بسم الله الرحمن الرحيم

PHYSIOLOGY

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FINAL | Lecture 1

Vascular Hemodynamics (Pt.1)

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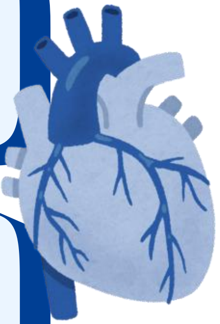

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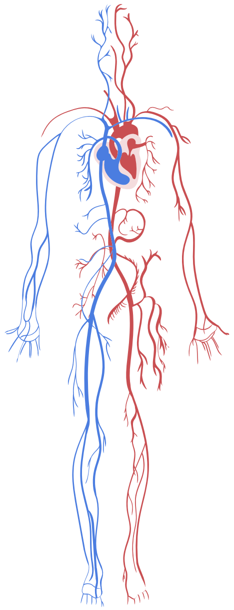

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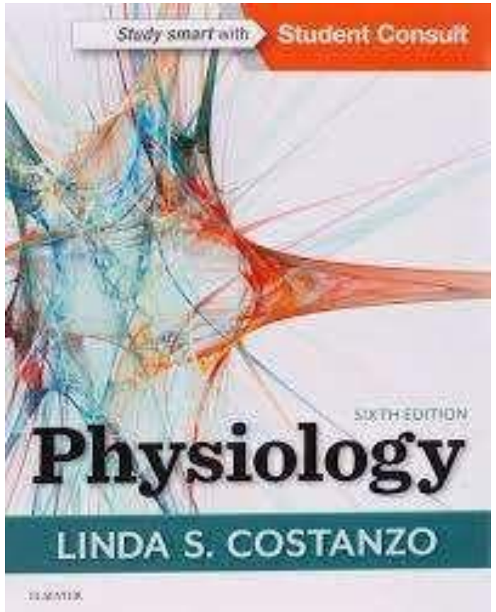
Vascular Hemodynamics-1

