PHYSIOLOGY

بسم الله الرحمن الرحيم

Final | Lecture #2

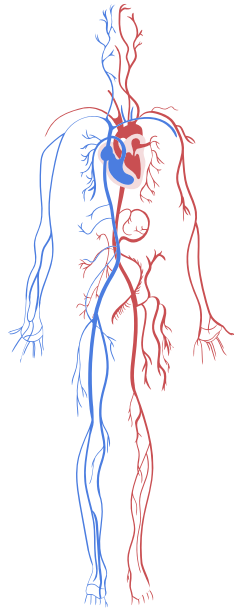
Vascular Hemodynamics (Pt.2)

وَلَقَدْ خَلَقْنَا الْإِنسَانَ وَنَعْلَمُ مَا تُوَسْوِسُ بِهِ نَفْسُهُ ۖ وَنَحْنُ أَقْرَبُ إِلَيْهِ مِنْ حَبْلِ الْوَرِيدِ

اللهم إنّا نعوذ بك من شرور أنفسنا ومن سيئات أعمالنا

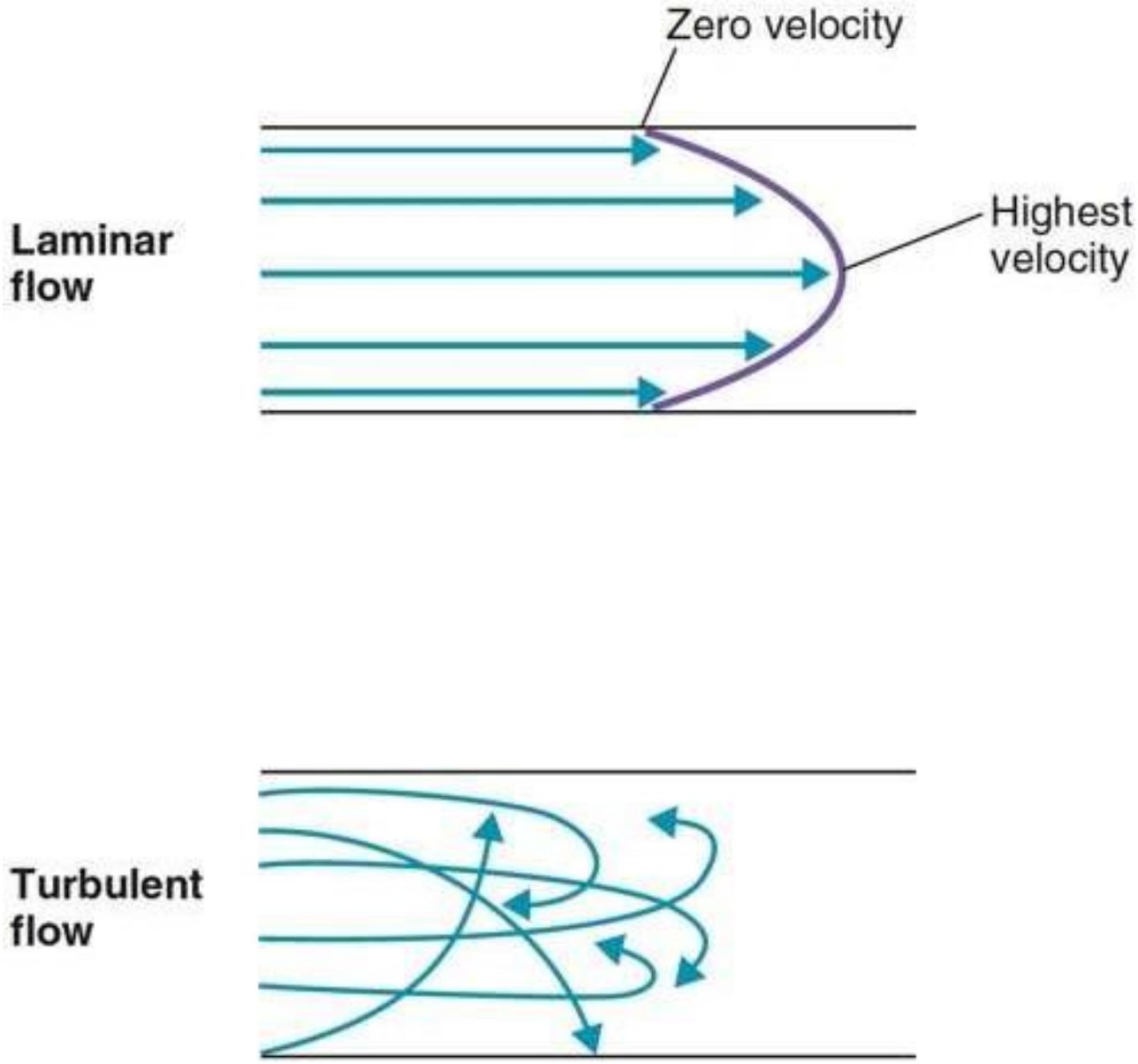
Written by: Leen Mamoon

Reviewed by: Leen Mamoon



Vascular hemodynamics-2

"اللهم إني أسألك فهم النبيين وحفظ المرسلين والملائكة المقربين، اللهم اجعل ألسنتنا
عامرة بذكرك، وقلوبنا بخشيتك، إنك على كل شيء قدير"



As previously explained, **blood flow** is primarily **laminar**, or streamlined, occurring in distinct layers. We also described the parabolic velocity profile of this laminar flow. Subsequently, it was noted that under certain **physiological** or **pathological conditions**, **blood flow** becomes **turbulent, losing its laminar organization and moving in multiple directions rather than in layers.** Consequently, it is necessary to have methods to predict whether blood flow will be laminar or turbulent.

