Lecture 8: Heart Physiology: Conductive System, Cardiac Output (Mechanics and Control), and Factor Affecting

Cardiac Conductive system

The cardiac conducting system, also known as the cardiac conduction system, is a specialized network of cells in the heart responsible for initiating and regulating the rhythmic contraction of the heart muscle. It ensures that the heart beats in a coordinated and efficient manner, pumping blood throughout the body. The primary components of the cardiac conducting system include the sinoatrial (SA) node, the atrioventricular (AV) node, the bundle of His, and the Purkinje fibers.

1- Sinoatrial (SA) Node:

The process begins in the right atrium of the heart, where the SA node is located.

The SA node is often referred to as the "natural pacemaker" of the heart because it spontaneously generates electrical impulses.

These electrical impulses initiate each heartbeat, causing the atria to contract and pump blood into the ventricles.

2- Atria Contraction:

When the electrical impulse from the SA node reaches the atrial muscle cells, it stimulates them to contract.

This contraction results in the atria pushing blood into the ventricles.

3- Atrioventricular (AV) Node:

The electrical signal then travels to the AV node, which is located between the atria and the ventricles. The AV node acts as a delay mechanism, allowing a brief pause to ensure that the ventricles have enough time to fill with blood from the atria.

4- Bundle of His:

From the AV node, the electrical impulse travels through the bundle of His, which is a bundle of specialized conduction fibers. The bundle of His splits into right and left bundle branches that extend down the interventricular septum.

5- Purkinje Fibers:

The bundle branches further divide into smaller fibers called Purkinje fibers, which spread

throughout the ventricles. The Purkinje fibers rapidly conduct the electrical impulse to the muscle cells of the ventricles.

6- Ventricular Contraction:

As the electrical signal reaches the ventricular muscle cells via the Purkinje fibers, it

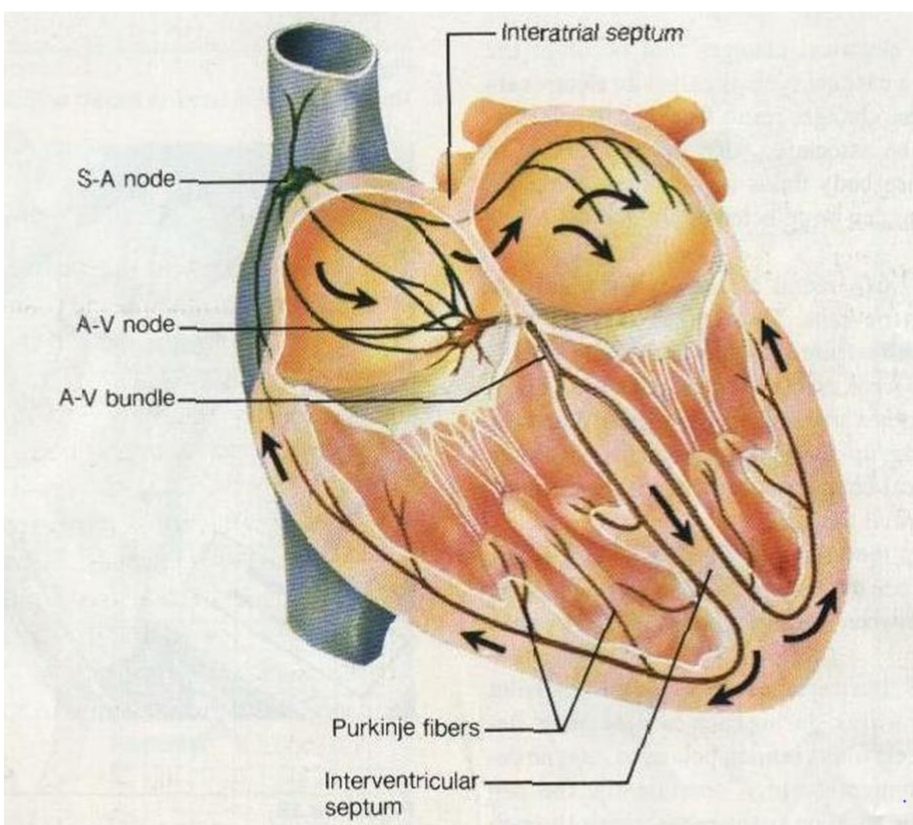
causes the ventricles to contract.

This coordinated contraction results in the ejection of blood from the ventricles into the pulmonary artery (from the right ventricle) and the aorta (from the left ventricle), allowing blood to be pumped to the lungs and the rest of the body.

