HEMODYNAMICS

DR. NAJEEB LECTURE NOTES

BY FATIMA HAIDER

KGMC

http://koracademy.com/

The function of cardiovascular system is to transfer nutrients to the tissue and takes the waste products from the tissues to the organ of disposals.

BLOOD CIRCULATION PATHWAY

Left Atrium → Left ventricle → Aorta → Arteries (Systemic arterial tree) → Arterioles → Capillaries → Venules → Veins → Vena Cava → Right Atrium → Right ventricle → Pulmonary artery → Pulmonary capillaries → Pulmonary veins → Left Atrium

Systemic circulation lies between left heart and right heart. Pump of the systemic circulation is the left heart. Systemic circulation is a high-pressure circulation.

Pulmonary circulation has major pump as right ventricle.

CARDIAC OUTPUT

In steady state circumstances, cardiac output of left heart and right heart is equal i.e. 5L/min

A fraction of cardiac output of left heart goes to every circulatory bed in systemic circulation.

However, total pulmonary vascular bed receives the whole cardiac output of right heart as between right heart and left heart there is only one vascular bed i.e. pulmonary vascular bed.

Percentage of cardiac output going to different tissues:

- Coronary circulation – 5%
- Cerebral circulation – 15%
- Gastrointestinal circulation – 25%
- Renal circulation – 25%
- Musculoskeletal circulation – 25%
- Cutaneous (skin) circulation – 5%

However blood flow to different vascular beds can be regulated and altered by changing the diameter of arterioles.

PRESSURE GRADIENTS

Pressures in:

- Left Atrium : 5 – 8 mmHg
- Left ventricle : 0 – 120 mmHg
- Aorta : 120 mmHg (systolic pressure)
  80 mmHg (Diastolic pressure)
- Mean arterial pressure : 93 mmHg
- Capillaries : 30 mmHg
  However in renal capillaries : 50 mmHg
- Venules : 15 mmHg
- Vena cava : 4 mmHg
- Right atrium : 0 mmHg
- Right ventricle : 0 – 25 mmHg
- Pulmonary artery : 25 mmHg (during systole)
  8 mmHg (during diastole)
- Pulmonary veins : 5 mmHg
- Mean arterial pressure in pulmonary system : 15 mmHg

MEAN ARTERIAL PRESSURE

Mean arterial Pressure = Diastolic pressue + 1/3 pulse pressure

Pulse pressure = systolic pressure – diastolic pressure

= 120 – 80

= 40 mmHg

Mean arterial Pressure = 80 + 40/3

= 80 + 13

= 93 mmHg

Hence we can say that with a pressure of 93mmHg, blood is pushed forward towards the arterioles from the major arteries.

ARTERIES

Aorta and its main branches are also called elastic arteries because of their elastic nature. During systole, when stroke volume enters into major arterial tree, the arterial tree stretches due to its elasticity and accommodates incoming stroke volume. In this manner, systolic pressure does not increase dangerously.

During diastole, due to elasticity of arteries, these arteries recoil inward so in this way they maintain diastolic pressure so blood keeps moving forward in systemic circulation.

ARTERIOLES

Arterioles are rich in smooth muscles. Hence they have a capacity to constrict and dilate.

In normal healthy person, arterioles are semi-constricted and offer major resistance to blood flow from systemic arterial side to venous side. This resistance to blood flow can be altered by arterioconstriction or arteriodilation.

Arterioles are richly innervated by sympathetic nerve endings.

Splanchnic, renal and cutaneous arterioles are very rich in α_1-adrenergic receptors. When epinephrine or norepinephrine stimulate these receptors, arterioconstriction takes place.

Skeletal muscles are rick in beta2-adrenergic receptors. When these receptors are stimulated, arteriodilation takes place.

When blood passes through the arterioles, pressure drops as pressure has been utilized in overcoming the resistance through the arterioles.