Reynolds number

- Rn : Inertia / Friction

✓ **Reynolds number** represents the ratio between **inertial** and **frictional** forces in the blood.

$$N_R = \frac{\rho d v}{\eta}$$

where

N_R = Reynolds number

ρ = Density of blood

d = Diameter of blood vessel

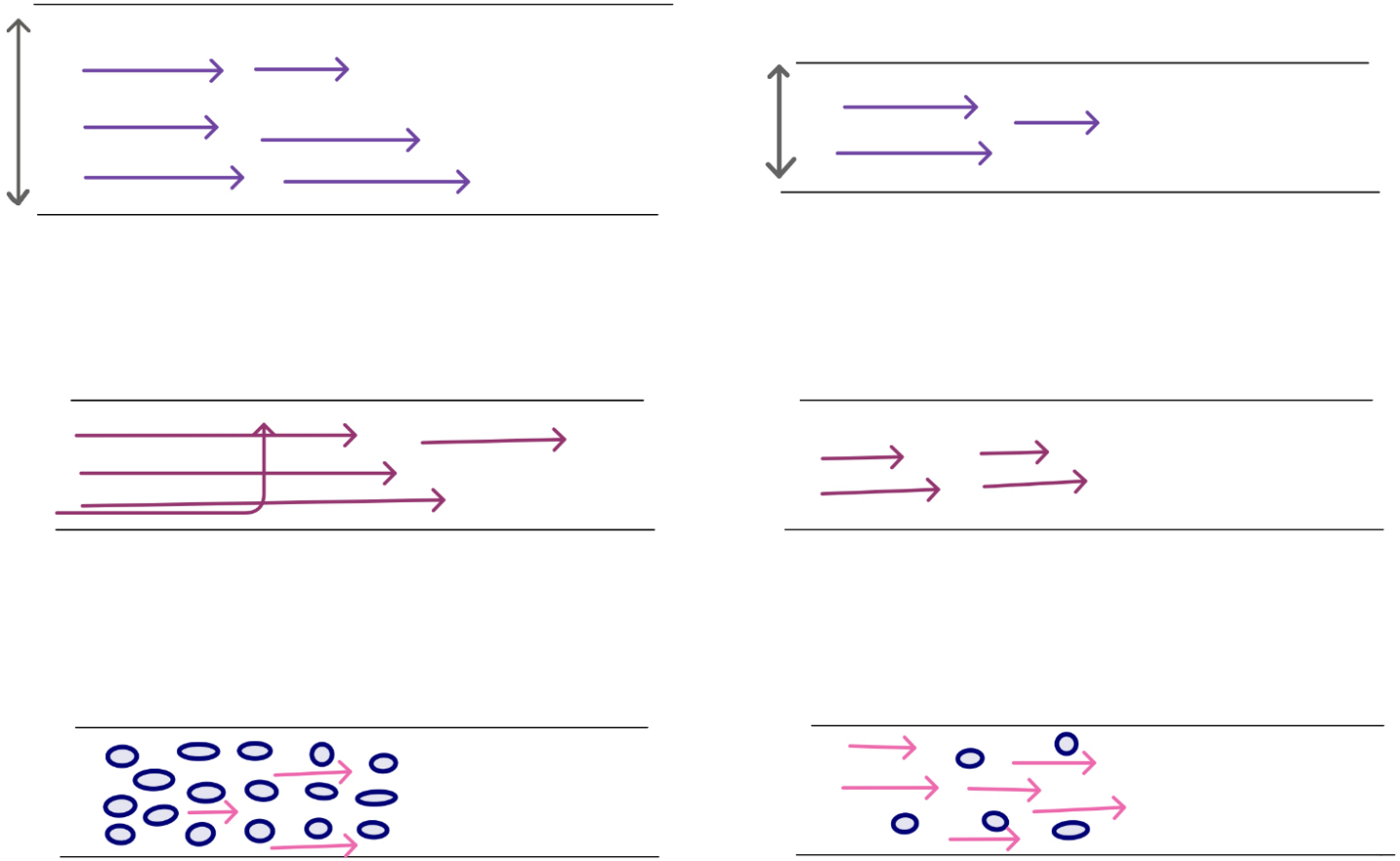
v = Velocity of blood flow

η = Viscosity of blood

- ✓ **A higher Reynolds number** indicates a **greater tendency** for **blood flow** to become **turbulent**, meaning **turbulence** occurs **when inertial forces dominate over viscous forces.**

- ✓ Although **blood density** contributes to the Reynolds number, it is physiologically the **least important factor** because it **rarely changes** or has **significant clinical implications**. In contrast, the **diameter** of a blood vessel is more **influential**: a **larger diameter increases** the **Reynolds number** and, consequently, the **tendency toward turbulence**. Similarly, **higher blood velocity increases** the **Reynolds number** and **promotes turbulence**.
- ✓ Conversely, **higher blood viscosity**, which reflects the frictional forces between blood cells, **lowers the Reynolds number** and reduces the tendency for turbulent flow… **next slide**

Reynolds number



A) Vessels Diameter

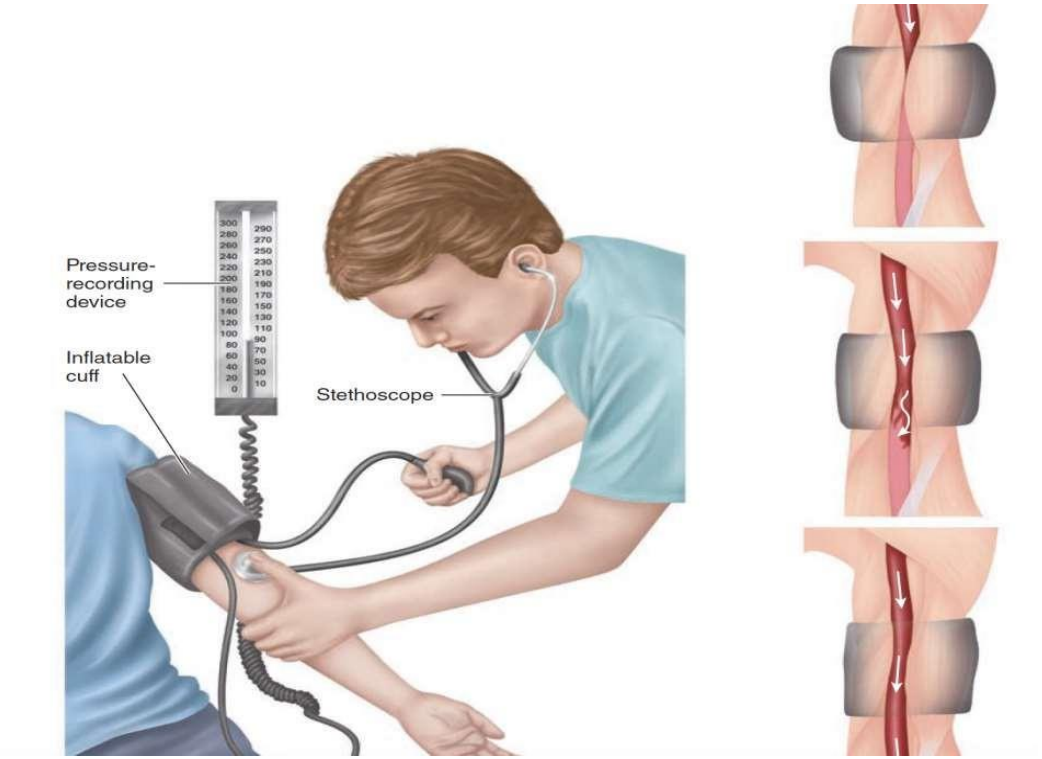
When comparing vessels of different diameters, a **larger** diameter **allows more layers of blood to flow**, **increasing** the likelihood of **turbulence** compared to a **smaller** diameter, which **restricts** the **potential for turbulent flow.**

B) Blood velocity

Higher flow velocity **increases** the Reynolds number and the **tendency toward turbulence,** analogous to vehicles on a highway: the faster the traffic moves, the greater the chance for disorderly movement.

