Circulatory System and Disorders

Course 5-6

Cardiac Output and Total Peripheral Resistance

Systemic Circulation

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Introduction

- **Cardiac output (CO)** is the quantity of blood pumped into the aorta each minute by the heart. This is also the quantity of blood that flows through the circulation.
- **Venous return** is the quantity of blood flowing from the veins into the right atrium each minute.
- The venous return and the cardiac output must **equal** each other.

Introduction

- Cardiac output varies widely with the level of activity of the body. The following factors, among others, directly affect cardiac output:
  1. the basic level of body metabolism
  2. whether the person is exercising
  3. the person's age
  4. the size of the body.

- For *young, healthy men,* resting cardiac output averages about **5.6 L/min**.
- For *women,* this value is about **4.9 L/min.**

CO = Stroke volume (SV) x Heart Rate (HR)

Stroke Volume x Heart Rate

- **Stroke volume** is the total amount of blood ejected from ventricle during systole (≈70 ml).
- The fraction of the end-diastolic volume that is ejected is called the **ejection fraction** (usually equal to about 0.6).
- **Heart rate** is the total number of heart beats per minute. Unit: Beats per minute (**bpm**). Normally between 60 – 100 bpm.

Factors that effect Stroke Volume

- Main factors that effect stroke volume
  1. **Preload** is the initial length to which muscle is stretched prior to contraction.
  2. **Afterload** is the pressure the heart must work against to eject blood during systole.
  3. **Contractility** is the intrinsic **contractile** function of the ventricle, <u>independent</u> of preload and afterload.

Preload

- Venous return is the primary determiner of preload.

- **Frank-Starling law** of the heart. *Within physiological limits, the heart pumps all the blood that returns to it by way of the veins.*

Preload

Preload

Venous Return

- Venous return is the primary determiner of the EDV or preload.

- Factors effecting venous return:
  1. Total blood volume
  2. Constriction of veins. Increase of venous tone.
  3. Intrathorasic pressure (respiratory pump)
  4. Posture or gravity (standing, sitting or lying)
  5. Muscular activity (pumping action of skeletal muscle = **musculovenous pump**)

Afterload

- **Afterload** is the pressure in the aorta that must be overcome by the contracting left ventricular muscle to open the aortic valve and eject the blood.
- Increases in afterload produce progressively higher peak systolic pressures.
- Normally, mean ventricular afterload is quite constant, because mean arterial pressure is held within tight limits by control mechanism.

Contractility (Inotropy)

- Contractility is the contractile strength of myocardium.
- It defines cardiac performance at a given preload and afterload.
- Increase in contractility = **positive inotropic effect**
- Decrease in contractility = **negative inotropic effect**

Contractility

- Modulation of contractility:
  1. Autonomic innervation (Sym/Parasym)
  2. Circulating cathecolamines
  3. Digitalis and other inotropic agents
  4. Pharmacologic depressants

Contractility Indexes

- The **ejection fraction** which is SV/EDV is widely used clinically as an index of contractility.

- In one method, cardiac catheters are placed in the ventricle and the **maximum rate of pressure development** (***dP/dt*max**) during the isovolumetric contraction is measured.

Heart Rate

- **Heart rate** is the speed of the **heartbeat** measured by the number of contractions (**beats**) of the **heart** per minute (bpm).

- Increase of heart rate (**positive choronotropy**), increases CO.

- Decrease of heart rate (**negative chronotropy**) decreases CO.

Heart Rate

- Change in heart rate does not necessarily result in a proportionate change in cardiac output.
- The reason is that changes in heart rate can inversely affect SV.
- Less time for diastolic filling.

Heart Rate

Factors that effecting heart rate:

1. Autonomic Innervation
   a) Sympathetic system increases
   b) Parasympathetic system decreases.

2. Stretch and Bainbridge Reflex

Stretch and Bainbridge Reflex

- Stretching the heart causes the heart to pump faster.

- That is, stretch of the ***sinus node*** increase the heart rate as much as 10 to 15%.

- In addition, the stretched right atrium initiates a nervous reflex called the ***Bainbridge reflex*** *which increases HR (SVxHR).*

Cardiac Index

- Experiments have shown that the cardiac output increases approximately in proportion to the surface area of the body.

- Therefore, cardiac output is frequently stated in terms of the ***cardiac index***, which is the *cardiac output per square meter of body surface area.*

- The average human being who weighs **70 kilograms** has a body surface area of about **1.7 square** meters, which means that the normal average cardiac index for adults is about **3 L/min/m²** of body surface area.

