Cardiovascular physiology

Introduction

The cardiovascular system includes **the Heart**, which serves as a pump for the blood, and **the blood vessels ,** which transport blood throughout the body.Under normal conditions, this system is a <u>continuous, closed circuit</u>, meaning that the blood is found only in the heart and blood vessels.

The heart actually consists of two separate pumps; The right side of the heart pumps blood to the lungs through the pulmonary circulation so that gas exchange, uptake of oxygen and elimination of carbon dioxide can takes place.

The left side of the heart pumps blood to the rest of the tissues of the body through the systemic circulation. In this way, oxygen and nutrients are delivered to the tissues to sustain their activities and carbon dioxide and other metabolic waste products are removed from the tissues.

In both circulations, blood vessels of the arterial system, arteries and arterioles, carry blood away from the heart and toward the tissues. The arterioles deliver blood to the capillaries where the exchange of substances between the blood and the tissues takes place. From the capillaries, blood flows into the vessels of the venous system , veins and venules, which carry blood back to the heart .

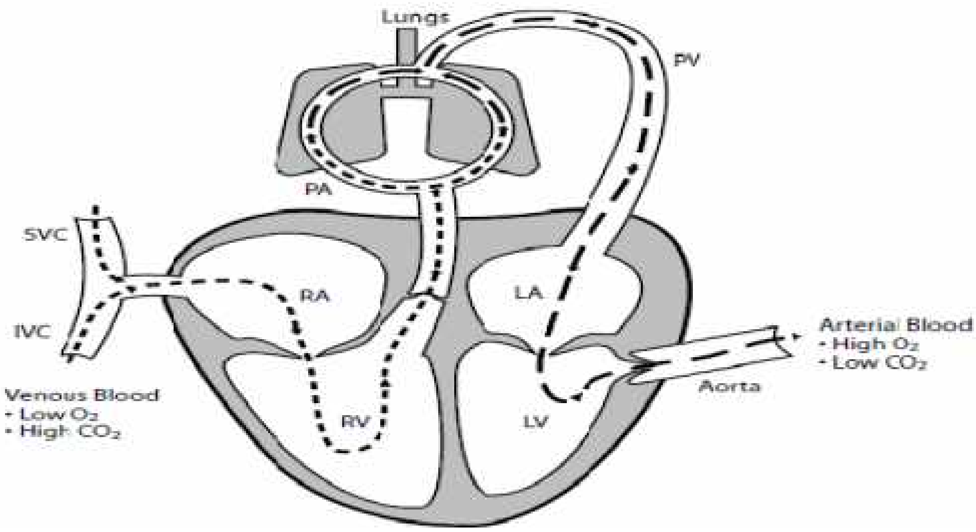

Figure (1-1) Route of blood flow through the heart.

Functional anatomy of the heart

The heart is composed of :

1. Receiving (input) chambers
2. Delivery (output) chambers
3. Valves

The atria (sing. Atrium) ; are chambers that receive blood returning to the heart through the veins. The blood then moves to the ventricles , or delivery chambers, of the heart. The powerful contractions of the ventricles generate a force sufficient to propel blood through the systemic or the pulmonary circulations. Valves ensure the one-way, or forward, flow of the blood.

The route of blood flow through the heart

The route of blood flow through the heart begins with the venae cavae, which return blood from the peripheral tissues to the right side of the heart (see Figure 1).

The superior vena cava returns blood from the head and arms to the heart and the inferior vena cava returns blood from the trunk of the body and the legs to the heart. As this blood has already passed through the tissues of the body, it is low in oxygen. Blood from the venae cavae first enters the right atrium and then the right ventricle .

Contraction of the right ventricle propels this blood to the lungs through the pulmonary circulation by way of the pulmonary artery. As it flows through the lungs, blood becomes enriched with oxygen and eliminates carbon dioxide to theatmosphere. Blood then returns to the heart through the pulmonary veins .

The blood first enters the left atrium and then the left ventricle. Contractionof the left ventricle propels the blood back to the peripheral tissues through systemic circulation by way of the aorta, the largest arterial vessel.