References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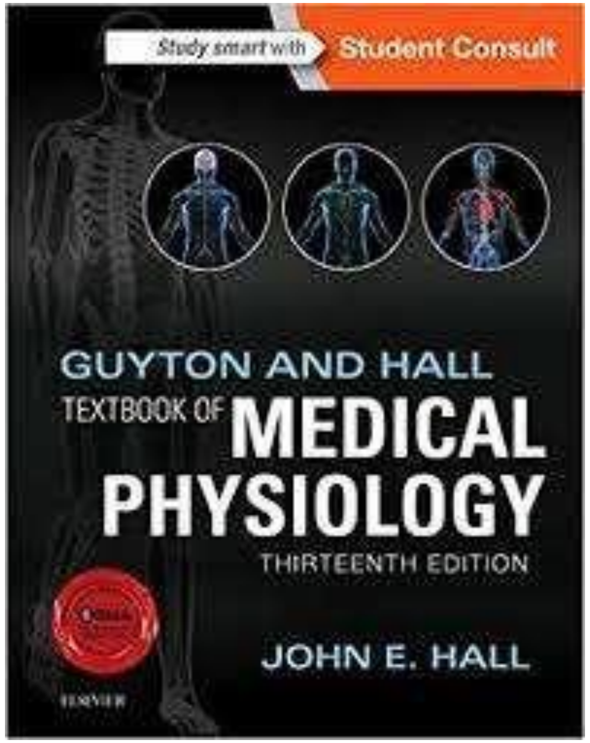
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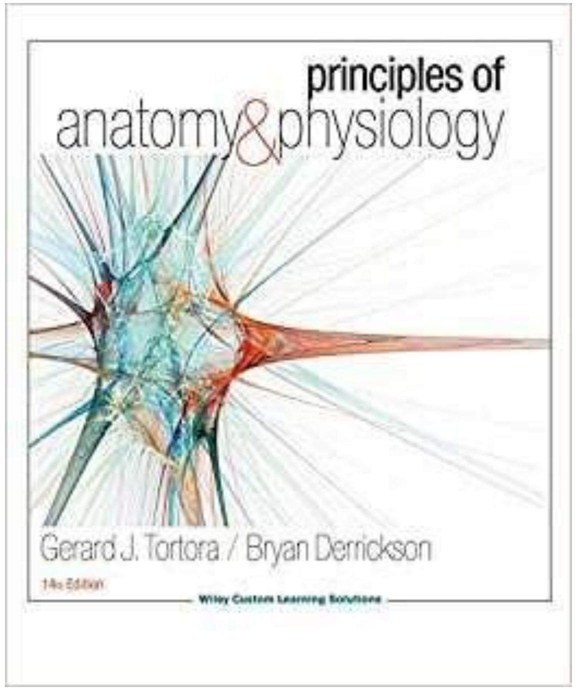
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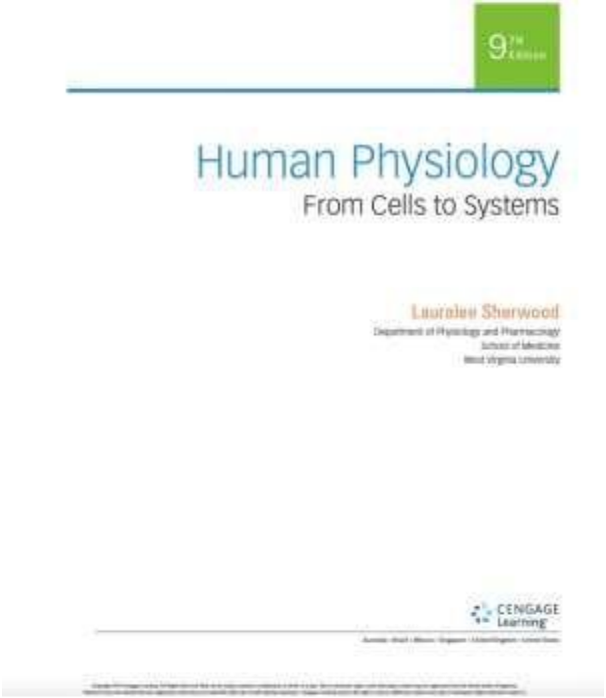
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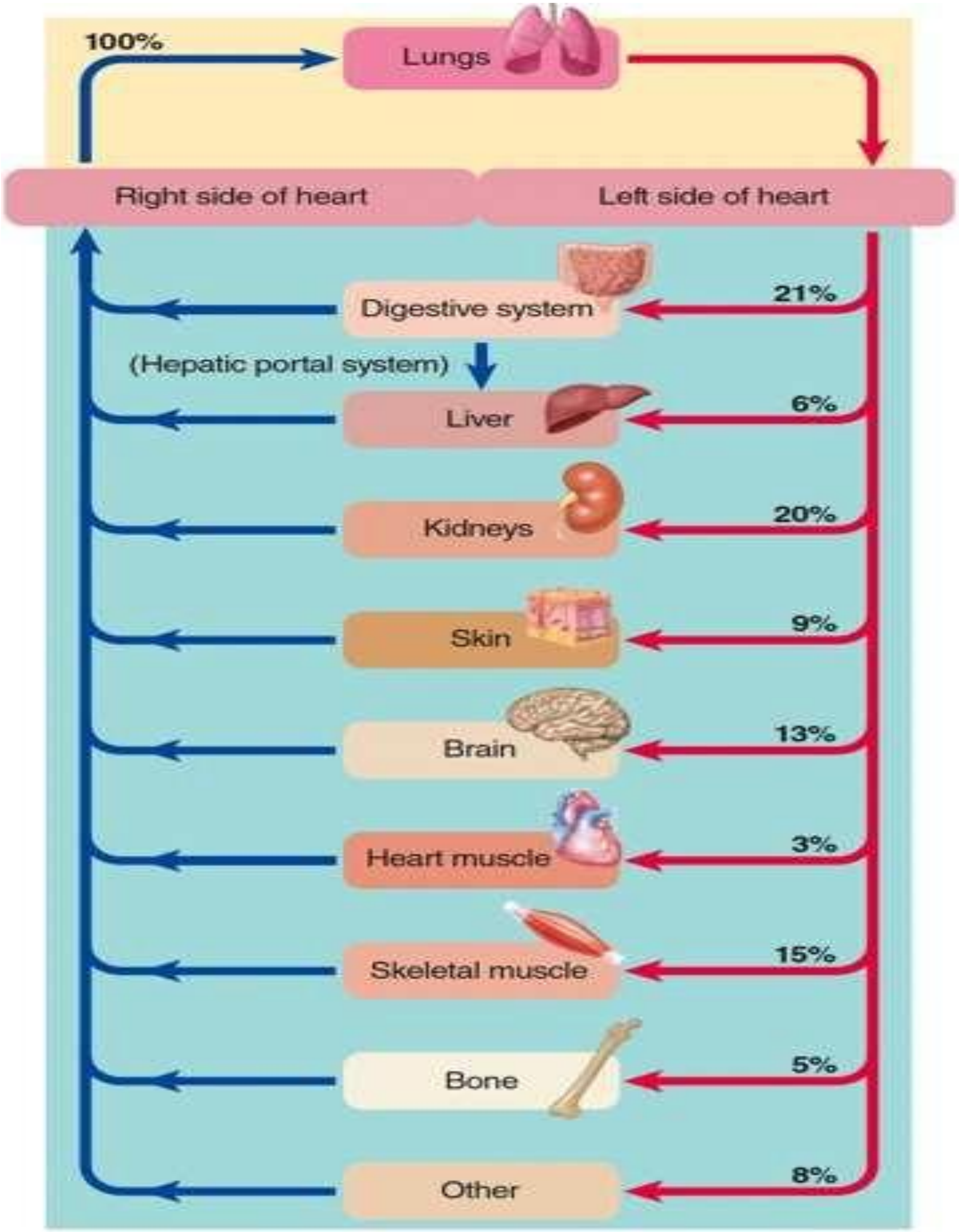
Introduction to Vascular Physiology

