

Human Performance & Limitations · Module B — The Living Machine

Breath & Blood

Chapter 5 — How the body takes in oxygen and moves it: the respiratory system and gas exchange, the heart and circulation, and blood pressure.

BOOK

Human Performance & Limitations

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EXAM

DGCA CPL / ATPL — HPL

CHAPTER

5 of 26 · Module B

In this chapter

1. [The Respiratory System & Gas Exchange](#)
2. [The Circulatory System & the Heart](#)
3. [Blood Pressure](#)
4. [Module B — Numbers to Know](#)



Plate 5.0 — The delivery system. Lungs load the oxygen; the heart and blood carry it to every cell that keeps you flying.

§ 8 The Respiratory System

OVERALL PURPOSE — ONE SENTENCE

Lungs are complex organs, but what they do is to get rid of carbon dioxide and exchange it for oxygen.

The respiratory process consists mainly of:

- the **diffusion of oxygen through the respiratory membranes into the blood**,
- **transportation to the cells**,
- **diffusion into the cells**, and
- **elimination of carbon dioxide from the body**.

8.1 The Pathway of Air — Nose to Alveoli

As you breathe air in through your nose or mouth, it travels along this path:

THE PATHWAY OF AIR

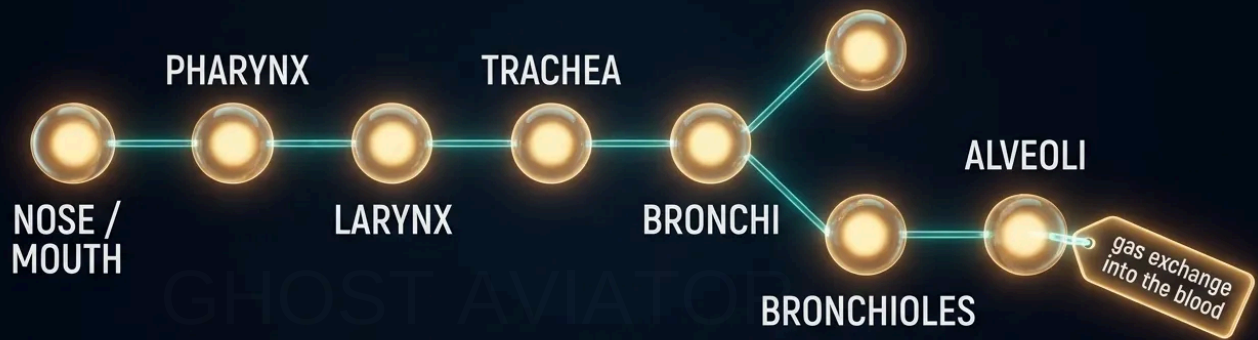


Figure 5.2 — The pathway of air, from nose and mouth down to the alveoli where oxygen crosses into the blood.

ANATOMICAL LANDMARKS — MEMORISE THESE LABELS

- | | |
|---|------------------------------|
| 1. A — Nasal cavity | 5. E — Alveoli |
| 2. B — Pharynx | 6. F — Bronchial tree |
| 3. C — Larynx (houses the vocal cords) | 7. G — Diaphragm |
| 4. D — Trachea | |