In summary ; the heart is a single organ consisting of two pumps; the right heart delivers blood to the lungs and the left heart delivers blood to the rest of the body. Both pumps work simultaneously. The atria fill with blood and then contract at the same time and the ventricles fill with blood and then contract at the same time. Contraction of the atria occurs prior to contraction of the ventricles in order to ensure proper filling of the ventricles with blood.

Heart valves

Two sets of valves in the heart maintain the one-way flow of blood asit passes through the heart chambers:

1. Atrioventricular (AV) valves
2. Semilunar valves

Each of these valves consists of thin flaps of flexible but tough fibrous tissue whose movements are passive.

The atrioventricular (AV) valves are found between the atria and the ventricles. The right AV valve is a tricuspid valve and has three cusps or leaflets. The left AV valve (the mitral valve) is a bicuspid valve because it has two cusps.

The semilunar valves separate the ventricles from their associated arteries; The pulmonary valve is found between the right ventricle and the pulmonaryartery and the aortic valve is found between the left ventricle and the aorta.

There are no valves between the venae cavae or the pulmonary veins and the atria into which they deliver blood.

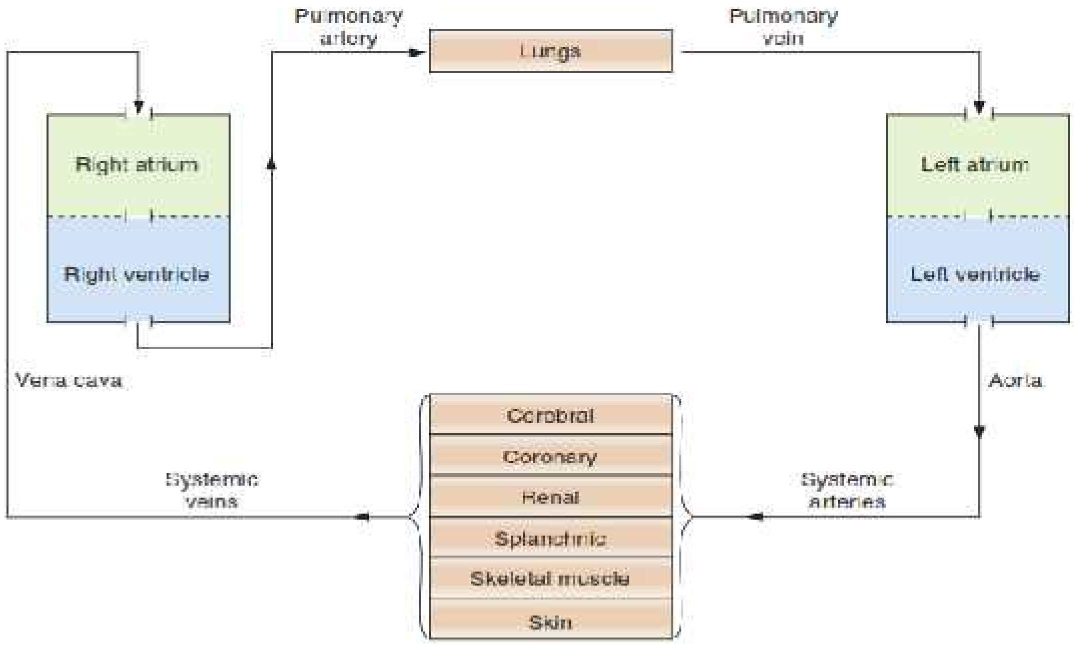

Figure (1-2) Route of blood flow through the heart.

Heart sound ; The closure of the valves causes **the "lub-dub" (** Heart sound **)** associated with the heart beat. **The first heart sound**, or the "lub," occurs when the ventricles contractand the AV valves close. **The second heart sound,** or the "dub," occurs when the ventricles relax and the semilunar valves close.

The heart wall

The wall of the heart has three layers:

1. Epicardium
2. Endocardium;The endocardium is continuous with the endothelium, which lines the blood vessels.
3. Myocardium;is the muscular layer of the heart. This is the thickest layer; Thickness is related to the amountof work that a given chamber must perform when pumping blood.