CAPILLARIES

Capillary play a role of exchange vessels. Capillaries are very thin walled. From capillaries, nutrients can easily pass into interstitial fluid and provide nutrition to tissues. The waste products move from the interstitial fluid into capillaries.

VEINS

Venous system acts a reservoir of blood. 70% of total blood volume is present in veins. Veins have large lumen and are thin walled.

Arteries	Veins
▫ High pressure	▫ Low pressure
▫ Low volume	▫ High volume
▫ Thick walled	▫ Thin walled
▫ Narrow lumen	▫ Wider lumen
▫ Provides blood to exchange vessels	▫ Drain blood from exchange vessels

▫ Systemic arteries have oxygenated blood	▫ Systemic veins have deoxygenated blood

STRESSED AND UNSTRESSED VOLUME

Volume of blood in arteries is called stressed volume as it is under high pressure.

Volume of blood in veins is called un-stressed volume.

Veins can also constrict and dilate. When veins constrict, blood is squeezed towards the heart and through heart, blood eventually shifts to arteries. So in strong vasoconstriction, unstressed volume is decreased while stressed volume increases.

When veins dilate, veins can pool more blood. Hence venous return is reduced. Cardiac output is reduced and stressed volume is also reduced. So venodilation increase the unstressed volume.

VELOCITY OF BLOOD FLOW

Velocity of blood flow $\propto \text{blood flow}$

Velocity of blood flow $\propto \frac{1}{cross\text{−}sectional\ area\ of\ blood\ vessel\ through\ which\ blood\ is\ passing}$

$\text{Velocity in aorta} > \text{arteries} > \text{capillaries}$

$\text{Velocity in vena cava} > \text{venules} > \text{capillaries}$

RELATIONSHIP BETWEEN BLOOD FLOW, PRESSURE GRADIENT AND RESISTANCE

- **Blood Flow** is the amount of blood passing through a part of circulatory system per minute
- **Pressure gradient** is the driving force which drives the blood from high pressure to low pressure
- **Resistance** is impediment to blood flow

Blood flow ∝ pressure gradient (ΔP)

Blood flow $\propto \frac{1}{Resistance\ (R)}$

$\textbf{Blood Flow} = \frac{\mathbf{\Delta P}}{\boldsymbol{R}}$

By re-arranging we can also get

$\mathrm{R} = \frac{\mathbf{\Delta P}}{\boldsymbol{Blood\ flow}}$

We can use this formula to find total peripheral resistance in systemic circulation

Total Peripheral Resistance (TPR) = $\frac{\Delta \mathrm{P}}{Blood\ flow}$

ΔP in systemic circulation = 93 – 0 = 93 mmHg

Total blood flow through the systemic circulation is equal to all the blood which is coming from left ventricle each minute. And amount of blood which is pumped by the heart is called cardiac output. So we can replace blood flow with cardiac output.

$$\textbf{Cardiac output} = \frac{\Delta \mathbf{P}}{\boldsymbol{TPR}}$$

$$\text{TPR} = \frac{\Delta \text{P}}{Cardiac\ output}$$

$$\text{TPR} = \frac{93\text{mmHg}}{5000\ ml/min}$$

$$\text{TPR} = 0.0186 = 0.02\ \text{mmHg/ml/min}$$

By this formula we can find resistance offered by vascular beds in systemic system e.g. to find resistance offered by renal vasculature

$$\text{Blood Flow} = \frac{\Delta \text{P}}{R}$$

$$\text{R} = \frac{\Delta \text{P}}{Blood\ flow}$$

$$\text{R} = \frac{\text{Pressure in renal artery} - \text{pressure in renal vein}}{Renal\ Blood\ flow}$$

POISEUILLE'S EQUATION

This equation sum up all the factors which determine the resistance to blood flow.

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

Here : viscosity of blood

l : length of vessel

r : radius of vessel

VISCOSITY AND RESISTANCE TO BLOOD FLOW

Increased viscosity is observed whenever there is hematocrit increase and is seen in polycythemia. More resistance to blood flow and blood flow is reduced.