- Function: Transporting nutrients to cells and supplying **them** with O_2 and getting **rid** of wastes.
- Tissues experience continuous changes and are **constantly** different from each other, **which suggests** that the transport system must be efficient enough to meet their different metabolic needs and be well regulated.
- However, surprisingly, **blood flow is actually not adjusted to match the metabolic needs of a tissue**.

Blood Distribution

- Look closely at this diagram and consider the percentages shown.
- You can notice that the digestive system receives 21% of the blood flow, with the liver receiving **6% of the total cardiac output**.
- The skin receives **over 9%** of the blood supply.
- Do these tissues really need that much blood flow? Think about sympathetic stimulation, where blood is shunted **away from the GIT and redirected toward vital organs** in the fight-or-flight response.



Blood Distribution Continued

- The blood gets loaded with nutrients in the GIT, and **this explains** why such a high percentage of blood is directed there.
- This means that the 21% of blood supply **does not represent only the metabolic need** of the GIT, but reflects the requirement for **reconditioning the blood with nutrients.**
- The same principle applies to the kidneys, where blood is filtered to remove waste products, and to the skin, where **temperature regulation** occurs.
- These cases explain how the blood flow is not directly matched to the metabolic need of a tissue.
- Organs such as the kidneys, liver, skin, and intestines that receive blood flow **exceeding their metabolic demands** are called **reconditioning organs.**