Under normal resting conditions, between heart beats, the pressure in the **pulmonary artery is approximately 8 mmHg** and pressure in the **aorta is approximately 80 mmHg**. Therefore, in order to eject blood into thepulmonary artery, the right ventricle must generate a pressure greater than8 mmHg and in order to eject blood into the aorta, the left ventricle must generate a pressure greater than 80 mmHg. Because **the left ventricle** performs significantly more work, **its wall is much thicker than that of the right ventricle.**

Coronary arteries supply blood to the heart muscle. Like all other tissues in the body, the heart muscle needs oxygen-rich blood to function. Also, oxygen-depleted blood must be carried away. ... Small branches dive into the heart muscle to bring it blood.
The 2 main coronary arteries are the left main and right coronary arteries;

1. Left main coronary artery (LMCA). The left main coronary artery supplies blood to the left side of the heart muscle (the left ventricle and left atrium). The left main coronary divides into branches:

The left anterior descending artery branches off the left coronary artery and supplies blood to the front of the left side of the heart.

The circumflex artery branches off the left coronary artery and encircles the heart muscle. This artery supplies blood to the outer side and back of the heart.

2. Right coronary artery (RCA). The right coronary artery supplies blood to the right ventricle, the right atrium, and the SA (sinoatrial) and AV (atrioventricular) nodes, which regulate the heart rhythm. The right coronary artery divides into smaller branches, including **the right posterior descending artery and the acute marginal artery**.

Ischemic heart diseases

Since coronary arteries deliver intermitent (ventricular contraction and relaxation effects) limited amount of blood to the heart muscle (5% of total cardiac output at rest) which reduced magnificently at contraction and excersizeand its 24 houre persistant work , any coronary artery disorder or disease can have serious implications by reducing the flow of oxygen and nutrients to the heart muscle **(ischemia)** tab 1-1 . This can lead to a heart attack and possibly death. **Atherosclerosis** (a buildup of plaque in the inner lining of an artery causing it to narrow or become blocked) is the most common cause of heart disease.

Circulation* (% of Resting Cardiac Output)	Local Metabolic Control	Vasoactive Metabolites	Sympathetic Control	Mechanical Effects
Coronary (5%)	Most important mechanism	Hypoxia Adenosine	Least important mechanism	Mechanical compression during systole
Cerebral (15%)	Most important mechanism	CO_2 H^+	Least important mechanism	Increases in intracranial pressure decrease cerebral blood flow
Muscle (20%)	Most important mechanism during exercise	Lactate K^+ Adenosine	Most important mechanism at rest (α_1 receptor causes vasoconstriction; β_2 receptor causes vasodilation)	Muscular activity causes temporary decrease in blood flow
Skin (5%)	Least important mechanism		Most important mechanism (temperature regulation)	
Pulmonary† (100%)	Most important mechanism	Hypoxia vasoconstricts	Least important mechanism	Lung inflation

table 1-1 blood distibution to organ at rest and mechanical effect .

Cardiac muscle

Properties of the cardiac muscle

1. Syncytium.
2. Automaticity and rhythmicity (Autorhythmicity).
3. Excitability and conductivity.
4. Contractility;
    a. **Systole** Contraction period of heart
    b. **Diastole** relaxation period of heart

Cardiac muscle has many structural and functional similarities with skeletal muscle (Table 1-2).

Cardiac muscle	Skeletal muscle
Organized into sarcomeres	Organized into sarcomeres
Sliding-filament mechanism of contraction	Sliding-filament mechanism of contraction
Source of calcium: Sarcoplasmic reticulum	Source of calcium: Sarcoplasmic reticulum
Tranverse tubules	
Resting length of sarcomere *less than* optimal length	Resting length of sarcomere *equal* to optimal length
Gap junctions provide electrical communication between cells, forming a functional syncytium	No gap junctions
Myogenic	Neurogenic
Contraction *modified* by autonomic nervous system	Contraction *elicited* by somatic nervous system

Table (1-2) Distinguishing Features of Cardiac Muscle and Skeletal Muscle

The contractile elements, composed of thin actin filaments and thick myosin filaments, are organized into sarcomere. Therefore, as with skeletal muscle, tension development within the myocardium occurs by way of the sliding filament mechanism.