- Mosteller Formula

$$BSA\ (m^2) = \sqrt{\frac{\text{height (cm)} \times \text{weight (kg)}}{3600\ (\text{cm kg/m}^4)}}$$

Vascular Network

Distribution Vessels

- The **aorta,** is the main vessel.
- **Large arteries** branching off the aorta (e.g., carotid, mesenteric, and renal arteries) distribute the blood.
- Large arteries, serve no significant role in the regulation of pressure and blood flow.
- Once the distributing artery reaches the organ, it branches into **small arteries.** Once they reach diameters of <200 µm, they are termed **arterioles.**

Resistance Vessels

- **Resistance vessels =** Small arteries and arterioles
- They regulate arterial blood pressure and blood flow within organs.
- Resistance vessels are highly innervated by autonomic nerves (particularly sympathetic adrenergic),
- They **constrict** or **dilate** in response to changes in nerve activity

Exchange Vessels

- Vessels that have no smooth muscle and are composed of only endothelial cells and a basement membrane are termed **capillaries.**

- They are the smallest vessels, they have the greatest cross–sectional area because they are so numerous.

Starling Forces

- The net filtration pressure (NFP) is calculated as:

$$NFP = Pc - Pif - \prod p - \prod if$$

Capacitance Vessels

- As small postcapillary venules converge and form larger venules, smooth muscle reappears.
- These vessels are capable of dilating and constricting.
- Changes in venular diameter (**venous tone**) regulate capillary pressure and venous blood volume (sym.stim). It is especially important in case of hemorrhage
- Venules converge to form larger veins.

Capacitance Vessels

- The peripheral veins have special valves and they can also propel blood forward by **venous pump**.

Capacitance Vessels

- Venous valve incompetence causes «**varicose**» veins.

- It happens when the veins have been overstretched by excess venous pressure lasting weeks or months.

- People with varicose veins stand for more than a few minutes, the venous and capillary pressures become very high and leakage of fluid from the capillaries causes constant edema in the legs.

Fainting Soldier

Specific Blood Reservoirs

- Certain portions of the circulatory system are so extensive and so compliant that they are called «specific blood reservoirs»:

- Contribution:
  1. The spleen (≈100 ml)
  2. The liver (≈100 - 300 ml)
  3. The veins (≈500 -1000 ml)
  4. The heart and the lungs may also be considered as reservoir. Heart ≈50-100 ml; lungs ≈ 100-200 ml

Blood Flow

- Blood flow through a blood vessel is determined by two factors:
  1. Pressure difference between two ends, pressure gradient (ΔP).
  2. Vascular Resistance

Ohm's law *(general law for fluid dynamics):*

$$F \text{ (flow)} = \frac{\Delta P}{R}$$

Blood Flow

- More detailed version of the Ohm's law:

Poiseuille's Law:

F(flow) = $\frac{\pi \, \Delta P \, r^4}{8 \, \eta l}$

ΔP :pressure gradient

r^4 :radius of the vessel

η :viscosity

l :length of the vessel

Flow Types

- **Laminar flow:** Blood flows in streamlines with each layer of blood remaining same distance from the vessel wall.
  – Blood flows quietly.

- **Turbulent flow:** Blood flowing in all directions in the vessel and contiunally mixing within the vessel.
  – Blood makes noise while flowing.

Reynold's Number

- ***Re*** is the **Reynold's Number** and is the measure of the tendency for turbulence to occur:

$$Re = \frac{v\ d\ p}{\eta}$$

v: velocity

d: vessel diameter

p: density

η: viscosity

Resistance to flow

- Resistance is the impediment to blood flow in a vessel, but it cannot be measured directly. It can be calculated via using **Ohm's law.**

$$\Delta P = F \times R$$

$$R = \frac{\Delta P}{F}$$

Total peripheral resistance calculation:

- Flow (CO) is apprx. 100 ml/sec
- ΔP is apprx 100 mmHg
- F= 100/100 = 1 **Peripheral Resistance Unit (PRU)**

Total Peripheral Resistance

- If blood vessels (mostly arterioles) strongly constricted total peripheral resistance increases to utmost **4 PRU** If they greatly dilate it decreases until **0,2 PRU.**
- **Remember r^4**
- Total peripheral resistance is one of the primary determiner of arterial blood pressure.