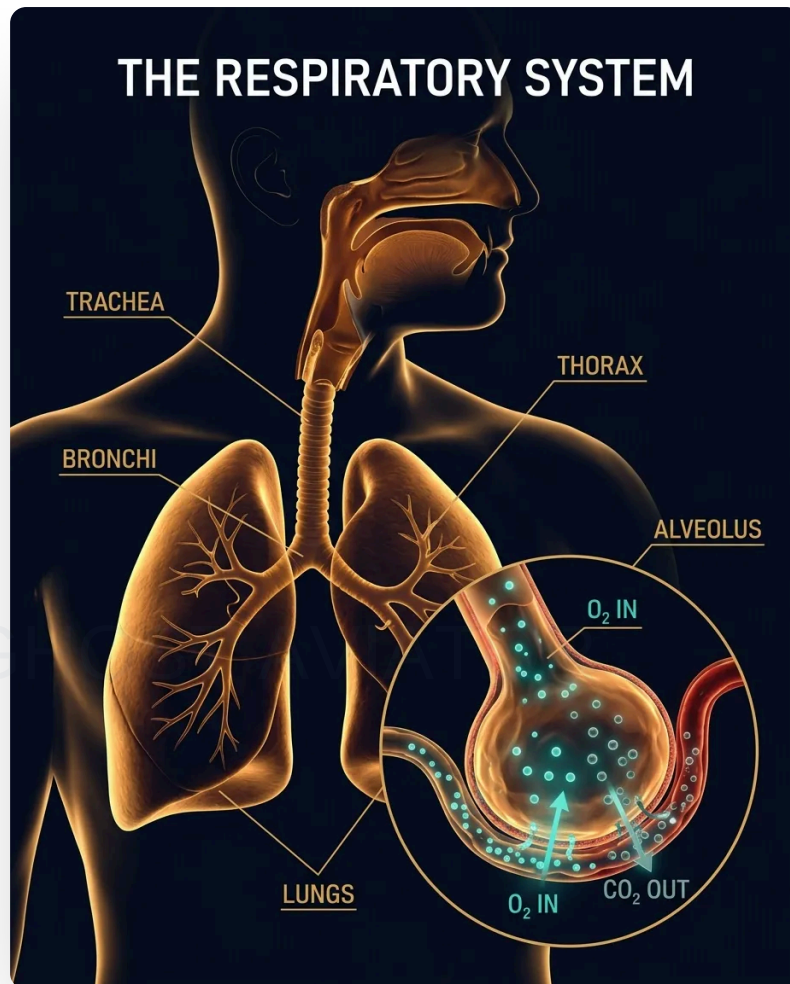


Figure 5.1 — The air pathway and the alveolus, site of all gas exchange; each alveolus is one cell thick.

8.2 What Happens Inside the Alveolus — Gas Exchange

THE DIFFUSION SEQUENCE (GRAHAM'S LAW IN ACTION)

1. Within each air sac, the **oxygen concentration is high**, so oxygen passes or **diffuses across the alveolar membrane into the pulmonary capillary**.
2. At the beginning of the pulmonary capillary, the **haemoglobin** in the red blood cells has **carbon dioxide bound to it and very little oxygen**.
3. The oxygen **binds to haemoglobin**, and the carbon dioxide is **released**.
4. **Carbon dioxide is also released from sodium bicarbonate dissolved in the blood** of the pulmonary capillary.
5. The concentration of carbon dioxide is high in the pulmonary capillary, so **CO₂ leaves the blood and passes across the alveolar membrane into the air sac**.
6. This exchange of gases occurs **rapidly (fractions of a second)**.
7. The carbon dioxide then leaves the alveolus (tiny air sacs of the lungs which allow for rapid gaseous exchange) when you **exhale**, and the **oxygen-enriched blood returns to the heart**.

THE PURPOSE, IN ONE LINE

The purpose of breathing is to keep the **oxygen concentration HIGH** and the **carbon dioxide concentration LOW** in the alveoli, so this gas exchange can occur.

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8.3 External vs Internal (Tissue) Respiration

External Respiration

External Respiration takes place through the **lungs** and refers to:

- The **absorption of Oxygen from the air into the blood.**
- The **excretion of Carbon Dioxide from the blood to the air.**

Internal / Tissue Respiration

Internal or Tissue Respiration refers to the **transfer of Oxygen from the blood to the tissues** of the body. At the same time as this occurs, the tissues **give up Carbon Dioxide to the blood.**

QUICK TEST **External = at the LUNGS** (air ↔ blood). **Internal = at the TISSUES** (blood ↔ cell). Don't mix these up — examiners love this distinction.

8.4 Breathing

DEFINITION

Normal breathing is a **purely automatic process under the unconscious control of the nervous system**. The normal rate of respiration in adults is **14 to 18 breaths per minute**.

WHAT REGULATES YOUR BREATHING RATE — COUNTER-INTUITIVE BUT VITAL

The level of carbon dioxide in the blood effectively regulates the rate and depth of breathing.

It is **NOT oxygen** that triggers your urge to breathe — it is **rising CO₂**. This is the core mechanism behind **Hyperventilation** (over-breathing → CO₂ washes out → urge to breathe drops → tingling, dizziness) which is dealt with separately in Part 3.

NORMAL ADULT RESPIRATION RATE

14 - 18 / min

CONTROL CENTRE

Medulla (Autonomic)

PRIMARY STIMULUS

Blood CO₂ Level

CONSCIOUS OVERRIDE

Possible (limited)

§ 9

The Circulatory System

WHY IT EXISTS

Blood supplies our organs with life-giving oxygen and carries away waste products. The circulatory system consists of the **heart and the blood vessels**, and maintains the **flow of blood throughout the body**. Without it, gas exchange at the lungs is pointless — there must be a delivery network.