C) Blood viscosity

reflects the proportion of particles such as red blood cells, affects frictional forces. **Higher** viscosity **increases internal friction and promotes laminar flow,** thereby **reducing** the likelihood of **turbulence**. Conversely, **lower** viscosity **decreases frictional resistance**, **allowing greater potential for turbulent flow.**



In Summary:
1) Inflate cuff ↑ above systolic → no blood flow → no sound.
2) Gradually deflate cuff ↓ → blood flows turbulently → first sound = systolic BP.
3) Fully deflate cuff ↓ → laminar flow → no sound = diastolic BP.

- ✓ **Laminar blood flow** is generally **silent**, whereas **turbulent flow** is **audible. Turbulent flow** is responsible for the **cardiovascular sounds detected with a stethoscope,** including **bruises** and **murmurs**, and it forms the **basis** for the **auscultatory method of measuring blood pressure**

- ✓ In this method, a **cuff** connected to a **mercury sphygmomanometer** is placed on the **arm**, and a **stethoscope** is positioned over the **antecubital artery,** The **cuff** is then **inflated** until its **pressure exceeds the systolic blood pressure, at which point blood flow ceases and no sound is heard.**

- ✓ As the **cuff** is gradually **deflated, blood begins to flow through the partially compressed artery**, creating **turbulent flow,** The **first audible sound corresponds to the systolic blood pressure,** This occurs because the **narrowing of the vessel increases the Reynolds number, thereby increasing the tendency for turbulence, which produces the audible sound.**

- ✓ **Further deflation of the cuff** eventually allows the **artery to fully reopen, restoring laminar flow and eliminating audible sounds.** The point at which **sounds disappear corresponds to the diastolic blood pressure.**

Reynolds number clinical implications

- Anemia
- Polycythemia
- Pregnancy
- Thrombus
- Shock
- Stenosis
- Hyperthyroidism

✓ Under normal **physiological conditions**, the **Reynolds number** typically **ranges between 200 and 400**, indicating **predominantly laminar blood flow except** at **branching points or regions of high flow velocity,** such as the aorta, **When the Reynolds number exceeds 2000**, **turbulent blood flow** is **predicted** in most vessels.

✓ In clinical cases, it is important to assess whether a given condition would result in a Reynolds number higher or lower than normal, and to understand the underlying mechanisms (**The doctor asked about these clinical conditions, I will explain them in the next slide**)

Reynolds number clinical implications

1.Anemia → Blood is less thick (↓ **viscosity**), so it flows more easily, This can make the flow more likely to become turbulent (↑ **turbulence**).

2.Polycythemia → Blood is thicker (↑ **viscosity**), which slows down turbulence (↓ **turbulence**).

3.Pregnancy → Heart pumps more blood (↑ **cardiac output**), so blood flows faster (↑ **velocity**) → ↑ **Reynolds number** →(↓ **turbulence**).

4.Thrombosis → A blood clot slows blood flow (↓ **velocity**) → ↓ **Reynolds number** →(↓ **turbulence**).

5.Shock → Heart pumps less blood (↓ **cardiac output**) → ↓ **velocity** → ↓ **Reynolds number** →(↓ **turbulence**).

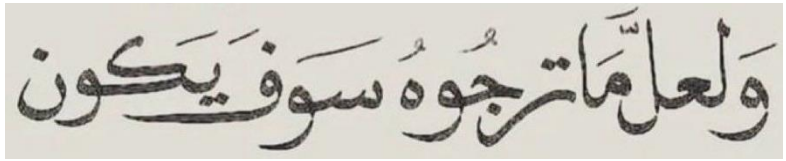
6.Stenosis → Narrowed blood vessel → blood has to move faster through the tight space (↑ **velocity**) → ↑ **Reynolds number** → ↑ **turbulence**.

7.Hyperthyroidism → Heart pumps more blood (↑ **cardiac output**) → ↑ **velocity** → ↑ **Reynolds number** → ↑ **turbulence**.

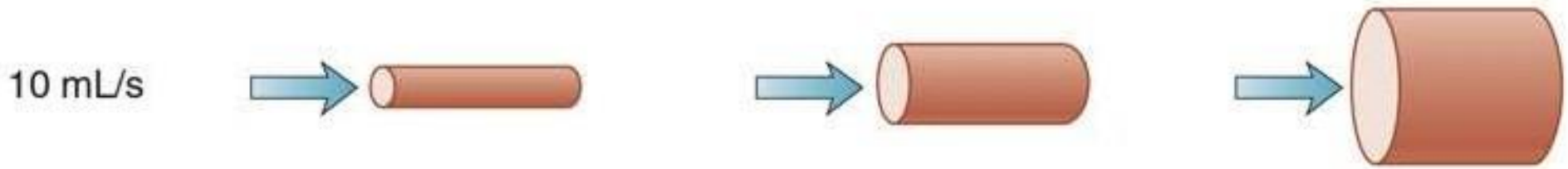
Velocity of blood flow

- ✓ **Velocity** is defined as the distance traveled per unit of time and can also be expressed as the **flow rate divided by the cross-sectional area of the blood vessel.**