As the action potential travels along the surface of the muscle cell membrane, the impulse also spreads into the interior of the cell along the transverse (T)tubules. This stimulates the release of calcium from the sarcoplasmic reticulum. Calcium promotes the interaction of actin and myosin resulting in cross bridge cycling and muscle shortening (Contraction) both isometric and isotonic contraction to achieve function .

Unlike skeletal muscle whose only source of calcium is the sarcoplasmic reticulum, cardiac muscle also obtains calcium from the T tubules, which are filled with extracellular fluid. This added calcium results in a much stronger contraction.

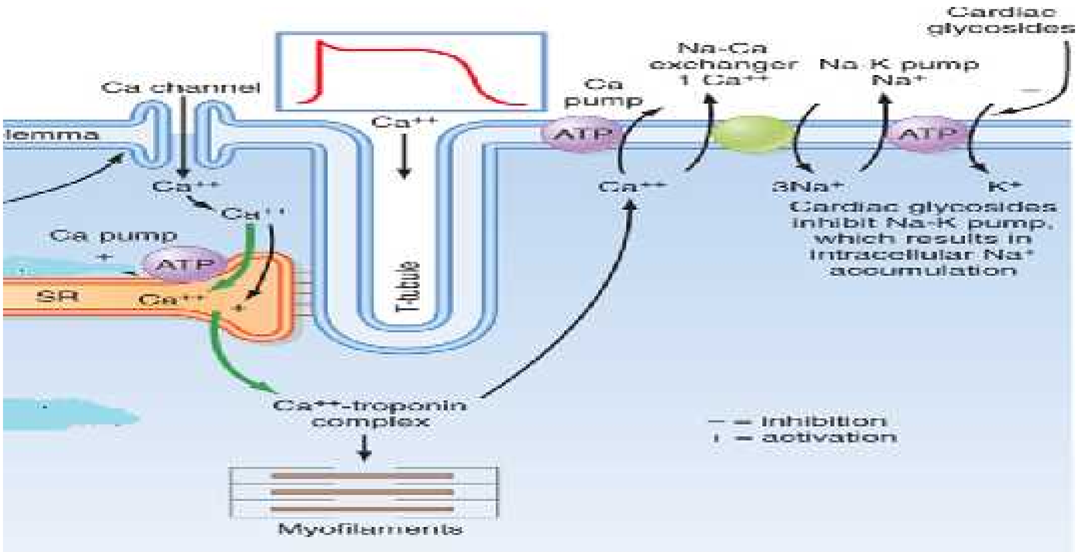

Figure (1-3) Excitation-Contraction coupling in the heart muscle

Excitation-Contraction coupling in the heart muscle:

Depolarization of myocardial cell stimulates opening of Ca channels in the T tubule membrane and sarcolema. Ca acts as a signal for the opening of Ca release channels in SR to release large amount of activator Ca from the SR (cytosolic Ca). **This cytosolic Ca that causes the contraction,** i.e. once Ca is in the cytoplasm Cytosolic Ca binds to troponin C and stimulates contraction , **Contraction ends when** the cytosolic Ca concentration restored to its original level which occurs by:

- Active re uptake of Ca into the sarcoplasmic reticulum by **Ca pump**
- Active pumping of excess Ca outside the fibres by **Na - Ca exchanger carrier Protein**;
- **Excess Na is pumped out by Na-K pump.**

Cardiac glycosides(Digoxin) inhibit Na-K pump and decreases the hearts ability to pump calcium out of the cardiac cell so we get increased contractility of the heart. This is known as an increased inotropic effect. This leads to an increase in cardiac output (greater contractility and duration) in a failing heart.

Frank–Starling mechanism;
The arrangement of the myofilaments into sarcomeres renders the cardiac muscle subject to **the length–tension relationship**; When the resting sarcomere length is altered, the amount of tension developed by the myocardium upon stimulation is altered as well (Proportionally).