9.1 The Heart

WHAT THE HEART DOES — CONCISE

The arteries **carry blood from the heart at HIGH pressure**, and the veins **return blood to the heart at LOW pressure**. The heart is a **pumping system** which:

- Intakes **de-oxygenated blood through the veins**.
- Delivers it to the **lungs for oxygenation**.
- Then pumps it into the various **arteries to be transmitted** where it is needed throughout the body for energy.

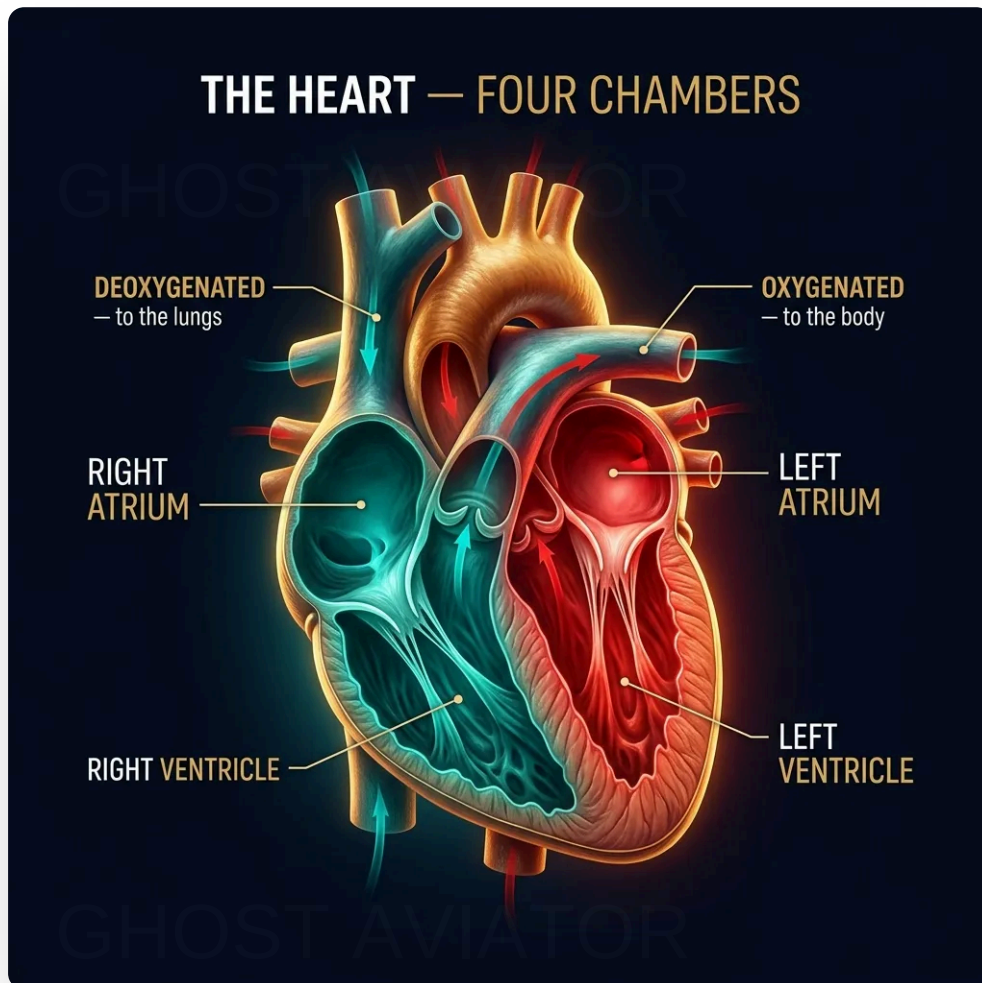


Figure 5.3 — The four chambers of the heart: the right side handles deoxygenated blood to the lungs, the left side oxygenated blood to the body.

MEMORISE — CARDIAC OUTPUT VALUES

At rest the **cardiac output** (the quantity of blood the heart pumps in one minute) of an adult with:

- Heart Rate = **72 beats per minute**
- Stroke Volume = **70 ml**

... is **about 5 litres per minute**. (Stroke volume × Heart rate = Cardiac output.)

9.2 How the Heart Works — Systole & Diastole

TWO PHASES OF THE CARDIAC CYCLE

When the heart muscle contracts or beats (called **SYSTOLE**), it **pumps blood out of the heart**. Then the heart muscle relaxes (called **DIASTOLE**) before the next heartbeat. This allows blood to **fill up the heart again**.

