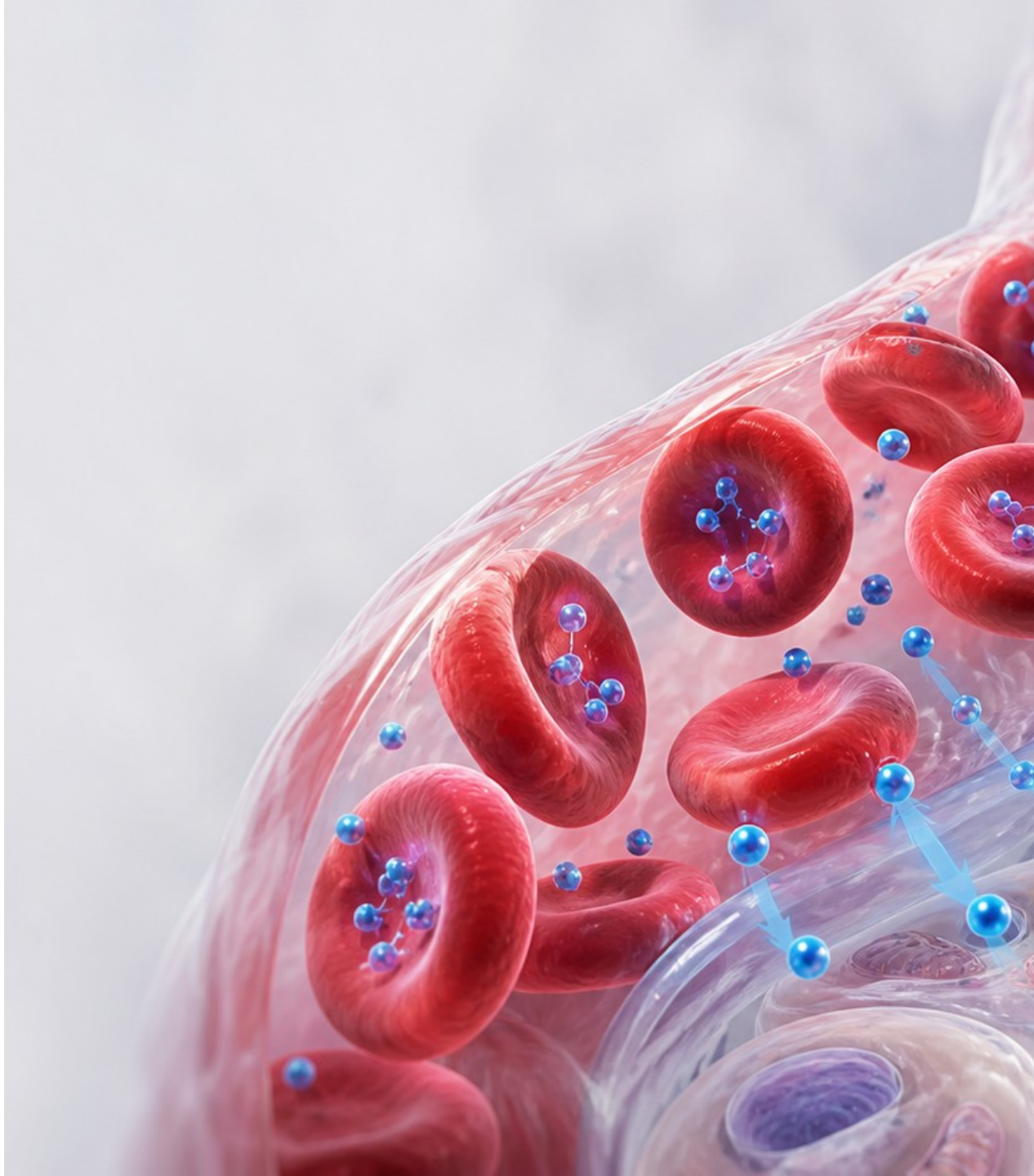
Oxygen Transport and Tissue Delivery

Foundations of Physiology

Year 1 Integrated Curriculum
Medical, Dental and Allied Health Sciences

Lecture 7

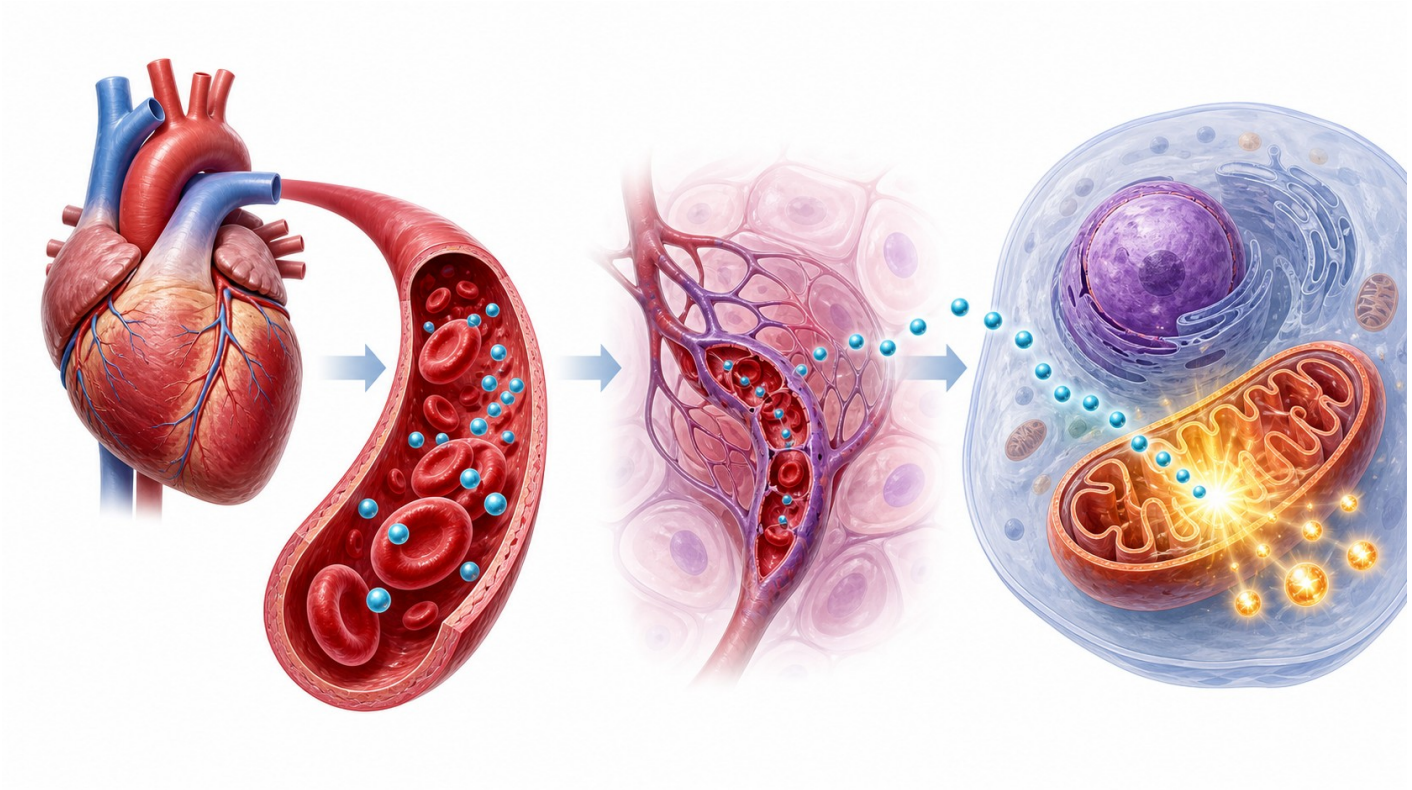
Department of Biomedical Sciences



Learning Objectives

- Describe the pathway of oxygen from inspired air to the mitochondria.
- Distinguish oxygen partial pressure, hemoglobin saturation and oxygen content.
- Explain how hemoglobin concentration and oxygen saturation determine arterial oxygen content.
- Interpret the oxygen-hemoglobin dissociation curve and predict the effects of pH, temperature, carbon dioxide and 2,3-BPG.
- Calculate arterial oxygen content and whole-body oxygen delivery from clinical data.
- Explain why normal pulse oximetry does not always indicate adequate tissue oxygen delivery.
- Apply the Fick principle to oxygen consumption and tissue extraction.

The Oxygen Pathway: Air to Mitochondria



- Ventilation brings oxygen to the alveoli; diffusion moves oxygen into pulmonary capillary blood.
- Hemoglobin carries oxygen, the heart generates blood flow and capillaries deliver oxygen to tissues.
- Mitochondria use oxygen as the final electron acceptor during oxidative phosphorylation.