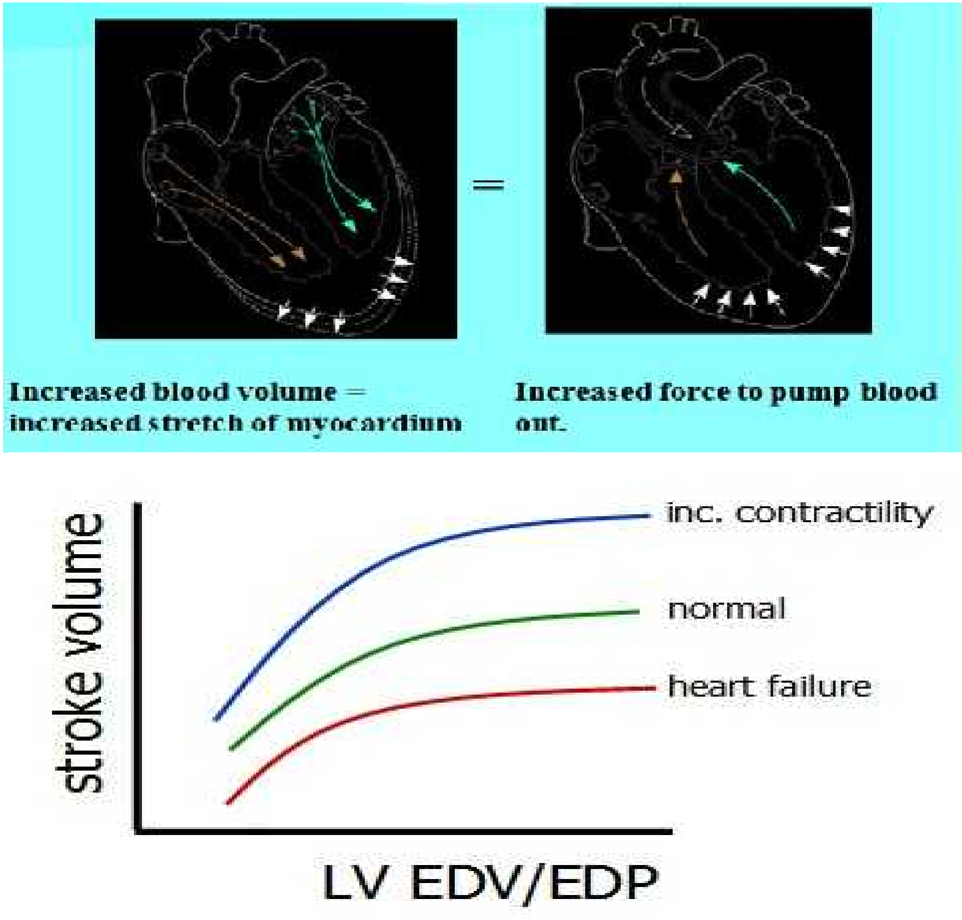

Figure (1-4) Frank–Starling mechanism; represents the relationship between stroke volume and end diastolic volume.

In the heart, the resting sarcomere length is determined by the volume of blood within the ventricle immediately prior to contraction. This length–tension relationship is described by **the Frank–Starling mechanism**; this concept is important in the **management of heart failure**;
Heart failure is a clinical syndrome that comprises a constellation of signs and symptoms that occur as a result of pump failure, a series of histopathological and structural changes occur in the left ventricular myocardium that lead to progressive decline in left ventricular performance.

Ultimately, **ventricular remodeling** may result in diminished contractile (systolic) function and reduced stroke volume ; (Heart Failure) , this can be reversed or delayed by some drugs like ACEI or spirinolactone.

The myocardium is a syncytium

Skeletal muscle cells have **no electrical communication between them,** Cardiac muscle cells, on the other hand, branch and interconnect with each other. Intercellular junctions found where adjoining cells meet end-to-end are of **Two types intercalated discs;**

- **Desmosomes** hold the muscle cells together and provide the structural support needed when the heart beats and exerts a mechanical stress that would tend to pull the cells apart.
- **Gap junctions** are areas of very low electrical resistance that allow free diffusion of ions. It is through the gap junctions that the electrical impulse, or heart beat, spreads rapidly from one cell to another. **As a result, the myocardium is a syncytium** in which the initiation of a heart beat in one region of the heart results in stimulation and contraction of all cardiac muscle cells at the same time.