The two-stage contraction of systole

1. **Stage 1:** The **right and left atria contract at the same time**, pumping blood to the right and left ventricles.
2. **Stage 2:** The **ventricles contract together** to propel blood out of the heart.

The two-sided traffic plan

Right Side of the Heart

Collects **oxygen-poor blood from the body** and pumps it to the **lungs**, where it picks up oxygen and releases carbon dioxide.

Left Side of the Heart

Collects **oxygen-rich blood from the lungs** and pumps it to the **body**, so that the cells throughout your body have the oxygen they need to function properly.

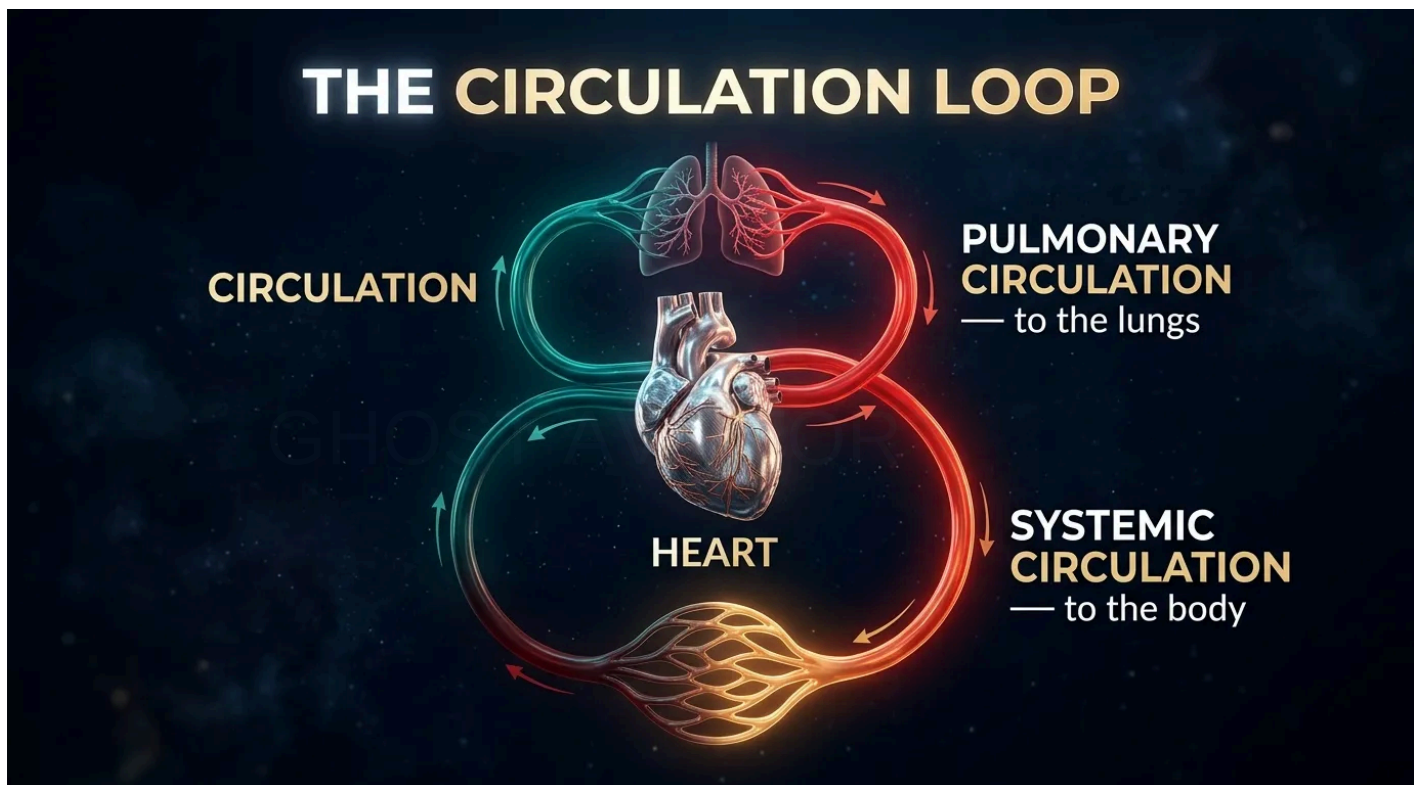


Figure 5.5 — The circulation loop: the pulmonary circuit to the lungs and the systemic circuit to the body.