Oxygen Has Three Different Measurements

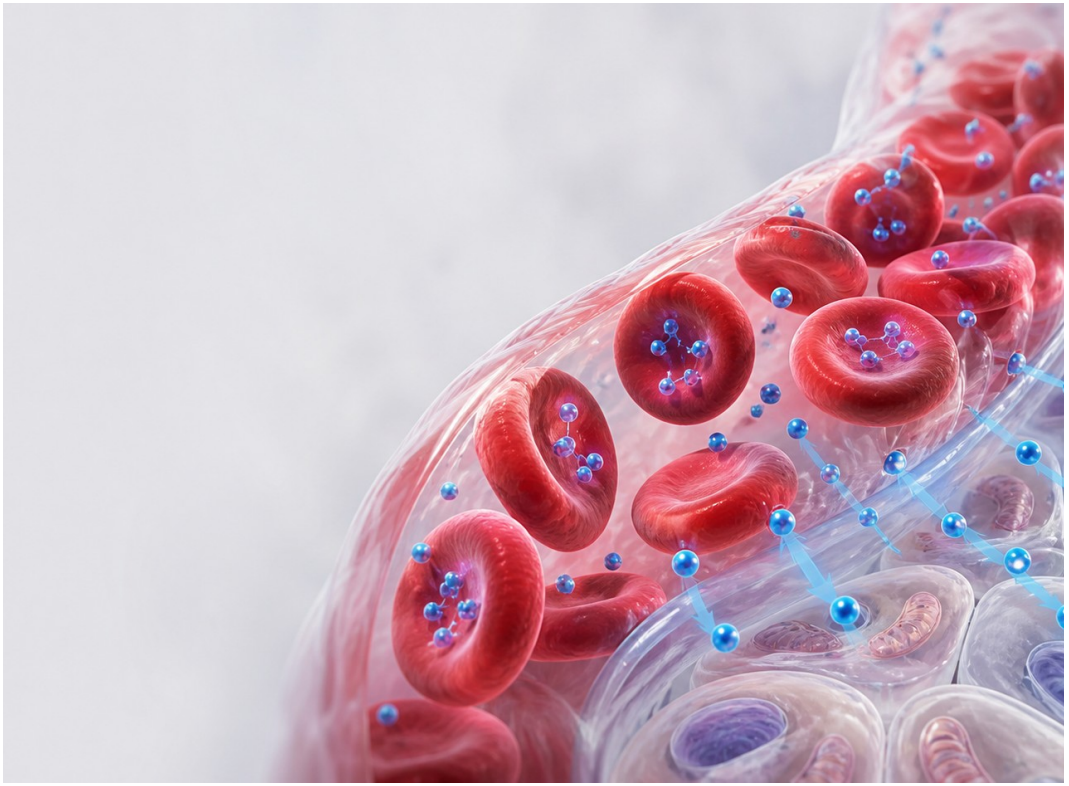
These terms are related, but they are not interchangeable.

Measurement	Common symbols	What it describes	Typical arterial value
Partial pressure	PaO_2	Dissolved oxygen molecules that create pressure and drive diffusion	~80-100 mmHg
Saturation	SaO_2 / SpO_2	Percent of available hemoglobin binding sites occupied by oxygen	~95-99%
Oxygen content	CaO_2	Total oxygen carried in arterial blood: hemoglobin-bound plus dissolved	~20 mL O_2/dL

Clinical point: pulse oximetry estimates saturation. It does not directly measure hemoglobin concentration, oxygen content or blood flow.