Reconditioning Organs

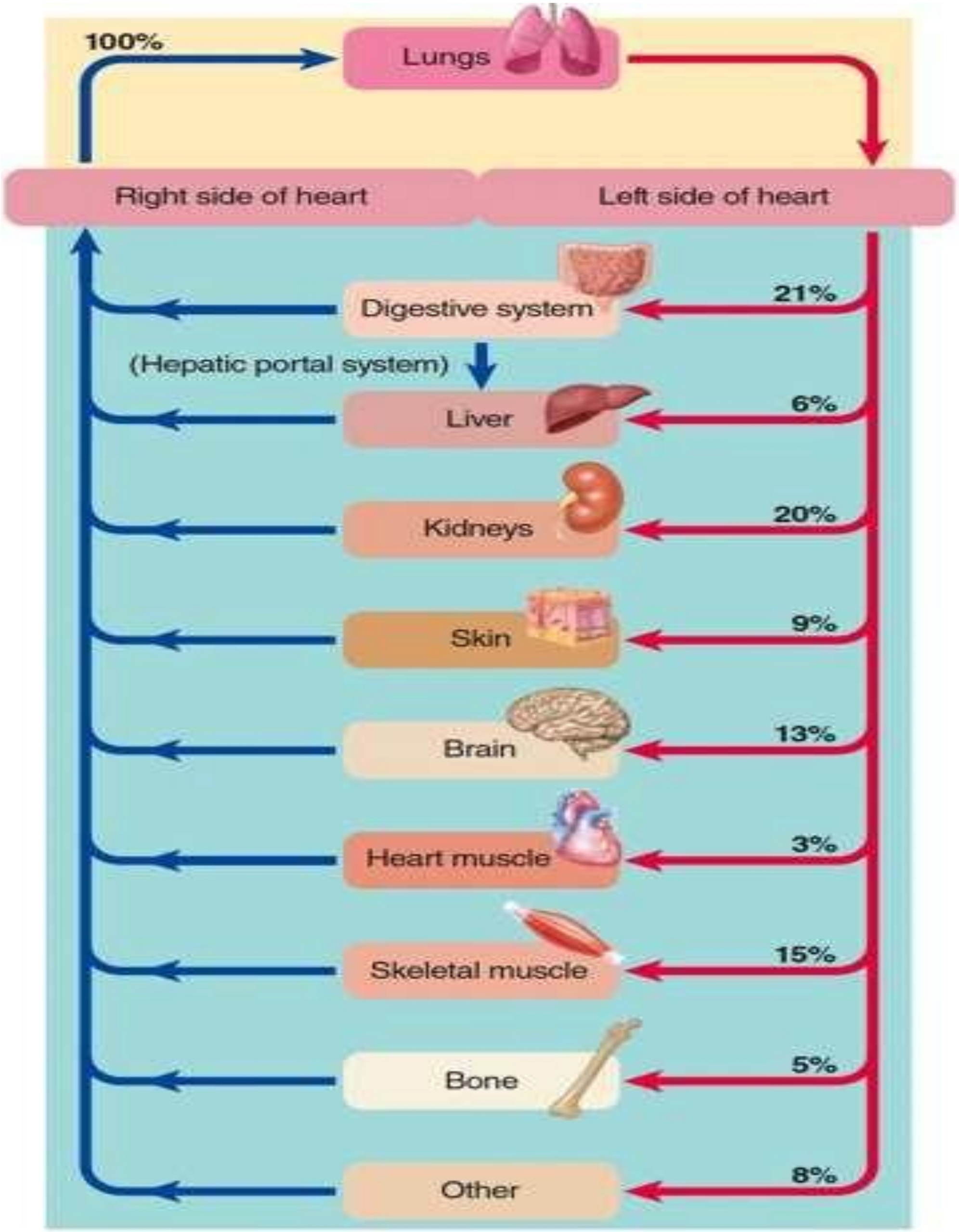
- Blood is constantly “reconditioned” so that its composition remains relatively constant despite an ongoing drain of supplies to support metabolic activities and despite continual addition of wastes from the tissues.
- Organs that recondition the blood normally receive much more blood flow than is necessary to meet their basic metabolic needs, so they can adjust the extra blood to achieve homeostasis.

Reconditioning Organs

- Blood flow to the other organs is for filling these organs’ metabolic needs and can be adjusted according to their level of activity.
- Because reconditioning organs—digestive organs, kidneys, and skin—receive blood flow in excess of their needs, they can withstand temporary reductions in blood flow much better than other organs can that do not have this extra margin of blood supply.
- The **brain**, which can least tolerate disrupted blood supply, is a high priority in the overall operation of the circulatory system.
- In contrast, the reconditioning organs can tolerate significant reductions in blood flow for quite a long time and often do.

Blood distribution

- Look closely at this diagram and consider the **parallel distribution** shown here.
- Why does not the blood flow in **series**?
- If the circulation were arranged in a series, it would **limit the ability to regulate each organ independently**, and any adjustment in blood flow to an **upstream organ** would affect all **downstream organs**, reducing their perfusion as the series continues.
- In addition, a series arrangement would alter **blood composition**, since the first organ would receive blood with the highest levels of O_2 and nutrients, while **downstream organs would receive partially depleted blood**.



The Parallel Arrangement

- The blood pumped by the left side of the heart into the systemic circulation is distributed in various proportions to the systemic organs through a **parallel arrangement** of vessels that branch from the aorta.

- This arrangement ensures that:
  1. all organs receive blood of the **same composition.**
  2. blood flow through each systemic organ can be **independently adjusted** as needed.