In severe anemia, blood becomes less viscous, internal resistance to blood flow becomes less and it will flow more efficiently.

RADIUS OF VESSEL AND RESISTANCE TO BLOOD FLOW

Increase or decrease in radius of vessel has a profound effect on resistance to blood flow as resistance is inversely related to fourth power of the radius. If radius is reduced to half, blood flow increases 16 times. Radius may increase in vasodilation while radius is seen to decrease in vasoconstriction and pathologically due to atherosclerosis.

ARRANGEMENT OF VESSELS AND RESISTANCE TO BLOOD FLOW

Arrangement of vessels also determines the resistance to blood flow. Series arrangement of vessels offer more resistance to blood flow than parallel arrangement of vessels.

VESSELS ARRANGED IN SERIES

The arteries, arterioles, capillaries and veins are an example of series arrangement of blood vessels. For vessels arranged in series, the total resistance is equal to the sum of all resistances.

$R_{total} = R_1 + R_2 + R_3...$

VESSELS ARRANGED IN PARALLEL

Blood leaves the heart through the aorta from which it is distributed to major organs by large arteries, each of which originates from the aorta. Therefore, these major distributing arteries (e.g. carotid, brachial, renal etc.) are arraenged in-parallel with eachother. This further means that the vascular networks of most individual organs are in-parallel with other organ networks. For example, the circulations of the head, arms, GIT, kidneys and legs are parallel circulations.

To find total resistance of vessels arranged in parallel

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.....$

LAMINAR FLOW AND REYNOLD'S NUMBER

Laminar flow is aso called stream-lined flow. Normally blood flow in cardiovascular system is laminar flow. In laminar flow, velocity of blood near the walls of vessels move slowly while velocity of blood is fast in the center of the vessel so parabolic movement is seen in laminar flow.

Turbulent flow is seen in narrow or atherosclerotic vessels. Turbulent flow dissipates a lot of energy. Turbulent blood flow can lead to murmurs or bruits.

Reynold's number predicts whether blood flow through a particular part of vascular system will be streamlined or turbulent. If Reynold's number is higher, blood flow will be turbulent.

Reynold's number = $\frac{\rho v d}{\eta}$

ρ: density of blood

v: velocity of blood flow

d: diameter of vessels

η: viscosity of blood

TURBULENT FLOW EXAMPLES

1. Aorta has high velocity of blood so turbulence can be easily produced in aorta
2. In a patient with severe anemia, viscosity of blood is decreased while velocity is increased so Reynold's number is high and there is turbulent blood flow
   In such patients, when left ventricle ejects the blood, blood moves with such fast turbulence from the left ventricle to the aorta that this turbulent flow becomes audible and is called functional murmur.
3. Due to any obstruction such as thrombus in a vessel, the blood flow passing through the area of thrombus has high velocity (as radius is reduced). Due to high velocity, Reynold's number increase and blood flow becomes turbulent
4. Vessels may also show some degree of turbulence at their branching point.

VASCULAR COMPLIANCE AND CAPACITANCE

Compliance means distensibility (stretching) of a vessel. Veins are more compliant than arteries.

Compliance is the capability of a vessel to hold a particular volume of blood under pressure. If a particular volume of blood is held under high pressure, it means the vessel is less compliant. If the same blood is held under less pressure, it means the vessel is more compliant.