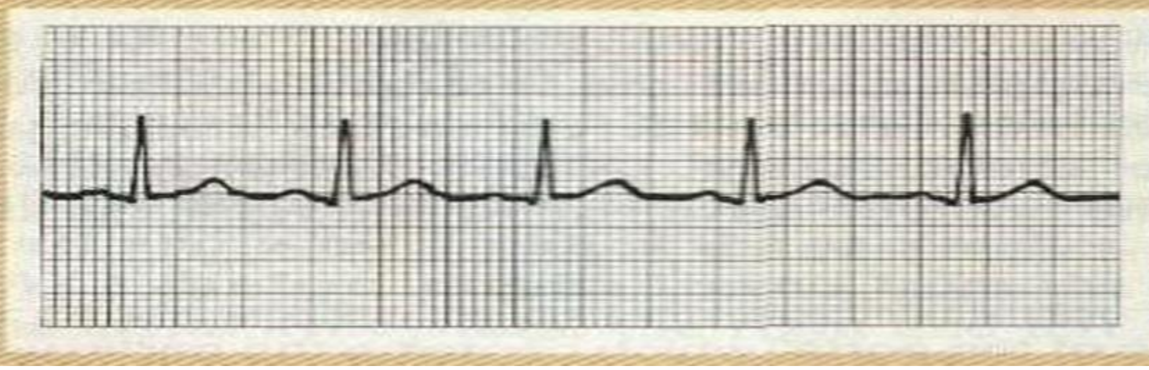
7- Repolarization and Rest:

After contraction, the heart cells undergo a repolarization phase, preparing them for the next electrical impulse and contraction. This cycle repeats with each heartbeat, maintaining a rhythmic

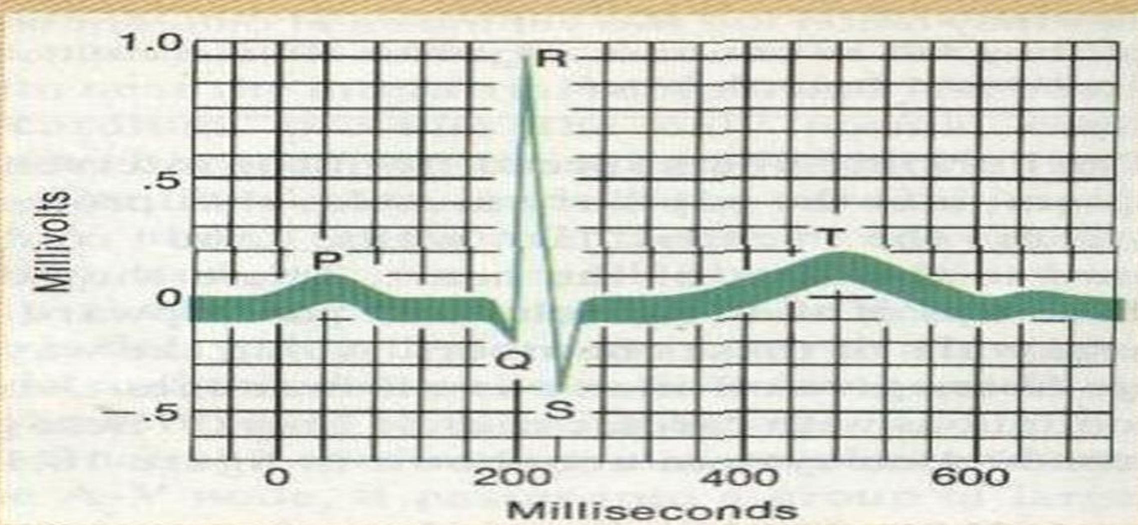
and synchronized pumping action.



A normal ECG.



In an ECG pattern, the P wave results from depolarization of th
atria, the QRS complex results from depolarization of the
ventricles, and the T wave results from repolarization of the
ventricles.