Hemodynamics

- Definition: The principles that govern blood flow in the cardiovascular system.

سبحان الله وبحمده، سبحان الله العظيم.

Flow rate

- The flow rate of blood through a vessel is the volume of blood passing through a section of that vessel per unit of time.
- It is directly proportional to the pressure gradient and inversely proportional to vascular resistance.
- $F = \Delta P/R$

Pressure

- BP Definition: The force exerted by blood on an area of the vascular wall.
- P=100 mmHg means the force exerted is sufficient to push a column of mercury against gravity up to a level of 100ml height.
- Another measure is 1 mmHg=13.6 mm H2O (due to higher specific gravity) however, it is not clinically used.
- The main driving force behind blood pressure is cardiac contraction.
- However, it is **not the absolute pressure** that drives blood flow, but **the pressure difference**

Pressure gradient

- The difference in pressure between the beginning and the end of a vessel.
- Blood flows from an area of **higher pressure to** an area of
- **lower pressure** down a pressure gradient.
- It is **generated by contraction of the heart**.
- Because of resistance, the **pressure drops as blood flows**
- throughout the vessel’s length.
- The greater the pressure gradient, the greater the flow rate through the vessel.

Resistance

- A measure of opposition to blood flow through the vessel, caused by friction between the moving fluid and the vascular walls.
- Can’t be measured directly.
  - However, there are ways to measure flow (using invasive or non-invasive methods such as Doppler ultrasound) and pressure (through invasive techniques using probes in different vessels, or by non-invasive methods), so resistance can be calculated.
- As resistance to flow increases, it is more difficult for blood to pass through the vessel, so flow rate decreases.
- Usually we use conductance = 1/R since it is easier to interpret

Resistance

- Resistance to blood flow is
    1. Directly proportional to **viscosity of the blood** (which refers to the **frictional forces between its particles**, most importantly **RBCs**),
    2. Directly proportional to **vessel length**,
    3. Inversely proportional to **vessel radius**, which is by far the most important.
- **Poiseuille equation**:

$$R = \frac{8\eta l}{\pi r^4}$$

→ 8 x viscosity x length

Viscosity

- The friction developed between the molecules of a fluid as they slide over each other during flow of the fluid.
- The thicker a liquid is, the greater its viscosity, the greater the resistance to flow.
- Blood viscosity is determined primarily by the number of circulating red blood cells.

Vessel Length & Radius

- The longer the vessel, the greater the surface area and the greater the resistance to flow.
- Resistance is inversely proportional to the **fourth power of the radius.**
- The radius of **arterioles** can be regulated and is the key factor in controlling resistance to blood flow throughout the vascular circuit.
    - (**Arterioles**, not capillaries, because arterioles **contain a smooth muscle layer**)

Resistance in a Single Organ

SAMPLE PROBLEM. Renal blood flow is measured by placing a flow meter on a woman's left renal artery. Simultaneously, pressure probes are inserted in her left renal artery and left renal vein to measure pressure. Renal blood flow measured by the flow meter is 500 mL/min. The pressure probes measure renal arterial pressure as 100 mm Hg and renal venous pressure as 10 mm Hg. *What is the vascular resistance of the left kidney in this woman?*

SOLUTION. Blood flow to the left kidney, as measured by the flow meter, is Q. The difference in pressure between the renal artery and renal vein is ΔP. The resistance to flow in the renal vasculature is calculated by rearranging the blood flow equation:

$$Q = \Delta P/R$$

Rearranging and solving for R,

$$\begin{aligned} R &= \Delta P/Q \\ &= (\text{Pressure in renal artery} - \text{Pressure in renal vein})/\\ &\quad\ \text{Renal blood flow} \end{aligned}$$

$$\begin{aligned} R &= (100 \text{ mm Hg} - 10 \text{ mm Hg})/500 \text{ mL per min} \\ &= 90 \text{ mm Hg}/500 \text{ mL per min} \\ &= 0.18 \text{ mm Hg/mL per min} \end{aligned}$$

Total Peripheral Resistance (TPR)