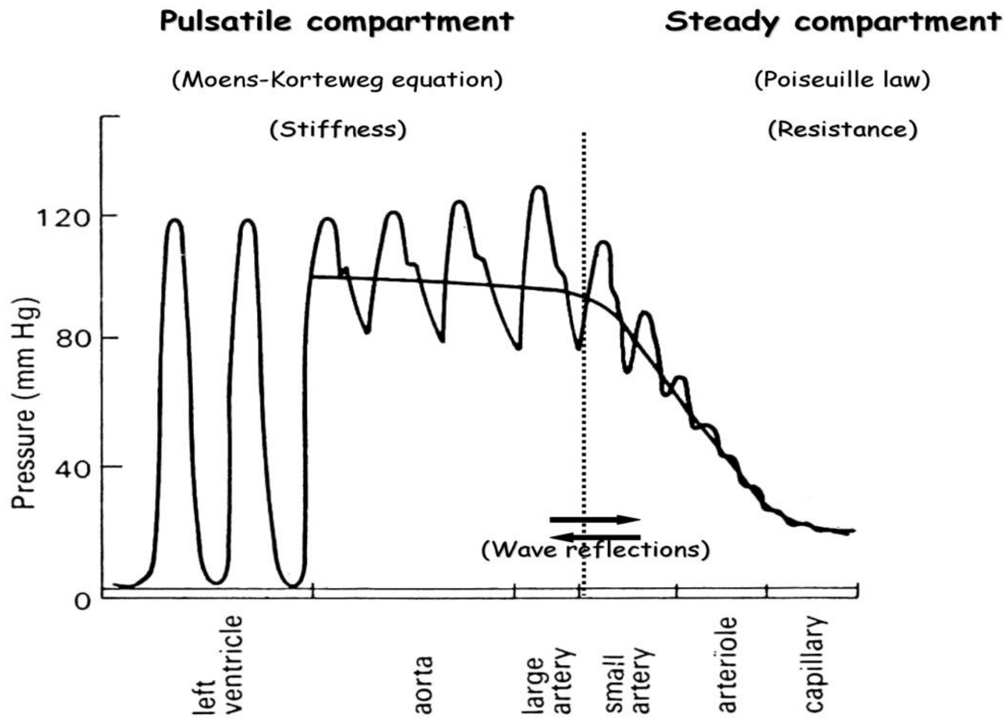
Compliance of veins can be changed e.g. in venoconstriction, compliance of veins decrease.

With aging, arteries becomes stiff and thick walled so they become less compliant which means little increase in volume will lead to high pressure.

Compliance = $\frac{Volume}{Pressure}$

If large volume is accommodated in vessels at less pressure, compliance is more.

PULSATIONS IN ARTERIAL TREE



Pulsations in aorta and arteries are observed due to systole and diastole of left ventricle.

The pulsations seen in major arteries is slightly augmented or increased i.e. pulse pressure of major arteries is greater than that of aorta. The reasons for this are:

1. When ventricles propel the blood into aorta, the pressure wave moves very rapidly towards the major arteries
2. When blood moves to smaller arteries from major arteries, some blood is reflected back into major arteries which increase the pressure in these arteries

Pulsations disappear in arterioles due to high resistance of arterioles.

SYSTOLIC BLOOD PRESSURE

Blood pressure produced during systole of left ventricle when blood is ejected into aorta is called systolic blood pressure.

FACTORS AFFECTING SYSTOLIC BLOOD PRESSURE

1. **Stroke Volume**:
   Larger stroke volume produce high systolic blood pressure
2. **Compliance of arteries:**
   If compliance of arteries is low, systolic blood pressure will be high as distensibility is reduced

DIASTOLIC BLOOD PRESSURE

In diastole there is no ejection of blood flow from left ventricle to aorta so blood pressure is reduced but some blood pressure is still maintained in aorta to propel the blood into arteries.

FACTORS AFFECTING DIASTOLIC BLOOD PRESSURE

1. **Total Peripheral Resistance:**
   If TPR increase e.g. in arterioloconstriction, diastolic blood pressure will increase
2. **Compliance of arterial tree:**
   When vessels becomes less compliant e.g. in old age, during diastole the stiff vessels cannot recoil back and diastolic blood pressure cannot be maintained so diastolic blood pressure drops.
   However in old age, diastolic pressure is seen to increase which is accounted to arteriolar thickening that increases total peripheral resistance.
   Hence the major factor affecting diastolic blood pressure is total peripheral resistance.