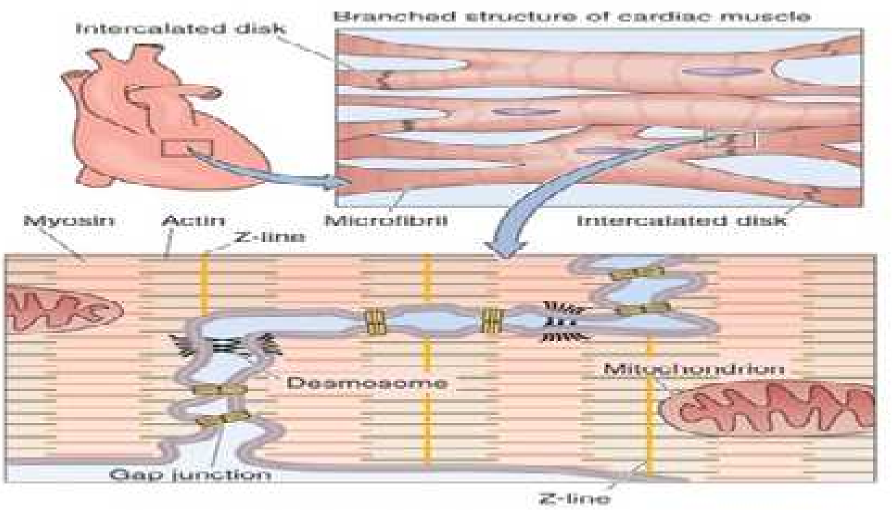

Figure (1-5) Cardiac muscle ; syncytium of myocyte with intercalated discs(Desmosomes and Gap junctions) .

The heart is actually composed of two syncytium: **atrial and ventricular.** In each case, but particularly in the ventricles, simultaneous stimulation of all the muscle cells results in a more powerful contraction, facilitating the pumping of blood.

The heart pacemaker

Skeletal muscle is neurogenic and requires stimulation from the somatic nervous system to initiate contraction.. **Cardiac muscle, however, is myogenic , or self-excitatory ;**this muscle spontaneously depolarizes to threshold and generates action potentials without external stimulation.

The region of the heart with the fastest rate of inherent depolarization initiates the heart beat and determines the heart rhythm. In normal hearts, **this "pacemaker" region is the**

sinoatrial node; in which alot of Na leakage channel are present , those channels are starting pacemaker activity.

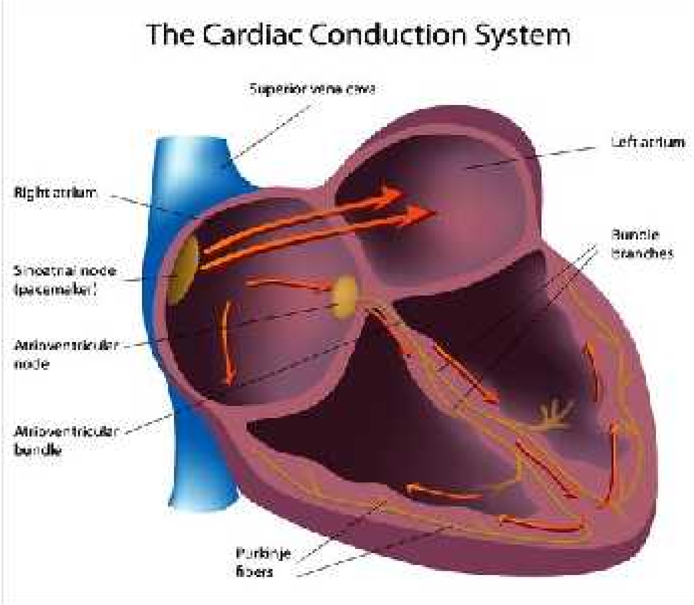

figure (1-6)Cardiac conductive system

locations of autorhythmic cell regions (superior to inferior);