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7 / 18

BLOOD'S JOURNEY FROM LEFT VENTRICLE TO CAPILLARIES

Blood containing oxygen is pumped around the body from the **left ventricle**. The oxygenated blood passes through the **aorta into the arteries** before arriving at the smallest vessels of the system, the **capillaries**. The **Oxygen–Carbon Dioxide exchange takes place through the walls of the capillaries**.

9.3 Pulse Rate

DEFINITION

The normal rate of the **pulse is the rate of the heartbeat**. A healthy person at rest has a pulse rate of between **60 and 80 beats per minute**. The rate is increased by:

- Exercise
- Emotional inputs
- Disease

STRESS & FEAR — AUTONOMIC ADRENALINE SURGE

When the body experiences **stress or fear**, **adrenaline is released into the bloodstream** causing an **immediate increase in the pulse rate**. (This is the ANS "fight-or-flight" response from §7.4.)

RESTING PULSE (HEALTHY)

60 – 80 bpm

CARDIAC OUTPUT REFERENCE

72 bpm × 70 ml

OUTPUT PER MINUTE

≈ 5 L/min

ADRENALINE EFFECT

Immediate ↑ pulse

9.4 Composition & Function of the Blood

TWO MAIN COMPONENTS OF BLOOD

Blood has **two main components** — **PLASMA** and **FORMED ELEMENTS**.

- **Plasma:** Nearly everything that blood carries — including **nutrients, hormones and waste** — is dissolved in plasma, which is **mostly water**.
- **Formed elements:** Cells and parts of cells that also **float in plasma**.

Formed elements — the three cell types

Cells and cell-fragments in the blood

Element	What it is / does	Notes
White Blood Cells (WBCs)	Part of the immune system	White corpuscles produce antibodies to fight bacteria.
Platelets	Help form clots	Smallest of the blood cells ; assist in the blood-clotting process.
Red Blood Cells (RBCs)	Carry oxygen & carbon dioxide	Numerous — make up more than 90 % of the formed elements in the blood . Virtually everything about them helps them carry oxygen more efficiently.

Inside a Red Blood Cell — Haemoglobin (Hb)

STRUCTURE OF HAEMOGLOBIN — DGCA-FAVOURITE QUESTION

A red blood cell's lack of nucleus also gives it **more room for haemoglobin (Hb)**, a complex molecule that carries oxygen. It is made of:

- A protein component called **GLOBIN**.
- **FOUR pigments called HEMES**.
- The hemes use **IRON** to bond to oxygen.

Inside each RBC are **~ 280 million haemoglobin molecules**.