- The resistance of the entire systemic vasculature is called the total peripheral resistance (TPR) or the systemic vascular resistance (SVR).
- TPR can be measured with the flow, pressure, and resistance relationship by substituting cardiac output for flow (F or Q) and the difference in pressure between the aorta and the vena cava for ΔP.
- **TPR** is a term commonly used in clinical practice to refer to the **resistance of the total systemic circulation.**

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Total Peripheral Resistance

- TRP = MAP / CO
- Resistance is defined as **R = ΔP / Flow**.
  Point 1 represents the **proximal aortic arch**, and Point 2 represents the **right atrium**.
- One challenge in measuring pressure is its **pulsatile nature**; systolic pressure occurs during ventricular contraction, and diastolic pressure occurs during relaxation.
- If we want to calculate the **mean arterial pressure (MAP)** between the proximal aortic arch and the right atrium, and the pressure at Point 1 is **100 mmHg** while the pressure at Point 2 is **0 mmHg**, then the MAP difference is **100 mmHg**.
  To determine flow, we use the **cardiac output**, which is the volume of blood pumped through the systemic circulation per minute. If the cardiac output is **5 L/min**, then the total peripheral resistance (TPR) is:
  - **TPR = 100 / 5 = 20**.
- In this example, the pressure **gradually decreases** from 100 mmHg at the proximal aortic arch to 0 mmHg at the right atrium.

Disclaimer:

- In cardiovascular physiology, resistance is calculated using the pressure difference between **mean arterial pressure (MAP)** and **right atrial pressure (RAP)**, not systolic pressure.
- **R = (MAP – RAP) / Cardiac Output**
- Right atrial pressure is **not truly zero**; physiologically, it is typically **2–6 mmHg**, and zero is used only for simplified calculations.
- Mean arterial pressure **cannot be equated with systolic pressure**. It must be calculated using a formula that accounts for the longer duration of diastole:
- **MAP = Diastolic Pressure + (1/3 × Pulse Pressure)**
- **Pulse Pressure = Systolic – Diastolic**
- MAP cannot be assumed to be **100 mmHg** unless that value is explicitly provided as the mean pressure; systolic pressure **cannot be used as a substitute** for MAP.
  Total peripheral resistance must be calculated using **MAP**, and using systolic pressure instead gives an **incorrect resistance**.
- Blood pressure does **not decrease linearly** through the systemic circulation. The greatest pressure drop occurs across the **arterioles**, which provide the highest resistance.

Laminar Blood Flow

- Ideally, blood flow in the cardiovascular system is laminar, or streamlined.
- In laminar flow, there is a smooth parabolic profile of velocity within a blood vessel, with the velocity of blood flow highest in the center of the vessel and lowest toward the vessel walls.