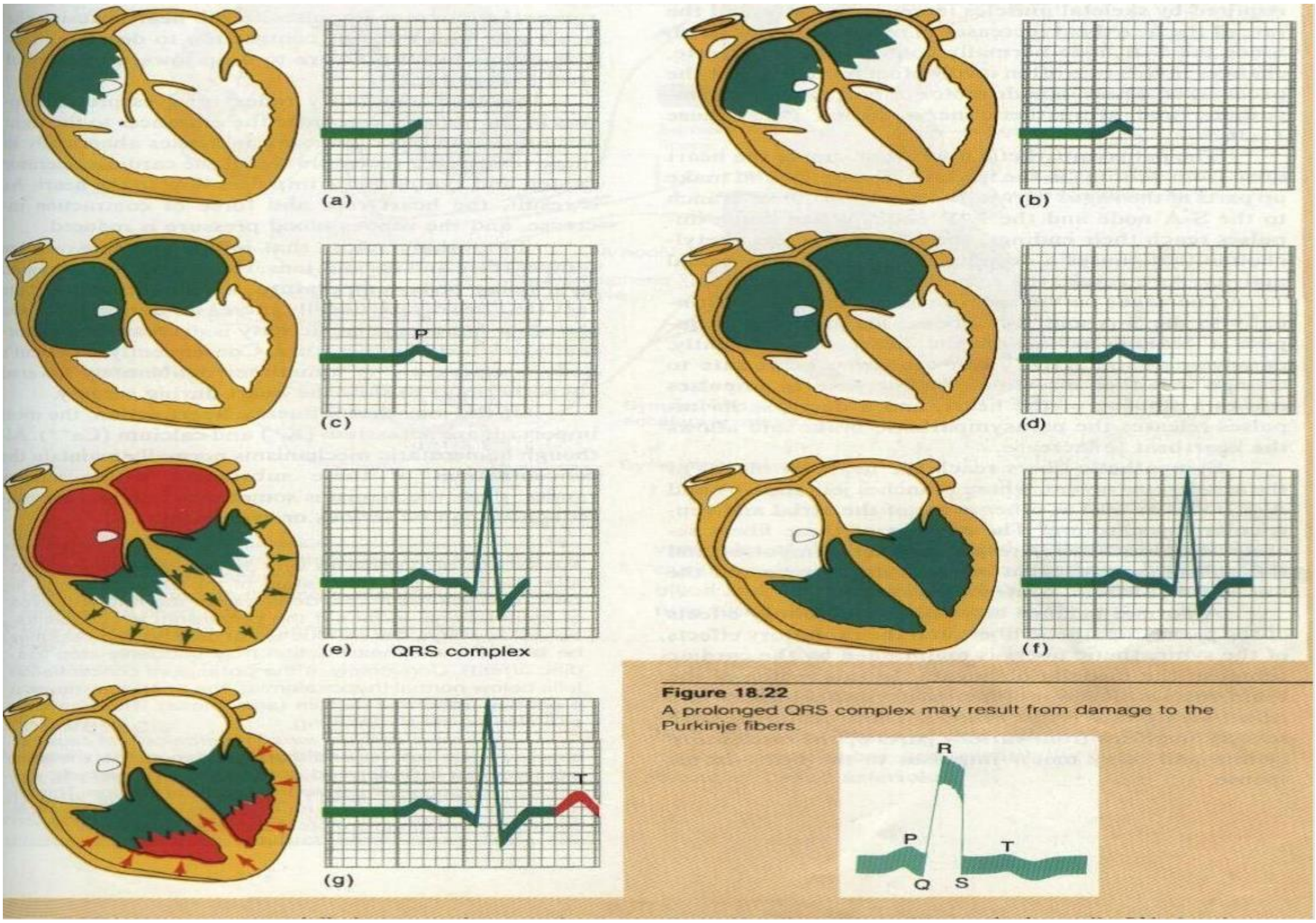


Figure 18.22
A prolonged QRS complex may result from damage to the Purkinje fibers

Cardiac Output

Cardiac output is the amount of blood pumped from each ventricle. Usually, it refers to left ventricular output through aorta. Cardiac output is the most important factor in cardiovascular system, because rate of blood flow through different parts of the body depends upon cardiac output.

Usually, cardiac output is expressed in three ways:

1. Stroke volume
2. Minute volume
3. Cardiac index.

However, in routine clinical practice, cardiac output refers to minute volume.

STROKE VOLUME

Stroke volume is the amount of blood pumped out by each ventricle during each beat.

***Normal value**:* 70 mL (60 to 80 mL) when the heart rate is normal (72/minute).

MINUTE VOLUME

Minute volume is the amount of blood pumped out by each ventricle in one minute. It is the product of stroke volume and heart rate:

Minute volume = Stroke volume × Heart rate

Normal value: 5 L/ventricle/minute.

CARDIAC INDEX

Cardiac index is the minute volume expressed in relation to square meter of body surface area. It is defined as the amount of blood pumped out per ventricle/minute/square meter of the body surface area.

Normal value: 2.8 ± 0.3 L/square meter of body surface area/minute (in an adult with average body surface area of 1.734 square meter and normal minute volume of 5 L/minute).

EJECTION FRACTION

Ejection fraction is the fraction of end diastolic volume that is ejected out by each ventricle.