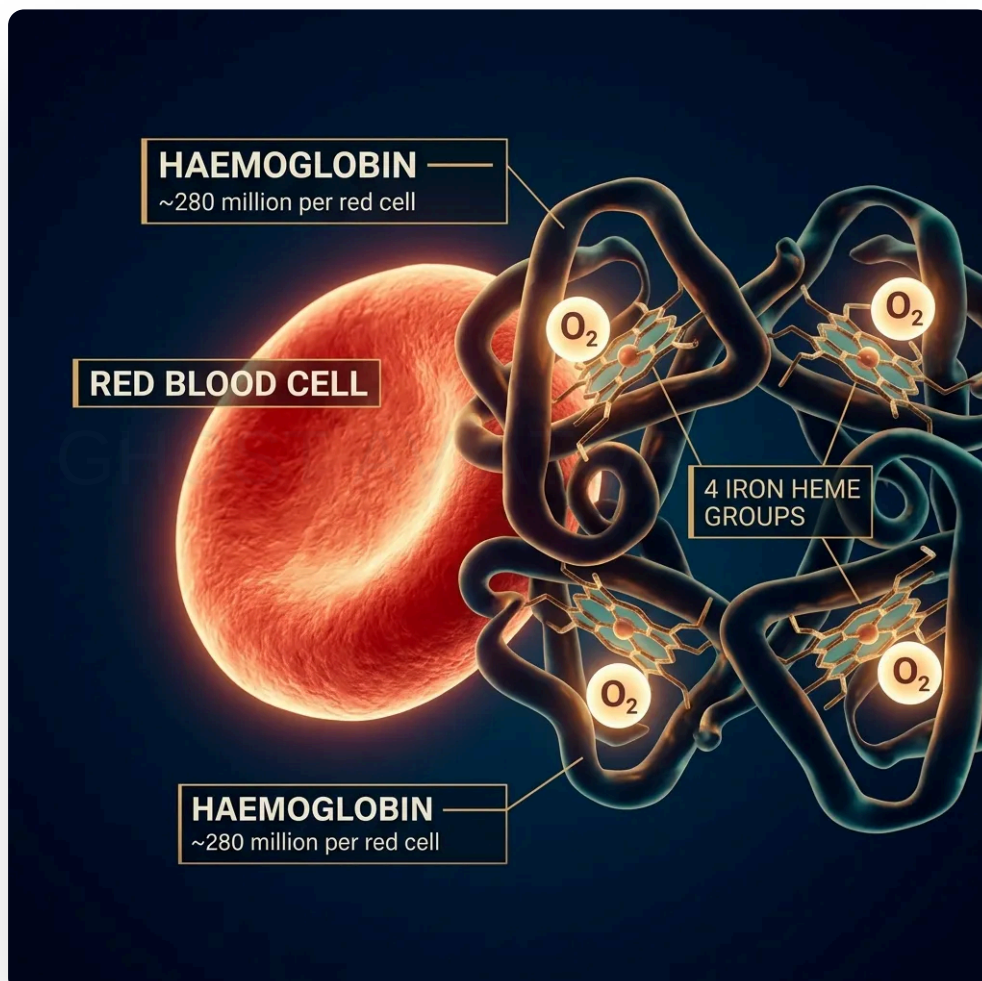


Figure 5.4 — Each red cell packs ~280 million haemoglobin molecules; each carries four iron-bearing hemes that grip oxygen.

If you lose a lot of blood...

WHY BLOOD LOSS IS DANGEROUS

If you lose a lot of blood, you lose a lot of your **oxygen delivery system**. The immune cells, nutrients and proteins that blood carries are important too, but doctors are generally **most concerned with whether your cells are getting enough oxygen**.

EMERGENCY MANAGEMENT

In an emergency situation, doctors will often give patients **volume expanders**, like **saline**, to make up for lost blood volume. This:

- Helps restore **normal blood pressure**.
- Lets the remaining red blood cells **continue to carry oxygen**.
- Sometimes is enough to keep the body going until it can produce new blood cells and other blood elements.

If not, doctors give **blood transfusions** to replace some of the lost blood. Blood transfusions are also fairly common during some **surgical procedures**.

The principal functions of the blood — full DGCA list

The five principal functions of blood		
#	Function	Mechanism
1	Carry oxygen to, and carbon dioxide from , the various tissues and organs of the body.	Haemoglobin in RBCs
2	Carry nutrients to tissues and remove waste products from these tissues.	Dissolved in plasma
3	Carry chemical messengers, such as hormones including ADRENALINE , to regulate the actions and secretions of various organs.	Plasma transport
4	Transport cells which can attack and destroy invading micro-organisms , enabling the body to resist disease.	WBCs / antibodies
5	Assist in temperature control of the body.	Vasodilation/constriction

9.5 Failures or Malfunctions of the Circulatory System

TWO PRINCIPAL FAILURE MODES

The circulatory system can malfunction in **two principal ways**:

1. The main component of the system, the **heart and the blood vessels**, may develop a fault.
2. The **blood may become unable to carry enough Oxygen** for the need of the organs and tissues of the body.

Angina & Heart Attack

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DEFINITIONS

A **lack of oxygen supply to the heart** may give rise to symptoms of **Angina**. A **heart attack** is when **low blood flow causes the heart to starve for oxygen**. Heart muscle **dies or becomes permanently damaged**. Your doctor calls this a **myocardial infarction**.

Causes of angina and heart attack

THE BLOOD-CLOT MECHANISM

- Most heart attacks are caused by a **blood clot that blocks one of the coronary arteries**.
- The **coronary arteries bring blood and oxygen to the heart**. If the blood flow is blocked, the heart starves for oxygen and heart cells die.
- A clot most often forms in a coronary artery that has become **narrow because of the build-up of a substance called PLAQUE** along the artery walls.
- Sometimes, **the plaque cracks and triggers a blood clot to form**.
- Occasionally, **sudden overwhelming stress can trigger a heart attack**.