Series and Parallel Vascular Circuits

a. Total Resistance = $R_1 + R_2$

b. Total Resistance = $\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$

Arterial Blood Pressure

- Ejection of blood into the aorta by the left ventricle results in a characteristic aortic **pressure pulse**.
- The peak pressure of the aortic pulse is termed the **systolic** pressure.
- Pressure of the aortic pulse is **diastolic pressure**.
- The difference between the systolic and diastolic pressures is the aortic **pulse pressure.**

Arterial Blood Pressure

- Compliance of the arterial tree reduces or «dampens» the pressure pulsations (*mostly arterioles*).
- It becomes **continuous flow** in capillaries.
- Pulse Pressure = Systolic P – Diastolic P

1. The stoke volume
2. Compliance (total distensibility) of arterial tree

Mean Arterial Blood Pressure

- The value for the **mean arterial pressure (MAP)** is less than the arithmetic average of the systolic and diastolic pressures.

- Because diastole (2/3) is longer than systole (1/3).

$$MAP \cong P_{dias} + \frac{1}{3}(P_{sys} - P_{dias})$$

Arterial BP Measurement

Auscultatory Method

- Stethoscope is placed over the antecubital artery and a blood pressure cuff is inflated around the upper arm.

- Korotkoff sounds.

The Lymphatic System

- The **lymphatic system** is a network of small organs (lymph nodes) and tubes (**lymphatic vessels** or simply “lymphatics”) through which **lymph**—a fluid derived from interstitial fluid—flows.

- Small amounts of interstitial fluid **continuously** enter the lymphatic capillaries by bulk flow.

The Lymphatic System

- Lymp. Capillaries → Lager Lymp. Vessels→ Lymp. Nodes → 2 large lymp. ducts → drain into **jugular** and **subclavian vein**
- Valves at these junctions permit only one-way flow from lymphatic ducts into the veins.
- Therefore, the lymphatic vessels carry interstitial fluid to the circulatory system (**drainage**).

The Lymphatic System

- Occlusion of lymph flow by infectious organisms can result in a condition called ***elephantiasis,*** in which there is massive edema of the involved area.

The Lympathic System

- In addition to draining excess interstitial fluid;
  - Provides a pathway for fat absorbtion.
  - Immune functions

Mechanism of Lymph Flow

- Lymphatic vessels beyond the lymphatic capillaries propel the lymph within them by their **own contractions**.
- The smooth muscle in the wall of the lymphatics exerts a pumplike action by inherent rhythmic contractions.
- Lymphatic vessels have **valves** similar to those in veins, these contractions produce a oneway flow.
- External forces (skeletal muscle contraction) also enhance lymph flow.

Coronary Circulation

- **Coronary circulation** is the **circulation** of blood in the blood vessels that supply the heart muscle (myocardium).
- Main coronary arteries lie on the surface of the heart and smaller arteries then penetrate from the surface into the cardiac muscle mass.
- Only the inner 1/10 millimeter of the endocardial surface can obtain significant nutrition directly from the blood inside the cardiac chambers. So **almost all** nutrition is supplied by coronary circulation.

Coronary Arteries

- The *left coronary artery* supplies mainly the anterior and left lateral portions of the left ventricle.

- The *right coronary artery* supplies most of the right ventricle, as well as the posterior part of the left ventricle

Coronary Arteries

Coronary Venous Blood

- Most of the coronary venous blood flow from the left ventricular muscle returns to the right atrium of the heart by way of the ***coronary sinus***, which is about 75 percent of the total coronary blood flow.

- A very small amount of coronary venous blood also flows back into the heart through very minute ***thebesian veins***, which empty directly into all chambers of the heart.

Coronary Blood Flow

- The normal coronary blood flow in the resting human being averages about 4 to 5 percent of the total cardiac output.

- During strenuous exercise, CO may increase sixfold to ninefold.
  - At the same time, the coronary blood flow increases threefold to fourfold to supply the extra nutrients needed by the heart.

- The “efficiency” of cardiac utilization of energy increases to make up for the relative deficiency of coronary blood supply.

Coronary Blood Flow

Phasic Flow:

- Strong compression of the intramuscular blood vessels by the left ventricular muscle during systolic contraction blocks the blood flow.

- During diastole, the cardiac muscle relaxes and no longer obstructs blood flow through the left ventricular muscle capillaries, so blood flows rapidly during all of diastole.