- $V = F/A$

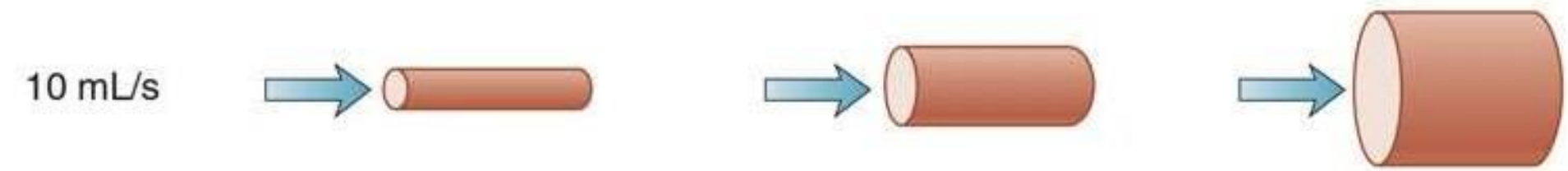


$$v = Q/A$$



Area (A)	1 cm^2	10 cm^2	100 cm^2
Flow (Q)	10 mL/s	10 mL/s	10 mL/s

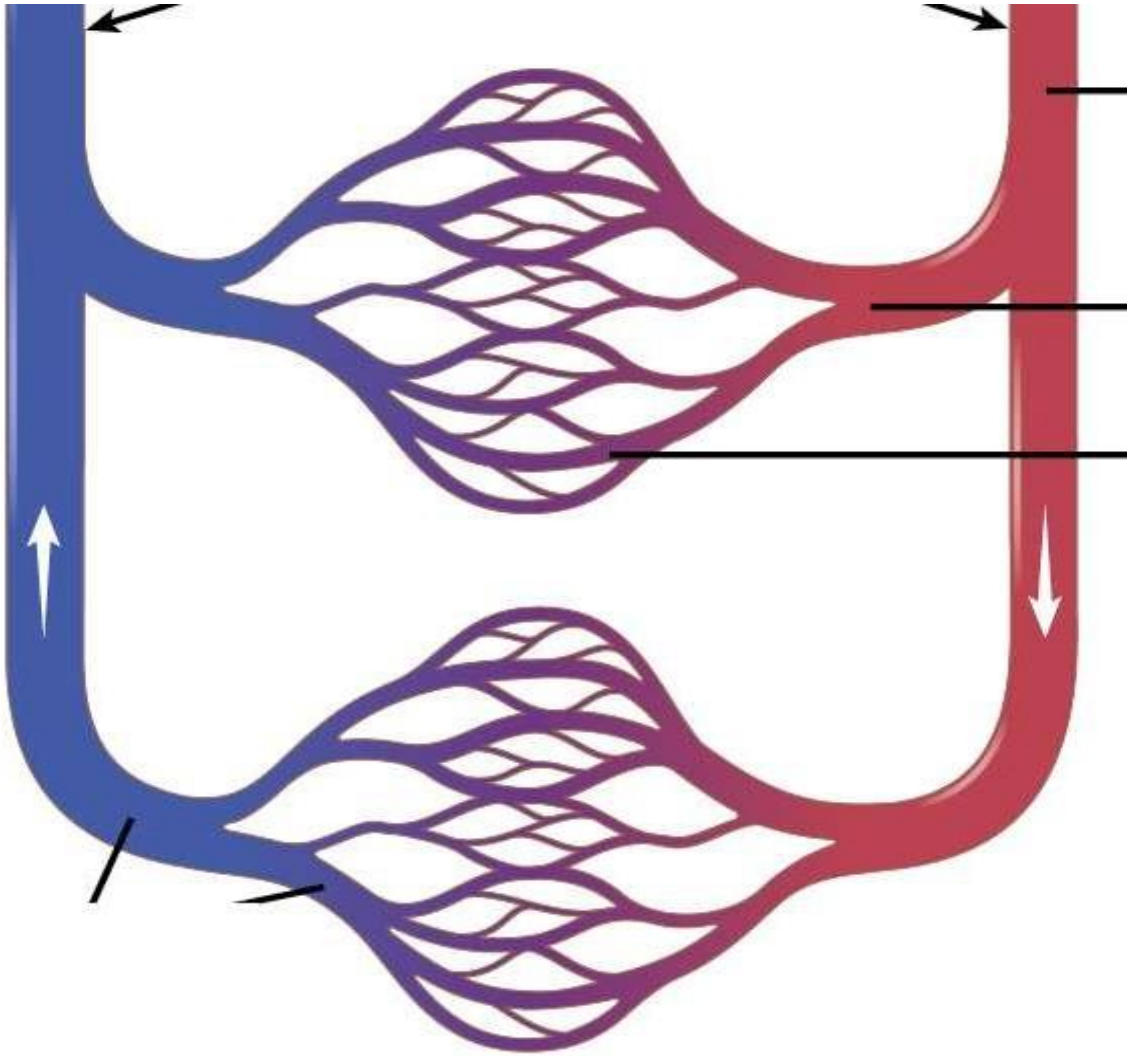
$$v = Q/A$$



Area (A)	1 cm^2	10 cm^2	100 cm^2
Flow (Q)	10 mL/s	10 mL/s	10 mL/s
Velocity (v)	**10 cm/s**	**1 cm/s**	**0.1 cm/s**

- ✓ **the larger the cross-sectional area or diameter, the lower the blood velocity. Therefore, there is an inverse relationship between cross-sectional area and blood velocity.**

- ❖ in which segment of the vasculature would you expect the highest blood velocity?