Risk factors for angina and heart attack — the full DGCA list

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Risk factors — pilots should be screened for these at every medical

Risk Factor	Why it matters
Bad genes (hereditary factors)	Family history is non-modifiable but flagged in flight-medical examinations.
Being male	Higher statistical risk than females (until menopause for women).
Diabetes	Damages blood-vessel linings and accelerates plaque build-up.
Getting older	Arterial elasticity falls; plaque accumulation rises.
High blood pressure	Damages arterial walls — central to plaque mechanism. <i>(See §14 in next part.)</i>
Smoking	Reduces O ₂ -carrying capacity 5–8 %, raises BP, accelerates atherosclerosis. <i>(§12 — next part.)</i>
Too much fat in your diet	Raises LDL cholesterol — primary feedstock for plaque.
Unhealthy cholesterol levels — especially HIGH LDL ("bad") cholesterol and LOW HDL ("good") cholesterol	Direct correlation with coronary artery narrowing.
Lack of exercise	Increases all of the above; lowers cardiac reserve.
Stress	Sustained adrenaline release damages the heart and vessels.
Obesity	Independent risk factor + driver of diabetes, BP, lipids.
Alcohol	Raises BP, damages heart muscle, raises triglycerides. <i>(§13 — next part.)</i>

WHY PILOTS CARE — DGCA MEDICAL IMPLICATIONS

Every one of these risk factors is screened at Class-I & Class-II DGCA medicals via ECG, lipid panel, fasting glucose, BMI, blood pressure measurement and history. *Even an unsuspected silent angina is a fitness-defeating condition; routine cardiac screening exists precisely because the in-flight failure mode is sudden incapacitation.*

Insufficiency of Oxygen — the second failure mode

WHY THIS IS ITS OWN CATEGORY

The second principal way the circulatory system can malfunction is "**Insufficiency of Oxygen**" — the blood becoming **unable to carry enough oxygen for the needs of the organs and tissues**. This is the gateway concept that leads directly into the next major topic — **HYPOXIA** — covered in detail in §10 (Part 3). Hold the term in mind.

9.6 Self-Check & Memory Aids — Part 2

Numbers you must know cold

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TRY THESE WITHOUT LOOKING BACK

1. State the three main divisions of the Nervous System. Which one controls the heart, lungs and gut *without* conscious effort?
2. Trace the path of air from the nose to the alveoli — name **every** structure.
3. What is the difference between External and Internal Respiration?
4. What is the normal adult respiration rate, and what is the primary regulator of breathing?
5. Define cardiac output. Compute it for HR 72 bpm, SV 70 ml.
6. What is the difference between Systole and Diastole? Describe the two-stage contraction.
7. State the two main components of blood and the three types of formed elements.
8. How many haemoglobin molecules are inside each RBC? How many hemes per Hb?
9. List the five principal functions of blood.
10. What are the two principal failure modes of the circulatory system? Name the medical term for a heart attack.
11. List at least eight risk factors for angina/heart attack relevant to a DGCA medical.
12. What is plaque, and why does it matter to coronary arteries?

MNEMONIC — AIR PATHWAY "Never Pinch The Lazy Bronchitis Boy's Alveoli" → **N**ose · **P**harynx · **T**rachea · **L**arynx · **B**ronchi · **B**ronchioles · **A**lveoli. (Note the epiglottis sits between nose/pharynx and trachea acting as the airway gatekeeper.)

MNEMONIC — 3 NS DIVISIONS "Cops Patrol Automatically" → **C**NS (Central — Brain + Cord, the HQ) · **P**NS (Peripheral — all peripheral nerves, the patrol) · **A**NS (Autonomic — runs without orders).

MNEMONIC — CARDIAC OUTPUT **CO = HR × SV** → Cardiac Output = Heart Rate × Stroke Volume. **72 × 70**
≈ **5040 ml** ≈ **5 L/min**.

MNEMONIC — RIGHT VS LEFT HEART "Right is BLUE, Left is RED" → Right side handles de-oxygenated blood (to lungs); Left side handles oxygenated blood (to body).

15.1 What Determines Blood Pressure

THE FOUR DETERMINANTS — DGCA-QUOTED

Blood pressure depends on:

- The **cardiac output**,
- The **resistance of the capillaries** (peripheral resistance),
- The **elasticity of the arterial walls**, and
- The **blood volume and viscosity**.

15.2 Definitions — pressure on the arteries

THREE KEY FACTS

- **Blood pressure is the pressure exerted by blood on the walls of the main arteries.**
- The blood-pressure which is measured during flight medical checks is the **pressure in the artery of the upper arm** (representing the pressure at heart level).
- The **permanent pressure against the arterial wall is called DIASTOLIC pressure.**
- The **increased pressure occurring with each beat of the heart is called the SYSTOLIC pressure.**

SYSTOLIC PRESSURE

The **increased pressure occurring with each beat of the heart.**

This is the higher number in the BP reading — generated during ventricular contraction (*systole*, §9.2). It is the pressure peak as blood is ejected from the left ventricle into the aorta.