CARDIAC RESERVE

Cardiac reserve is the maximum amount of blood that can be pumped out by heart above the normal value. Cardiac reserve plays an important role in increasing the cardiac output during the conditions like exercise. It is essential to withstand the stress of exercise.

Cardiac reserve is usually expressed in percentage. In a normal young healthy adult, the cardiac reserve is 300% to 400%. In old age, it is about 200% to 250%. It increases to 500% to 600% in athletes. In cardiac diseases, the cardiac reserve is minimum or nil.

VARIATIONS IN CARDIAC OUTPUT

PHYSIOLOGICAL VARIATIONS

1. *Age:* In children, cardiac output is less because of less blood volume. Cardiac index is more than that in adults because of less body surface area.
2. *Sex:* In females, cardiac output is less than in males because of less blood volume. Cardiac index is more than in males, because of less body surface area.
3. *Body build:* Greater the body build, more is the cardiac output.
4. *Diurnal variation:* Cardiac output is low in early morning and increases in day time. It depends upon the basal conditions of the individuals.
5. *Environmental temperature:* Moderate change in temperature does not affect cardiac output. Increase in temperature above 30°C raises cardiac output.
6. *Emotional conditions:* Anxiety, apprehension and excitement increases cardiac output about 50% to 100% through the release of catecholamines, which increase the heart rate and force of contraction.
7. *After meals:* During the first one hour after taking meals, cardiac output increases.
8. *Exercise:* Cardiac output increases during exercise because of increase in heart rate and force of contraction.
9. *High altitude:* In high altitude, the cardiac output increases because of increase in secretion of adrenaline. Adrenaline secretion is stimulated by hypoxia (lack of oxygen).
10. *Posture:* While changing from recumbent to upright position, the cardiac output decreases.
11. *Pregnancy:* During the later months of pregnancy, cardiac output increases by 40%.
12. *Sleep:* Cardiac output is slightly decreased or it is unaltered during sleep.

PATHOLOGICAL VARIATIONS

Increase in Cardiac Output

Cardiac output increases in the following conditions:

1. *Fever:* Due to increased oxidative processes
2. *Anemia:* Due to hypoxia
3. *Hyperthyroidism:* Due to increased basal metabolic rate.

Decrease in Cardiac Output

Cardiac output decreases in the following conditions:

1. *Hypothyroidism:* Due to decreased basal metabolic rate
2. *Atrial fibrillation:* Because of incomplete filling of ventricles
3. *Incomplete heart block with coronary sclerosis or myocardial degeneration:* Due to defective pumping action of the heart
4. *Congestive cardiac failure:* Because of weak contractions of heart
5. *Shock:* Due to poor pumping and circulation
6. *Hemorrhage:* Because of decreased blood volume.

DISTRIBUTION OF CARDIAC OUTPUT

The whole amount of blood pumped out by the right ventricle goes to lungs. But, the blood pumped by the left ventricle is distributed to different parts of the body.

Fraction of cardiac output distributed to a particular region or organ depends upon the metabolic activities of that region or organ.

Distribution of Blood Pumped out of Left Ventricle

Distribution of blood pumped out of left ventricle to different organs and the percentage of cardiac output are given in Table1. Heart, which pumps the blood to all other organs, receives the least amount of blood. Liver receives maximum amount of blood.

FACTORS MAINTAINING CARDIAC OUTPUT

Cardiac output is maintained (determined) by four factors:

1. Venous return
2. Force of contraction
3. Heart rate
4. Peripheral resistance.

1. VENOUS RETURN

Venous return is the amount of blood which is returned to heart from different parts of the body. When it increases, the ventricular filling and cardiac output are increased. Thus, cardiac output is **directly proportional** to venous return, provided the other factors (force of contraction, heart rate and peripheral resistance) remain constant.

Venous return in turn, depends upon five factors:

i. Respiratory pump
ii. Muscle pump
iii. Gravity
iv. Venous pressure
v. Sympathetic tone.

i. Respiratory Pump

Respiratory pump is the respiratory activity that helps the return of blood, to heart during inspiration. It is also called **abdominothoracic pump.** During inspiration, thoracic cavity expands and makes the intrathoracic pressure more negative. It increases the diameter of inferior vena cava, resulting in increased venous return. At the same time, descent of diaphragm increases the intra-abdominal pressure, which compresses abdominal veins and pushes the blood upward towards the heart and thereby the venous return is increased (Fig 1).