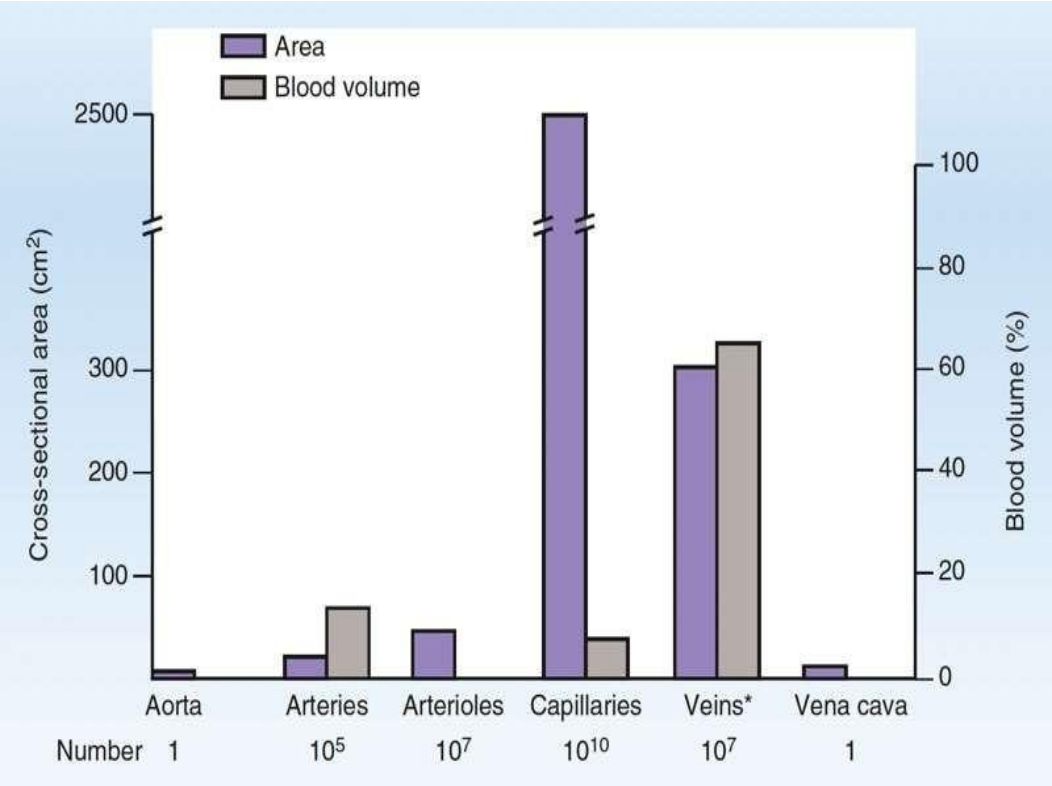


- ✓ **The aorta** exhibits the **highest blood velocity,** despite **its large diameter,** This can be understood by considering that **blood velocity is inversely related to cross-sectional area when flow is constant, This is important because the aorta acts as a conduit, transferring blood from the left ventricle to the smaller downstream vessels after dampening the pulsatility of the flow.**

- ✓ If we compare **the total flow through the major arteries, arterioles, capillaries, venules, and veins, the total cross-sectional area of each segment becomes critical Because the body contains an enormous number of capillaries–** billions in total–**the capillaries collectively have the largest cross-sectional area**, which results in the **lowest blood velocity within the vasculature.**

Velocity of blood flow

- Because of the **inverse relationship between velocity and total cross-sectional area**, the velocity of blood flow will be highest in the **aorta** and lowest in the **capillaries**.
- From the standpoint of capillary function (i.e., exchange of nutrients, solutes, and water), the low velocity of blood flow is advantageous, as it maximizes the time for exchange across the capillary walls.



- ✓ This figure illustrates **the cross-sectional area** and **blood volume** for each segment of the vasculature, The **capillaries** have the **largest cross-sectional area** due to their **enormous number, despite having the smallest diameter.** The large cross-sectional area of capillaries results in the **lowest blood velocity**, which is **critical for efficient nutrient and gas exchange between blood and tissues.**

- ✓ Next are the **veins**, which also have a relatively high cross-sectional area, resulting in low blood velocity, In addition, veins possess unique characteristics, such as **high compliance and capacity, which allow them to store the largest proportion of blood in the body, functioning as a blood reservoir.**

Vessel	Cross-Sectional Area (cm^2)
Aorta	2.5
Small arteries	20
Arterioles	40
Capillaries	2500
Venules	250
Small veins	80
Venae cavae	8

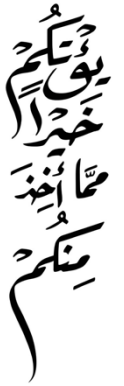
All the information mentioned by the doctor here has been mentioned previously.

Series resistances

- Within organ.
- The total resistance of the system arranged in series is equal to the sum of the individual resistances.
- The total resistance of a vascular bed is determined in large part by the arteriolar resistance.
- When resistances are arranged in series, the total flow at each level of the system is the same.

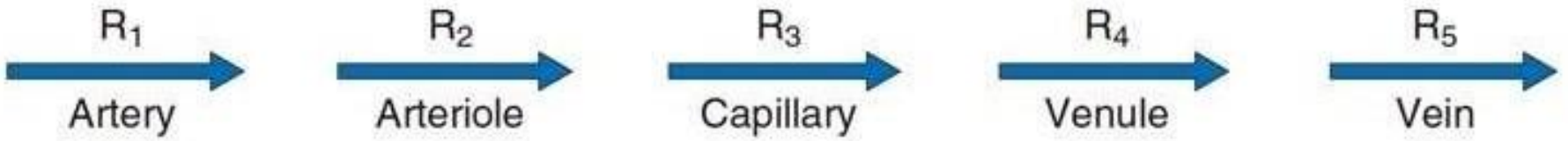
Series resistances

- Although total flow is constant at each level in the series, the pressure decreases progressively as blood flows through each sequential component.
- The greatest decrease in pressure occurs in the arterioles because they contribute the largest portion of the resistance.



SERIES RESISTANCES

$$R_{total} = R_1 + R_2 + R_3 + R_4 + R_5$$



- ✓ **Increasing the resistance in any individual segment will increase the total resistance.** For example, in **chronic hypertension, arterioles constrict**, which **increases their resistance** (As a reminder, the radius of the vessel is the most important factor controlling resistance) Therefore, **increasing resistance in the arterioles increases the total vascular resistance.**

Parallel resistances

- ✓ In a parallel arrangement, such as **when the aorta branches into different arteries to supply blood to various organs and systems,** each branch acts as a parallel circuit, **This arrangement is important because it allows individualized control of blood flow to each organ, relatively independent of blood flow in other organs.**