1. sinoatrial (SA) node
2. atrioventricular (AV) node
3. atrioventricular (AV) bundle
4. right & left bundle branches
5. purkinje fibers

Cardiac cycle:

<u>The cardiac events that occur from the beginning of one heart beat to the beginning of the next</u> are called **the cardiac cycle.**

Each cycle is initiated by **spontaneous generation of an action potential** in the **sinus node** which travels rapidly through **both atria** and then through the **A-V bundle** into the **ventricles.**

Because of this special arrangement of the conducting system from the atria into the ventricles, there is **a delay of more than 0.1 second** during passage of the cardiac impulse from the atria into the ventricles. This allows the atria to contract, pumping blood into the ventricles before the strong ventricular contraction begins. Thus, **the atria act as *primer pumps* for the ventricles**, and the **ventricles** in turn provide the major source of power for **moving blood through the body's vascular system.**

In a normal heart, cardiac activity <u>is repeated in a regular cycle.</u> At a normal heart rate of about 72 beats/minute. **The duration of each cardiac cycle lasts about 0.8 second;**

for the **atria**, the cycle lasts for about 0.15 second in systole and 0.65 second in diastole.

For the ventricles, the two major phases of the cardiac cycle are:

The diastole; a period of ventricular relaxation in which the ventricles fill with blood and it last for about 0.5 second.

The systole; a period of ventricular contraction and blood ejection, lastingabout 0.3 second.

If the heart rate increases, the diastole decreases, which means that the heart beating very fast may not remain relaxed long enough to allow complete filling of the ventricles before the next contraction.

Phases of the cardiac cycle:

The cardiac cycle starts by **atrial systole followed by ventricular systole then by diastole of the whole heart.**

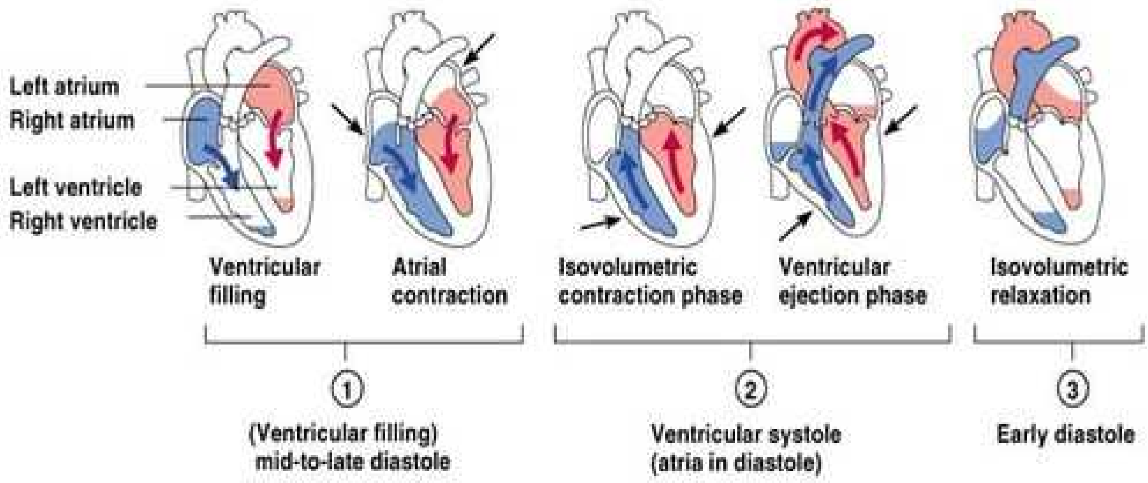

Figure (1-7) Phases of cardiac cycle

Atrial systole (atria as a pump):

It is the first phase of cardiac cycle. Blood normally flows continually (passively) from the veins into the atria and about 75% of the blood in the atria flow directly into the ventricles even before the atrial contraction. Then, atrial contraction usually causes an additional 25% filling of the ventricles. So the heart can continue to operate satisfactorily under most condition without this extra 25%, yet this 25% is needed in case of exercise.