DIASTOLIC PRESSURE

The **permanent pressure against the arterial wall.**

This is the lower number — the resting pressure between heartbeats, when the heart muscle relaxes (*diastole*) and refills with blood. It represents the baseline strain on the arteries.

15.3 120/80 — the Normal Benchmark

THE NUMBER EVERY PILOT MUST KNOW

120/80 is a normal blood pressure for a healthy young adult.

The notation reads "120 over 80" — meaning **systolic 120 mmHg, diastolic 80 mmHg**. This is the figure that DGCA aero-medical examiners measure against at every Class-1 and Class-2 medical.



Figure 5.6 — Measuring blood pressure: the cuff inflates around the upper arm, then deflates while the examiner listens for arterial sounds.

15.4 High Blood Pressure (Hypertension) — Causes & Pilot Implications

DGCA-QUOTED — THE UNFITNESS CLAUSE

High blood pressure or hypertension is a **MAJOR CAUSE** of unfitness in pilots.

This single sentence is the most important takeaway from §15. The DGCA aero-medical examiner will **defer or restrict** a pilot's medical certificate the moment hypertension is detected and not adequately controlled.

Causes of Blood Pressure (Hypertension) — full DGCA list

Seven causes of hypertension a pilot must remember

#	Cause	Pilot-Specific Note
1	Stress	Sustained ANS / adrenaline activation. Pilots are exposed to chronic occupational stress — duty rosters, weather, currency requirements.
2	Smoking	Direct link to §13. Nicotine constricts vessels; CO damages endothelium.
3	Poor diet (excess fat or salt)	Salt → fluid retention → ↑ blood volume. Fat → plaque → ↑ peripheral resistance.
4	Obesity	Greater body mass requires more cardiac output; metabolic syndrome adds insulin resistance.
5	Lack of exercise	Deconditioned heart, stiffer vessels, higher resting BP.
6	Age	Arterial elasticity falls with age (recall §9.5 risk-factor list). Non-modifiable.
7	Narrowing of the arteries	Atherosclerosis — plaque-narrowed vessels create higher peripheral resistance. Same plaque that causes angina/MI.

WHAT DETERMINES BLOOD PRESSURE



Figure 5.7 — What determines blood pressure: cardiac output and peripheral resistance.

WHAT A PILOT CAN DO — THE MODIFIABLES

Of the seven causes, **five are modifiable** (stress management, no smoking, low-salt/low-fat diet, weight control, regular exercise). Only **age** and (to a large extent) **narrowing of arteries from existing plaque** are non-modifiable. **The pilot who fails his Class-1 medical because of hypertension has lost his career to a condition that was, in most cases, preventable.**

CROSS-LINKS — SEE ALSO

- **§9.1 / 9.2:** cardiac output = HR × stroke volume — directly drives systolic pressure.
- **§9.5:** hypertension is one of the 12 risk factors for angina / heart attack.
- **§13.3:** smoking causes circulatory problems and accelerates plaque.
- **§14.5:** alcohol contributes to liver/heart/brain damage.

The DGCA HPL paper frequently *combines* these topics in one MCQ stem — e.g. "A 48-year-old smoker with BP 145/95 ..." — testing whether you can connect the dots.

B Module B — Numbers to Know

Master cheat-sheet — the body's systems

Parameter	Exact Value	Where
Normal adult respiration rate	14 – 18 breaths/min	§8.4
Primary regulator of breathing rate	Blood CO ₂ level	§8.4
Resting pulse (healthy)	60 – 80 bpm	§9.3
Reference heart rate (for CO calc)	72 bpm	§9.1
Stroke volume (reference)	70 ml	§9.1
Cardiac output at rest	≈ 5 L/min	§9.1
RBCs as % of formed elements	> 90 %	§9.4
Haemoglobin molecules per RBC	≈ 280 million	§9.4
Hemes per Hb molecule	4	§9.4
Metal that bonds O ₂ to heme	Iron	§9.4
Protein component of Hb	Globin	§9.4
Heart attack medical term	Myocardial Infarction	§9.5
"Bad" cholesterol	LDL (high = bad)	§9.5
"Good" cholesterol	HDL (high = good)	§9.5

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✦ END OF CHAPTER 5 ✦

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18 / 18