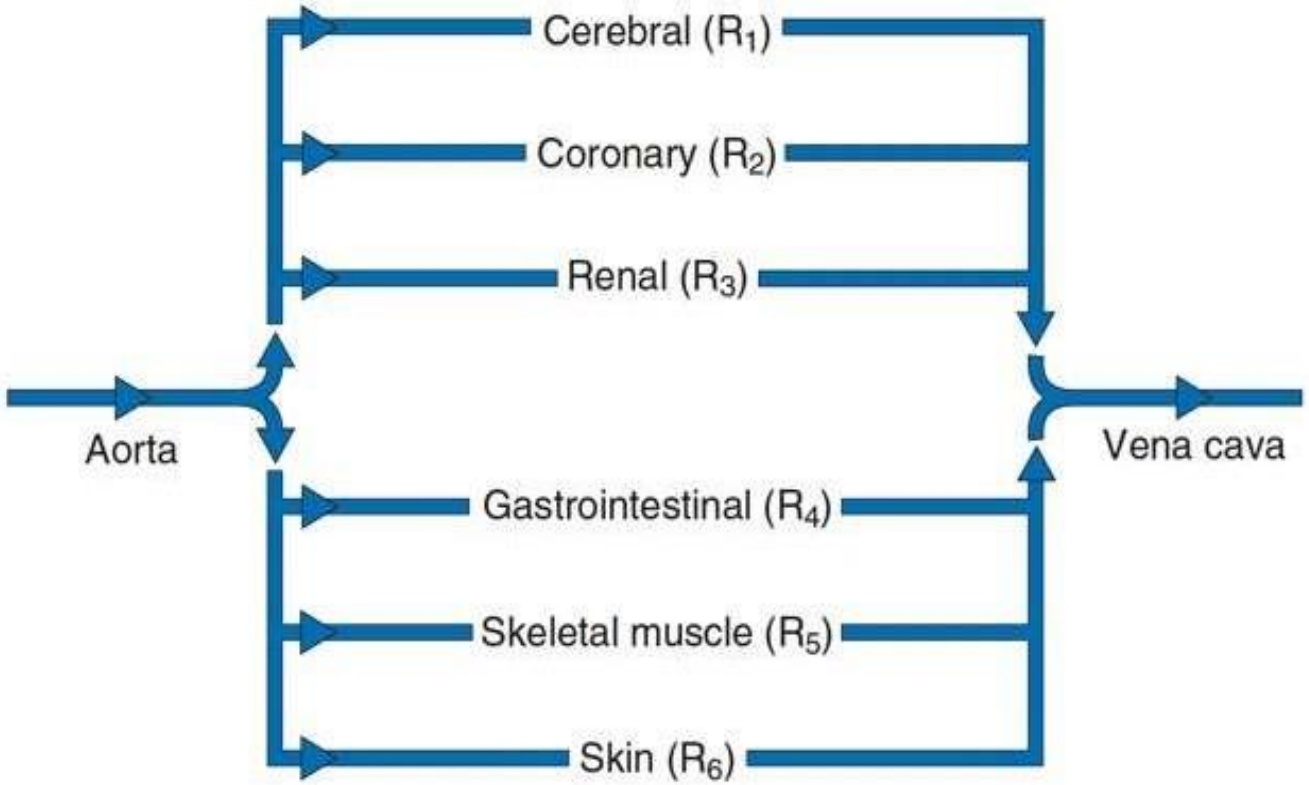
- the total resistance in a parallel arrangement is less than any of the individual resistances.
- When blood flow is distributed through a set of parallel resistances, the flow through each organ is a fraction of the total blood flow.
- The effects of this arrangement are that there is no loss of pressure in the major arteries and that mean pressure in each major artery will be the same and be approximately the same as mean pressure in the aorta.

Parallel resistances

- Another predictable consequence of a parallel arrangement is that adding a resistance to the circuit causes total resistance to decrease.
- if the resistance of one of the individual vessels in a parallel arrangement increases, then total resistance increases.

PARALLEL RESISTANCES

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} + \frac{1}{R_6}$$



- Consider a scenario in which one of these parallel circuits is removed—for example, a patient undergoing nephrectomy due to kidney disease. With the removal of the kidney, that parallel circuit is eliminated. **The question arises: what happens to the total vascular resistance in this patient?**

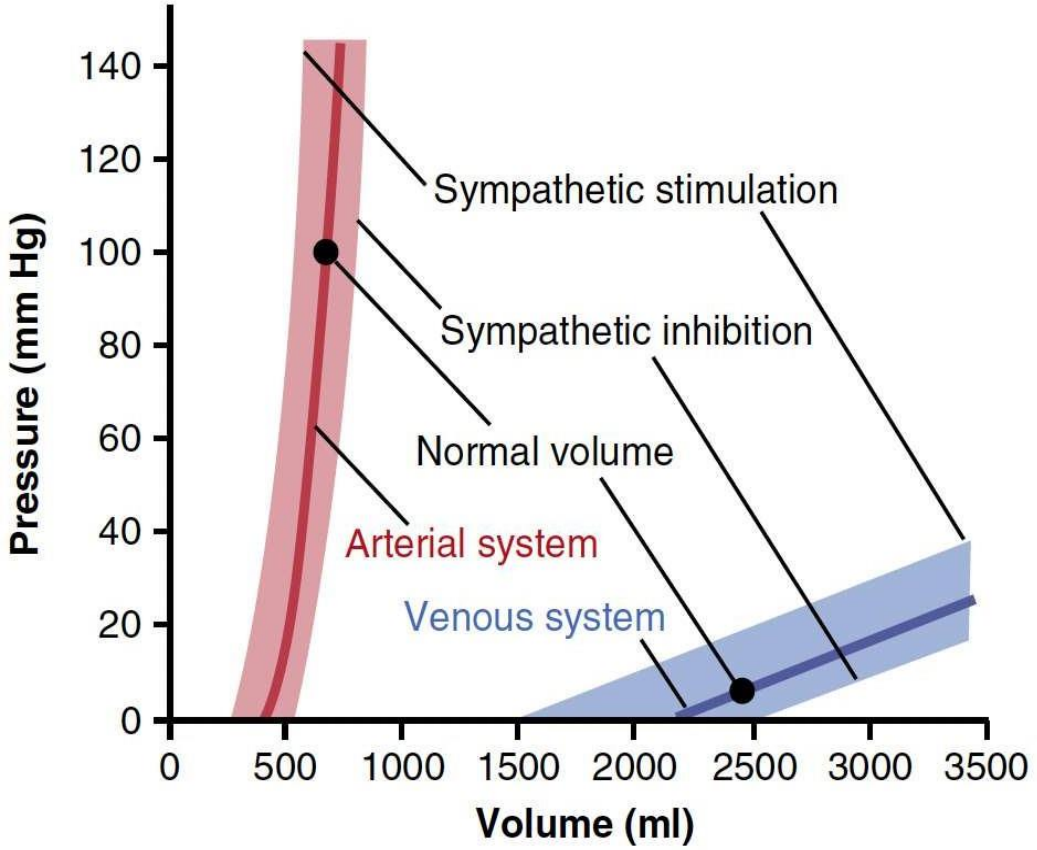
✓ After nephrectomy, the total vascular resistance of the system increases because the blood no longer has that parallel pathway that helped lower the overall resistance.