Phasic Flow

Organization of Vessels

- On the outer surface ***epicardial coronary arteries*** that supply most of the muscle.

- Smaller, intramuscular arteries derived from the epicardial arteries penetrate the muscle, supplying the needed nutrients.

- Lying immediately beneath the endocardium is a plexus of ***subendocardial*** *arteries*

Control of Coronary Blood Flow

- Blood flow through the coronary system is regulated mostly by local arteriolar vasodilation in response to the nutritional needs of cardiac muscle.

- Normally, about 70% of the oxygen in the coronary arterial blood is used by heart muscle.
  - Little additional oxygen can be supplied to the heart musculature unless the coronary blood flow increases.

Control of Coronary Blood Flow

Local Control (Importance of Adenosine)

- Low O_2 in the muscle cells → ATP is degraded to adenosine.
- Adenosine causes vasodilation.
- After vasodilation adenosine is reabsorbed into the cardiac cells to be reused for production of ATP.

Control of Coronary Blood Flow

Nervous Control (Direct Effect)

- The distribution of parasympathetic (vagal) nerve fibers to the ventricular coronary system is not very great.
  - Parasympathetic stimulation has a direct effect to dilate the coronary arteries.

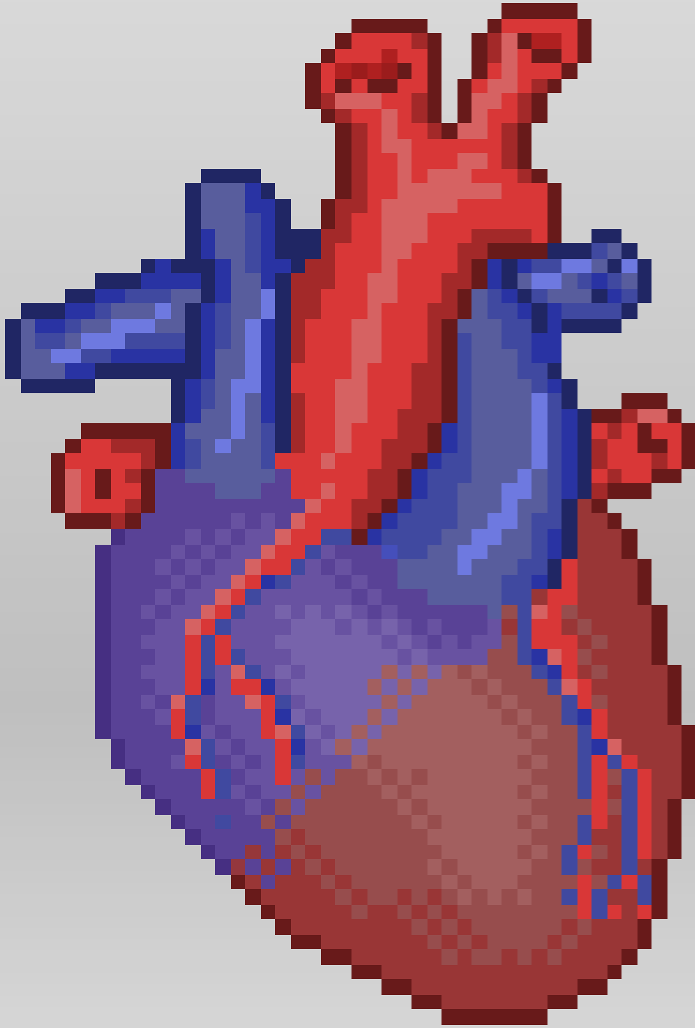
- Much more extensive sympathetic innervation of the coronary vessels occurs.
  - Both constictor (α rec.) and dilator effects (β rec.)
  - The epicardial coronary vessels have a preponderance of α receptors, whereas the intramuscular arteries may have a preponderance of β receptors.
  - Therefore, sympathetic stimulation can, at least theoretically, cause slight overall coronary constriction or dilation, but usually constriction.

Control of Coronary Blood Flow

Nervous Control (Indirect Effects)

- Metabolic factors, especially myocardial oxygen consumption, are the major controllers of myocardial blood flow. Overrides nervous effects within seconds.

- The indirect effects, which are mostly opposite to the direct effects,
  - Sym.Stim ↑ Myocardial O_2 consumtion ↑ V.dil↑
  - ParaSym.Stim ↑ Myocardial O_2 consumtion ↓ V.dil ↓



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Thank you for your patience!