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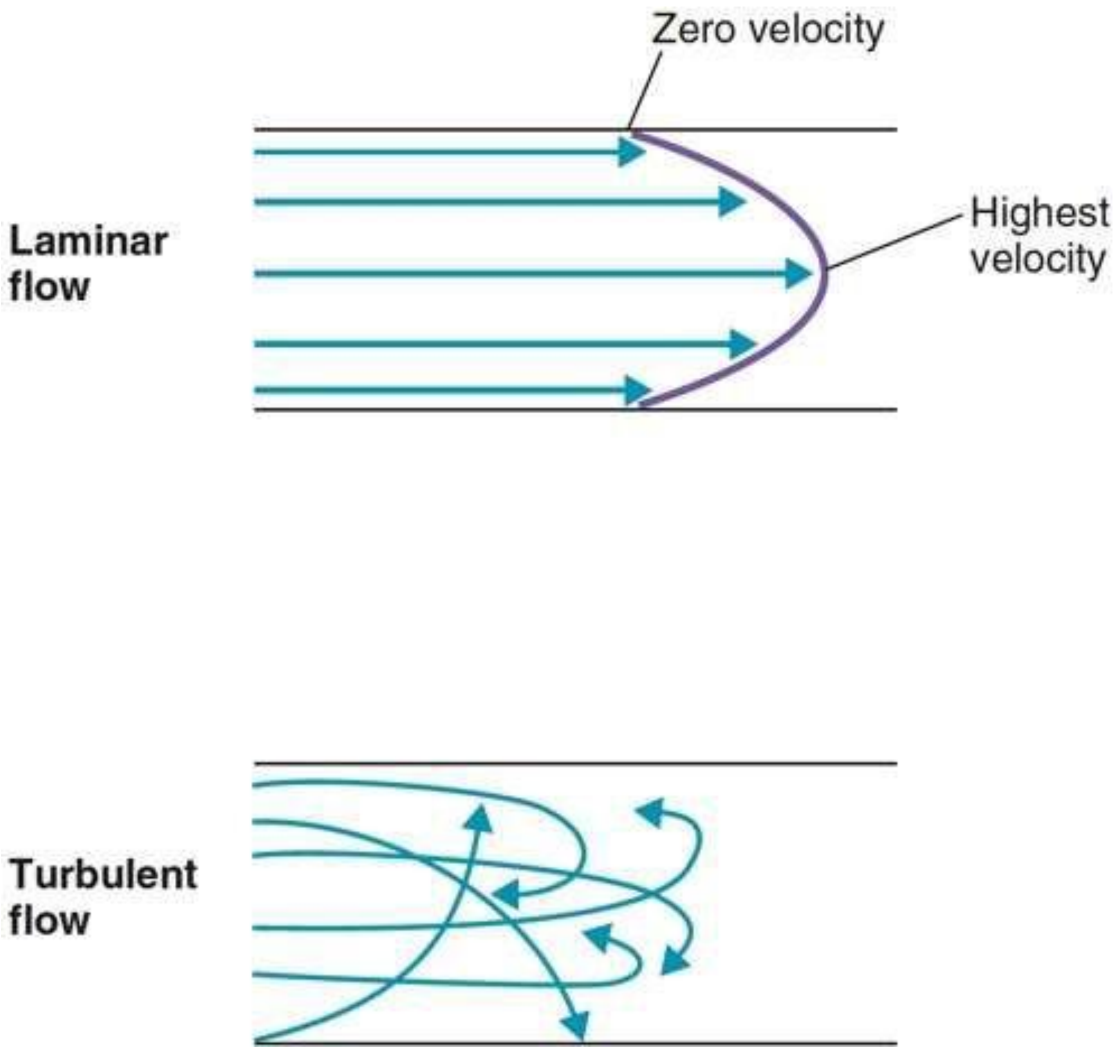