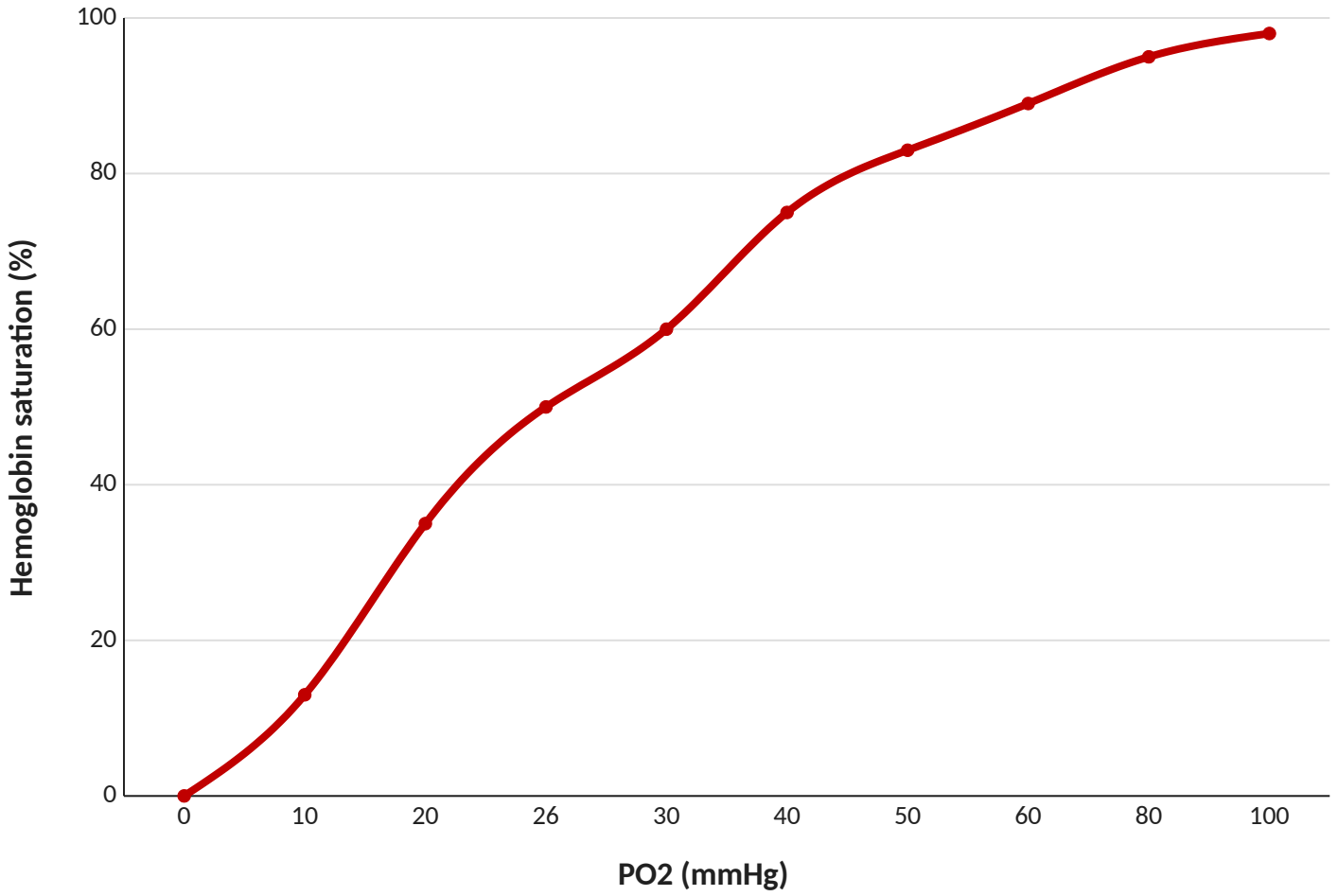
Hemoglobin Carries Nearly All Oxygen in Blood

- Only a small fraction of oxygen is physically dissolved in plasma.
- Most oxygen binds reversibly to hemoglobin inside erythrocytes.
- Each hemoglobin molecule contains four heme groups and can bind four oxygen molecules.
- Binding is cooperative: attachment of one oxygen molecule increases affinity for the next.
- Hemoglobin concentration therefore has a major effect on the total oxygen-carrying capacity of blood.



Hb + O2 <-> HbO2

The Oxygen-Hemoglobin Dissociation Curve



Key regions

- Plateau: high saturation is maintained across a range of alveolar PO2 values.
- Steep region: small reductions in tissue PO2 release a larger amount of oxygen.
- P50: the PO2 at which hemoglobin is 50% saturated (about 26-27 mmHg).
- Cooperativity produces the sigmoid shape of the curve.

The curve links oxygen pressure to hemoglobin loading and unloading.