Compliance

- ✓ **Delta V / Delta P represents how much volume a blood vessel can accommodate for a given change in pressure.**

- increase in vascular smooth muscle tone caused by sympathetic stimulation increases the pressure at each volume of the arteries or veins, whereas sympathetic inhibition decreases the pressure at each volume.
- For example, an increase in vascular tone throughout the systemic circulation can cause large volumes of blood to shift into the heart, which is one of the principal methods that the body uses to rapidly increase heart pumping.
- Sympathetic control of vascular capacitance is also highly important during hemorrhage.

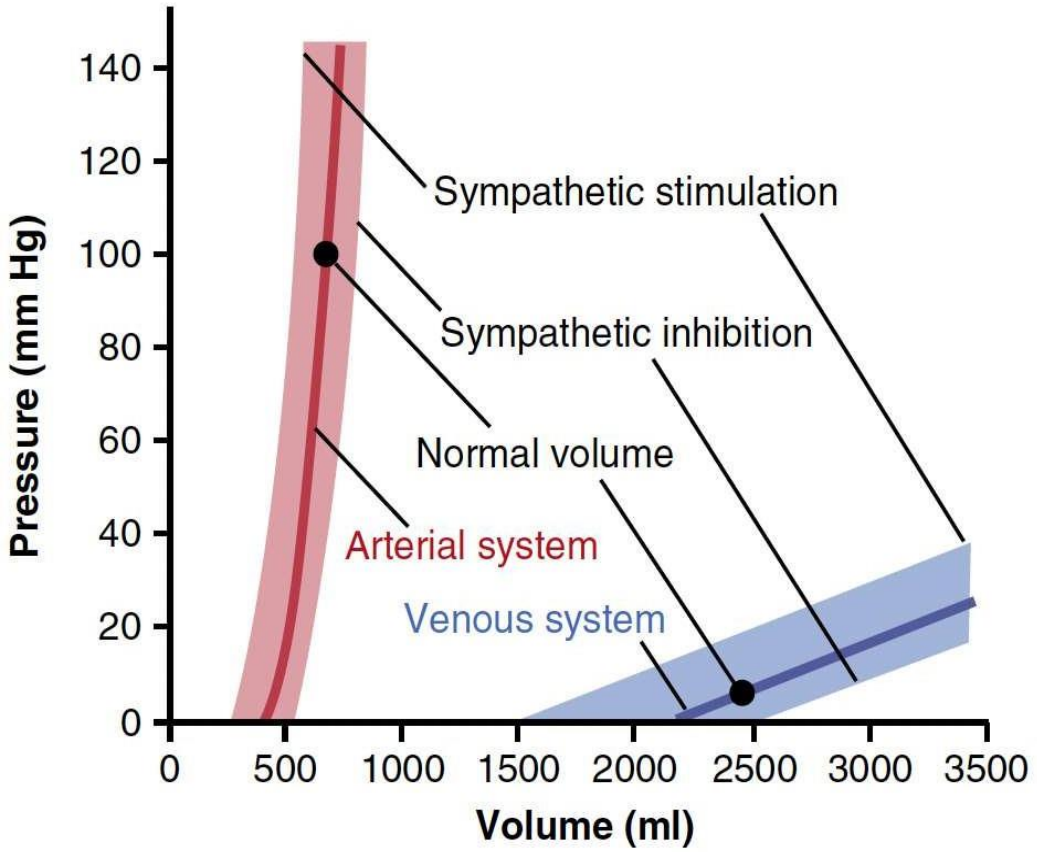
Volume-Pressure Curve



- ✓ This figure illustrates the **relationship between volume, pressure, and the compliance curve. The red curve represents the arterial system, whereas the blue curve represents the venous system.** We aim to examine how a change in blood volume is accompanied by a corresponding change in pressure in both systems.

- ✓ Starting with the **arterial system**: A volume of approximately **400 mL** corresponds to a pressure of **0 mmHg**. When the **pressure increases** to **100** mmHg, the **blood volume rises** to nearly **700 mL.** Thus, a volume change of **300 mL** results in a **100 mmHg increase** in **arterial pressure.**

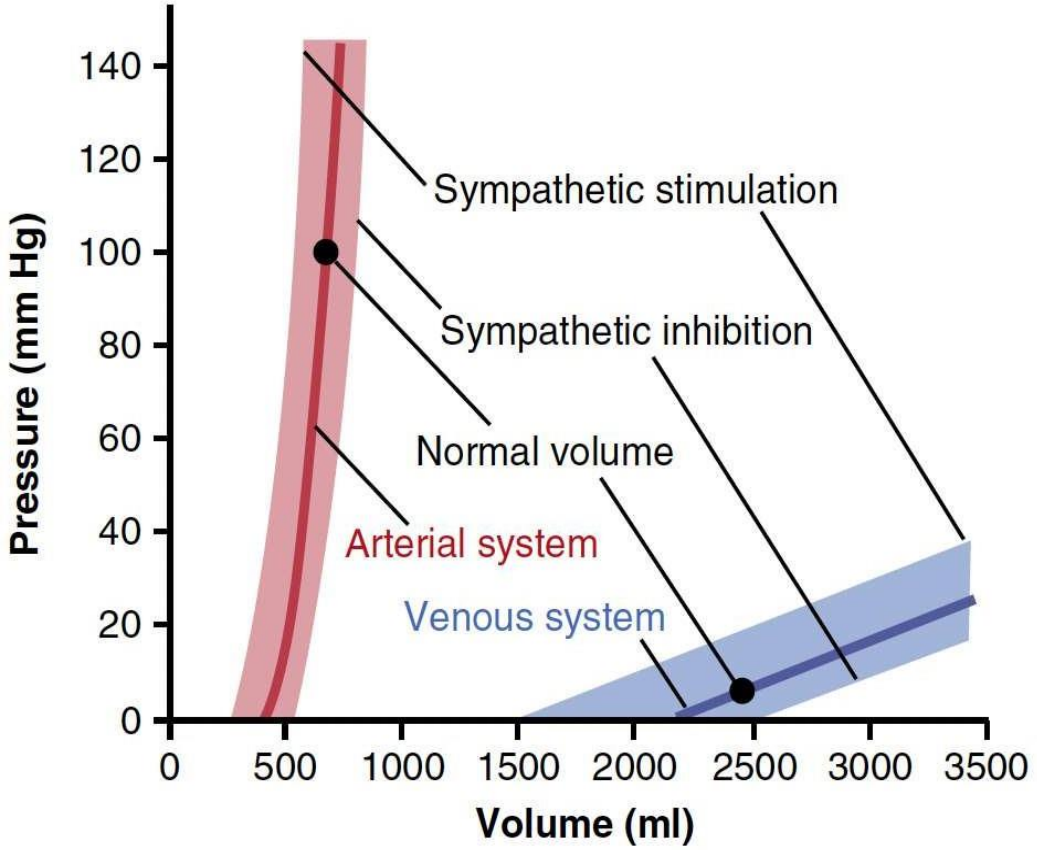
Volume-Pressure Curve



- ✓ In contrast, **the venous system** begins with a much **higher baseline volume and much lower pressures.** For example, a volume of about **2,200 mL** corresponds to **0 mmHg**. Increasing this volume by roughly **300 mL** produces a pressure change of less than **5 mmHg,** This demonstrates that veins are far more compliant than arteries, meaning that **a large change in volume produces only a minimal change in pressure.**