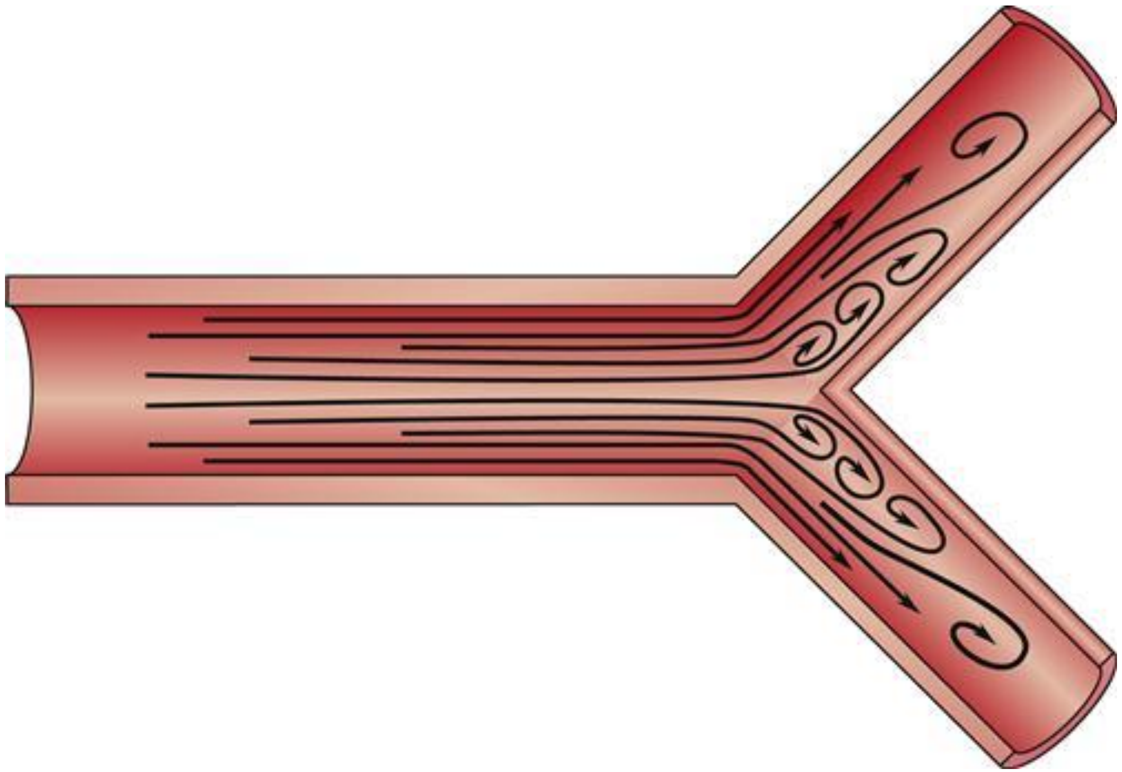

This additional figure illustrates the physiological turbulence occurring at vascular branch points.

Further Explanation:

- Blood flow in normal vessels typically exhibits **laminar flow (streamline flow)**. This means the blood moves in **parallel layers**, and the **distance between each layer and the vessel wall remains constant**. Laminar flow is the **most efficient** form of flow and **requires the least amount of energy**.
- The velocity profile of laminar flow is **parabolic**, not linear. This occurs because the layer of blood in direct contact with the vessel wall experiences the **greatest frictional forces**, so its velocity is **nearly zero**. Each successive layer toward the center encounters **less resistance** and moves at a **progressively higher velocity**, with the **highest velocity at the central axis** of the vessel.
- In certain situations, obstacles in the flow path disrupt laminar flow and create **turbulent flow**. In turbulent flow, blood movement becomes **disorganized**, with **eddies and vortices**, and this type of flow **requires more energy**.
- Physiologically, turbulent flow can occur in **large vessels** such as the **proximal aorta** and **pulmonary artery**, and at **arterial branch points**. Pathological conditions can also produce turbulence, such as **vascular stenosis** or **irregular, rough endothelial surfaces**.

Further Explanation:

- In general, laminar blood flow is silent, whereas **turbulent flow is audible**. Turbulence can therefore be heard at **branching points** or in the **proximal aorta and pulmonary arteries**. In vessels with smooth endothelium and normal laminar flow, **no sound is detected**.
- This principle is also applied clinically—for example, in **hemodialysis arteriovenous shunts**, where turbulence produces a **palpable thrill** and **audible bruit**, and in **blood pressure measurement** using a mercury sphygmomanometer. When the cuff is inflated around the arm, it compresses the vessel, creating **partial occlusion** and generating turbulence.
- As the vessel begins to reopen, the turbulent flow becomes audible through the stethoscope, allowing identification of the **systolic pressure** (**the first audible turbulent sound as the vessel reopens**) and the **diastolic pressure** (**the point at which the sounds disappear as flow returns to laminar**).

Laminar Blood Flow

- The parabolic profile develops because the layer of blood next to the vessel wall adheres to the wall and, essentially, does not move.
- The next layer of blood slips past the motionless layer and moves a bit faster.
- Each successive layer of blood toward the center moves faster yet, with less adherence to adjacent layers.
- Thus, the velocity of flow at the vessel wall is zero, and the velocity at the center of the stream is maximal.

لا حول ولا قوة إلا بالله

Turbulent Blood Flow

- In turbulent flow, the fluid streams do not remain in the parabolic profile; instead, the streams mix radially and axially.
- Because kinetic energy is wasted in propelling blood radially and axially, more energy (pressure) is required to drive turbulent blood flow than laminar blood flow.
- Laminar flow is silent, while turbulent flow is audible.

Reynold number

- A dimensionless number that is used to predict whether blood flow will be laminar or turbulent.
- If Reynolds number is 200-400, blood flow is turbulent at some branches.
- If Reynolds number is greater than 2000 it is turbulent flow even in straight smooth vessels.
- The tendency of blood flow in a given vessel to become turbulent can be assessed by calculating the Reynolds number (discussed in the next lecture). If the Reynolds number **falls** between 200 and 400, the flow is generally laminar, except at certain vascular branches. However, if the Reynolds number **is greater than** 2000, turbulent flow may occur even in smooth, straight vessels. Do your own research.

PHYSIOLOGY QUIZ LECTURE 1

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