Factors That Shift Hemoglobin Affinity

Variable	Right shift	Effect of a right shift
pH	Decreased pH	Lower affinity; oxygen unloads more readily in acidic tissues
PCO2	Increased PCO2	Lower affinity; supports oxygen release in metabolically active tissue
Temperature	Increased temperature	Lower affinity; facilitates unloading during exercise or fever
2,3-BPG	Increased 2,3-BPG	Lower affinity; increases unloading during chronic hypoxemia or anemia
Opposite changes	Cause a left shift	Higher affinity; supports loading but may reduce tissue unloading

CADET face Right

CO2 - Acid - 2,3-DPG - Exercise - Temperature

Right shift = easier oxygen unloading

Arterial Oxygen Content (CaO2)

$$CaO_2 = (1.34 \times Hb \times SaO_2) + (0.003 \times PaO_2)$$

Hemoglobin-bound oxygen

- 1.34 mL O2 per gram of hemoglobin
- Hb is measured in g/dL
- SaO2 is written as a decimal
- This term contributes almost all arterial oxygen content

Dissolved oxygen

- 0.003 mL O2/dL per mmHg
- Depends directly on PaO2
- Contributes relatively little at normal PaO2
- Becomes more important with high inspired oxygen

Normal example: (1.34 x 15 x 0.98) + (0.003 x 100) = 20.0 mL O2/dL

Why a Normal SpO2 Can Be Misleading

Both patients have a pulse oximeter reading of 98%.

Variable	Patient A	Patient B
SpO2 / SaO2	98%	98%
PaO2	100 mmHg	100 mmHg
Hemoglobin	15 g/dL	7.5 g/dL
Calculated CaO2	20.0 mL O2/dL	**10.2 mL O2/dL**
Interpretation	Normal oxygen content	**Severe reduction despite normal saturation**

A saturation percentage can be normal even when there is not enough hemoglobin to carry an adequate amount of oxygen.