- ✓ This property is clinically important, During fluid administration or blood transfusion, **the venous system can accommodate significant volumes without major disturbances in hemodynamics because of its high compliance and capacitance,** Likewise, during blood loss, veins act as an effective blood reservoir.

Volume-Pressure Curve



- ✓ The figure also shows **the effect of sympathetic stimulation and sympathetic inhibition on both arteries and veins.**
- ✓ **Sympathetic activation stimulates vascular smooth muscle**—primarily in the arterioles—**causing vasoconstriction**. As a result, at a pressure of **100 mmHg, the arterial volume decreases** from about **700 mL** (normal) to roughly **300 mL** with **sympathetic stimulation.** A similar **reduction** in **volume per pressure occurs in the venous system**. This mechanism is important when an **increase in venous return or cardiac output is required, as blood volume is shifted centrally.**

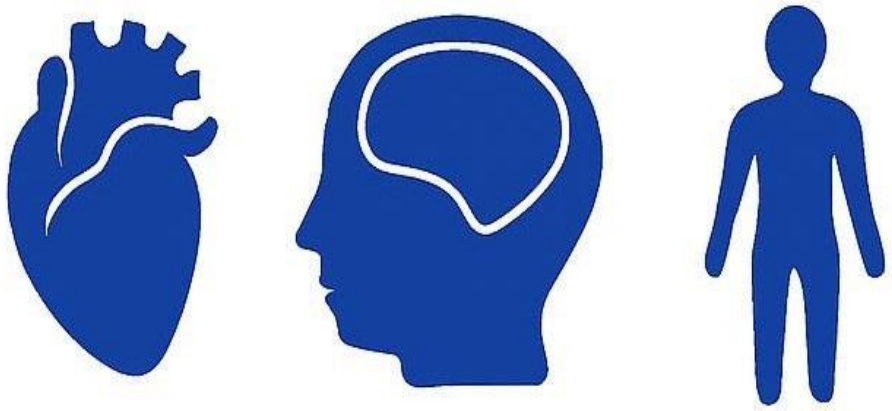
وَلِلَّهِ الْأَسْمَاءُ الْحُسْنَى فَادْعُوهُ بِهَا

العلم بأسماء الله الحسنى أجل العلوم وأشرفها، لأن به يعرف الناس ربهم وخالقهم، خالق السماوات والأرض، ويتبع ذلك عبادته، ومحبته، وخشيته، وتعظيمه سبحانه وتعالى، ثم إنّ شرف العلم يكون من شرف المَعلوم، ولمّا كان المَعلوم من تعلّم أسماء الله الحسنى هو الله سبحانه وتعالى؛ كان شرف تعلّم أسماء الله تعالى عظيمًا.

فتظهر أهمية معرفة أسماء الله وصفاته في جوانب عدّة لا يجب أن تخفى على كل مسلمٍ، ومنها:

1. أن العلم بالله تعالى وأسمائه وصفاته أصل العلوم وأساس الإيمان، فإذا عرف العبدُ ربَّه عَبَدَهُ حقَّ العبادة. يقول الأصبهاني: "قال بعض العلماء: أول فرض فرضه الله تعالى على خلقه معرفته، فإذا عرفه الناس عبدوه قال الله تعالى: {فاعلم أنه لا إله إلا الله}". وقال: "ولو أراد إنسان أن يتزوج أو يزوِّج أو يعامل إنسانا؛ طلب أن يعرف اسمه وكنيته، واسم أبيه وجده، وسأل عن صغير أمره وكبيره، فالله الذي خلقنا ورزقنا ونحن نرجوا رحمته ونخاف من سخطه أولى أن نعرف أسماءه ونعرف تفسيرها ".
2. التلازم الوثيق بين صفات الله تعالى وما تقتضيه من العبادات الظاهرة والباطنة، فلكل صفة عبادة خاصة هي من مقتضاها، وفي ذلك يقول ابن القيم: "فلكل صفة عبودية خاصة هي من موجباتها ومقتضياتها، أعني: من موجبات العلم بها والتحقق بمعرفتها وهذا مطرد في جميع أنواع العبودية التي على القلب والجوارح: فعلم العبد بتفرد الرب تعالى بالضر والنفع، والعطاء والمنع، والخلق والرزق، والإحياء والإماتة؛ يثمر له عبودية التوكل عليه باطنا، ولوازم التوكل وثمراته ظاهرًا. وعلمه بسمعه تعالى وبصره وعلمه، وأنه لا يخفى عليه مثقال ذرة في السموات ولا في الأرض، وأنه يعلم السر وأخفى...، فرجعت العبودية كلها إلى مقتضى الأسماء والصفات".
3. . للعلم بأسماء الله الحسنى وصفاته ثمرات طيبة في التعامل مع الفتن والمصائب والمكروهات التي تصيب العبد، فالعبد إذا علم أن الله تعالى حكيم لا يفعل شيئًا عبثًا، وأنه عدل لا يظلم أحدًا، وأنه رحيم بعباده يبتليهم ليغفر لهم؛ إذا علم العبد ذلك كله رضي وصبر على المكروه والمصاب الذي ينزل به، واطمأن قلبه وفوض أمره لربه سبحانه.

وغيرها الكثير من الثمرات التي تنعكس على عبادة المسلم وجميع جوانب حياته الدنيوية...



PHYSIOLOGY
QUIZ
LECTURE 2

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Corrections from previous versions:

Versions	Slide # and Place of Error	Before Correction	After Correction
V0 → V1			
V1 → V2			