEV₁, MVV **Incentive-spirometer & flow-volume loop simulation**

Blood-Gas Case Scenarios

Skill Gained

Muscle recruitment analysis

Identify obstructive vs restrictive patterns

Teach patient coaching cues

Diagnose respiratory vs metabolic acidosis, devise breathing strategies

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.

2 Disorder Snapshots

Feature Asthma

COPD (Chronic Bronchitis &/or Emphysema)

Pneumonia

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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 & SpO₂ 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·wk⁻¹, 40-60 % HRR. Inspiratory muscle training (IMT) if reduced Plmax. 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 ; \downarrow hospitalisations; enhance QOL.	Restore premorbid function; prevent recurrence / complications (VTE, deconditioning).

4 Key Physiological Concepts for PT Intervention

1. Dynamic Hyperinflation (COPD):

Air-trapping \uparrow end-expiratory lung volume \rightarrow flattened diaphragm $\& \downarrow$ inspiratory capacity. PLB & interval training allow longer expiratory time $\& \downarrow$ hyperinflation.

2. Asthmatic Airway Resistance:

Bronchospasm + mucus plugs narrow radius (Poiseuille: $R \propto 1/r^4$).

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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):

↑ CO₂ + ↓ pH shift curve right (Bohr), aiding O₂ unloading but risking hypoxemia. Controlled O₂ (target 88-92 %) in COPD prevents CO₂ narcosis.

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 (FiO₂ > 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 FEV₁ ≥ 12 % and ≥ 200 mL denotes reversibility typical of asthma.
- 2. High FiO₂ suppresses the **hypoxic respiratory drive** and worsens V/Q mismatch by reversing hypoxic pulmonary vasoconstriction, leading to **CO₂ 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.

7 Key Take-Home Points

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

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- 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.