Oxygen Delivery Depends on Content and Blood Flow

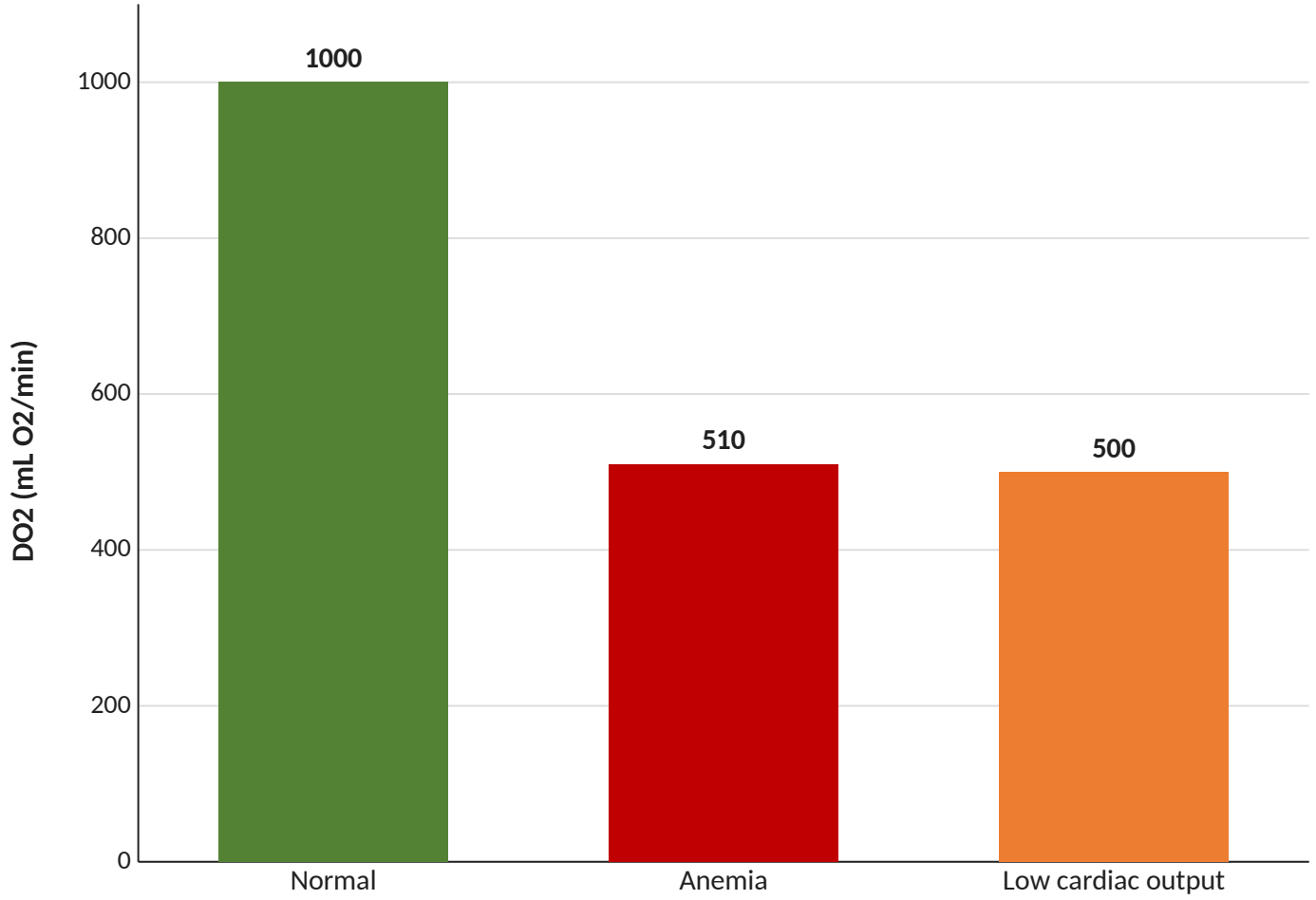
DO_2 = Cardiac Output x CaO_2 x 10

Cardiac output **x** **Arterial O_2 content** **=** **O_2 delivered / min**

- Cardiac output = heart rate x stroke volume.
- CaO_2 depends mainly on hemoglobin concentration and hemoglobin saturation.
- The factor of 10 converts liters of blood to deciliters.
- A reduction in either cardiac output or arterial oxygen content reduces total tissue oxygen delivery.

Normal example: 5 L/min x 20 mL O_2/dL x 10 dL/L = 1000 mL O_2/min

Two Common Ways to Reduce Tissue Oxygen Delivery



Anemia

- Hb = 7.5 g/dL
- SaO2 = 98%
- Cardiac output = 5 L/min
- DO2 approximately 510 mL O2/min

Low cardiac output

- Hb = 15 g/dL
- SaO2 = 98%
- Cardiac output = 2.5 L/min
- DO2 approximately 500 mL O2/min

Tissues Extract Only Part of the Delivered Oxygen

VO_2 = Cardiac Output x (CaO_2 - CvO_2) x 10

- The Fick principle calculates oxygen consumption from blood flow and the arterial-venous oxygen content difference.
- At rest, oxygen delivery is about 1000 mL O_2/min while oxygen consumption is about 250 mL O_2/min.
- Therefore, resting tissues extract approximately 25% of the oxygen delivered to them.
- The remaining oxygen provides a reserve that can be used when metabolic demand rises.
- If delivery falls, tissues initially compensate by extracting a greater fraction of available oxygen.

Example: 5 L/min x (20 - 15 mL O_2/dL) x 10 = 250 mL O_2/min

Clinical Application

A 24-year-old patient presents 12 hours after significant postoperative bleeding.

Finding	Value
Heart rate	118/min
Blood pressure	102/66 mmHg
SpO2	99% on room air
Hemoglobin	7.0 g/dL
Symptoms	Fatigue, dizziness

Questions

- Is the patient's arterial oxygen saturation normal?
- Is arterial oxygen content likely to be normal?
- Which term in the CaO2 equation has changed?
- Why might tachycardia partially compensate?
- Would supplemental oxygen completely correct the underlying problem?

Normal SpO2 does not exclude inadequate oxygen content or delivery.

Summary and Self-Check

Key points

• PaO_2, SaO_2/SpO_2 and CaO_2 describe different properties of oxygen in blood.

• Hemoglobin-bound oxygen contributes most arterial oxygen content.

• DO_2 depends on both cardiac output and arterial oxygen content.

• Anemia and low cardiac output can impair delivery despite normal saturation.

• Tissues can temporarily compensate by increasing oxygen extraction.

Self-check

• Which variable does a pulse oximeter estimate?

• What is the largest contributor to CaO_2?

• What happens to oxygen unloading during a right shift?

• How does low cardiac output affect DO_2?

• Why can severe anemia cause fatigue at an SpO_2 of 99%?

Central idea: oxygen must be loaded, carried, pumped and extracted.

References and Figure Attribution

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Figures

- Cover oxygen microcirculation image: original AI-generated artwork created for Synaptic Recall, 2026-08-16.
- Oxygen delivery chain image: original AI-generated artwork created for Synaptic Recall, 2026-08-16.
- All tables, equations, charts and clinical examples were assembled for this demonstration lecture.

This lecture is intended as a reusable sample input for a Synaptic Recall product demonstration.