Ventricular cardiac cycle

1- Ventricular filling

The accumulated large amounts of blood in the atria push the closed AV valves;the AV valves open and allow blood to flow rapidly into the ventricles. During atrial contraction, an additional amount of blood flows into the ventricles represent 25%of the filling of the ventricles.

2-Ventricular systole:

Subdivided into two phases:

A. **Isovolumic, isometric contraction** (isovolumetric contraction).
B. **Ventricular ejection (isotonic contraction).**

A-Isovolumetric contraction

It is ventricular contraction but without blood ejection (no emptying) just to close the AV valves and to open semilunar valves by the rise in intraventricular pressure (from 0 to 80 mmHg in the left ventricle). It is the isovolumetric contraction, which means only the tension is increasing in the ventricular muscle without shortening of the muscle and with no change in blood volume.

B-Ventricular ejection

The blood ejected from the ventricles into pulmonary trunk and aorta when the ventricular pressure rises and forces the semilunar valves open. Left ventricular pressure rises above 80 mmHg. Right ventricular pressure rises above 8 mmHg.

Isovolumetric relaxation:

Isovolumic, isometric relaxation; following ventricular systole, ventricular relaxation begins suddenly and ventricular pressure falls. The blood in the aorta and pulmonary trunk backflows toward the heart closing the semilunar valves. For another 0.03 to 0.06 second, the ventricular muscle continues to relax, even though the ventricular volume does not change giving rise to the period of isovolumic relaxation in which the intraventricular pressure falls rapidly back to their low diastolic levels. Meanwhile, the atria have been filling with blood. When the pressure exerted by the blood on the atrial side of AV valves exceeds that in the ventricles, AV valves forced open and the ventricular filling phase begins again for a new cycle of ventricular pumping.

Cardio dynamics

• Cardiac output = CO (mL/min): volume of blood pumped by heart each minute.

(CO = SV × HR)

• Stroke volume = SV (70 mL/beat): volume of blood pumped by heart with each ventricular contraction.

• Heart rate = HR (72 beats/min)

(CO = SV × HR)

(CO = 70 × 72)

(CO = 5040 ml/minutes)

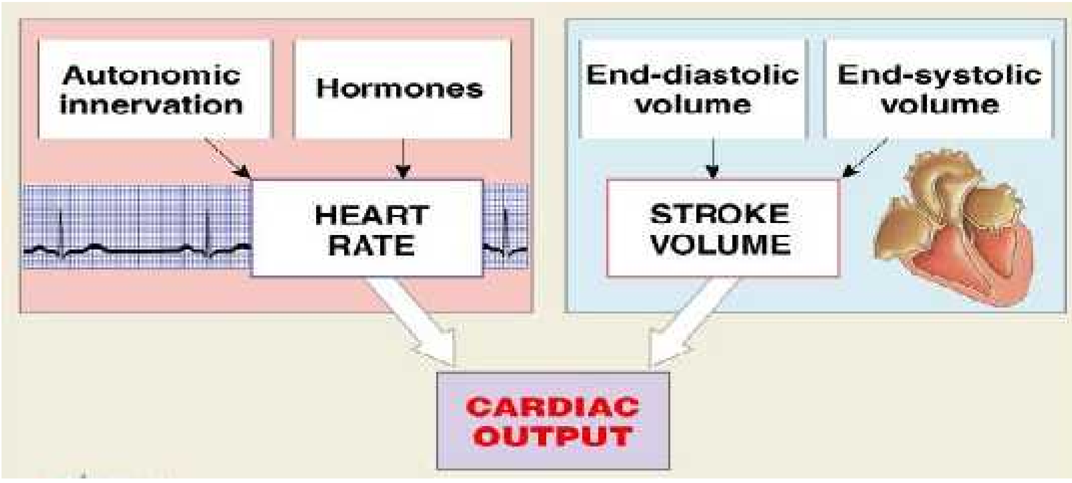

Figure (1-8) cardiac output parameters

Mean arterial pressure = cardiac output x peripheral resistance

Total peripheral resistance (TPR) is the resistance to blood flow offered by all systemic vessels taken together, especially by the arterioles, which are the primary resistance vessels.