Respiratory pump is much stronger in forced respiration and in severe muscular exercise.

ii. Muscle Pump

Muscle pump is the muscular activity that helps in return of the blood to heart. During muscular activities, the veins are compressed or squeezed. Due to the presence of valves in veins, during compression the blood is moved towards the heart (Fig. 2). When muscular activity increases, the venous return is more.

When the skeletal muscles contract, the vein located in between the muscles is compressed. Valve of the vein

TABLE 1: Distribution of blood pumped out of left ventricle

Organ	Amount of blood (mL/ minute)	Percentage
Liver	1,500	30
Kidney	1,300	26
Skeletal muscles	900	18
Brain	800	16
Skin, bone and GI tract	300	6
Heart	200	4
Total	5,000	100

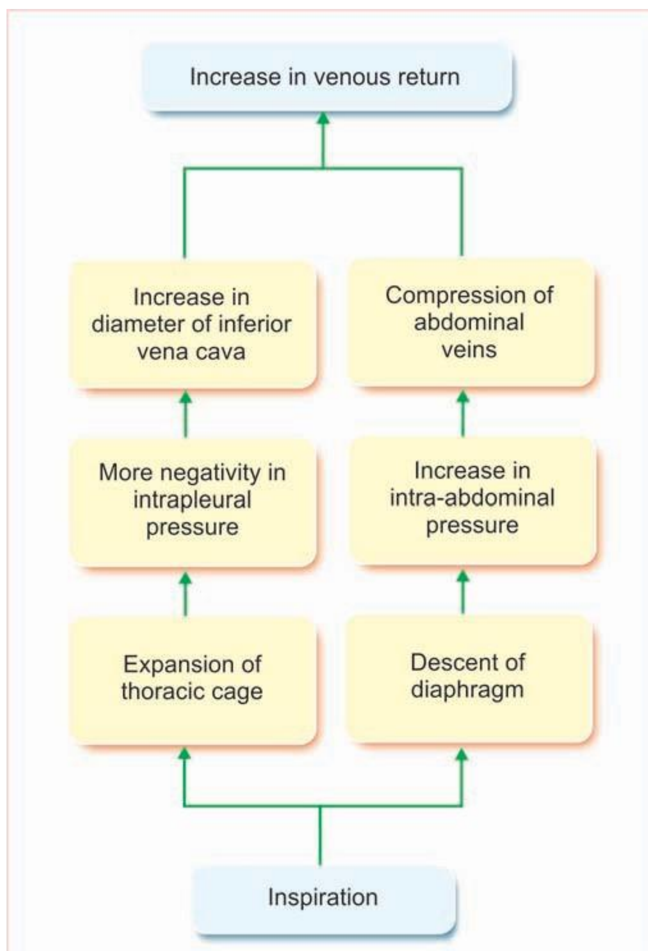


FIGURE 1: Effect of respiratory pump on venous return

proximal to the contracting muscles (Fig. 2 A) is opened and the blood is propelled towards the heart. Valve of the vein distal to the muscles is closed by the back flow of blood.

During relaxation of the muscles (Fig. 2 B), the valve proximal to muscles closes and prevents the back flow of blood. The valve distal to the muscles opens and allows the blood to flow upwards.

iii. *Gravity*

Gravitational force reduces the venous return. When a person stands for a long period, gravity causes pooling of blood in the legs, which is called **venous pooling.** Because of venous pooling, the amount of blood returning to heart decreases.

iv. *Venous Pressure*

Venous pressure also affects the venous return. Pressure in the venules is 12 to 18 mm Hg. In the smaller and larger veins, the pressure gradually decreases. In the great veins, i.e. inferior vena cava and superior vena cava, the pressure falls to about 5.5 mm Hg. At the junction of venae cavae and right atrium, it is about 4.6 mm Hg. Pressure in the right atrium is still low and it alters during cardiac action. It falls to zero during atrial diastole. This pressure gradient at every part of venous tree helps as a driving force for venous return.

v. *Sympathetic Tone*

Venous return is aided by sympathetic or vasomotor tone, which causes constriction of venules. Venoconstriction pushes the blood towards heart.

■ 2. FORCE OF CONTRACTION

Cardiac output is **directly proportional** to the force of contraction, provided the other three factors remain constant. According to **Frank-Starling law,** force of contraction of heart is directly proportional to the initial length of muscle fibers, before the onset of contraction.

Force of contraction depends upon preload and afterload.

Preload

Preload is the stretching of the cardiac muscle fibers at the end of diastole, just before contraction. It is due to increase in ventricular pressure caused by filling of blood during diastole. Stretching of muscle fibers increases their length, which increases the force of contraction and cardiac output.

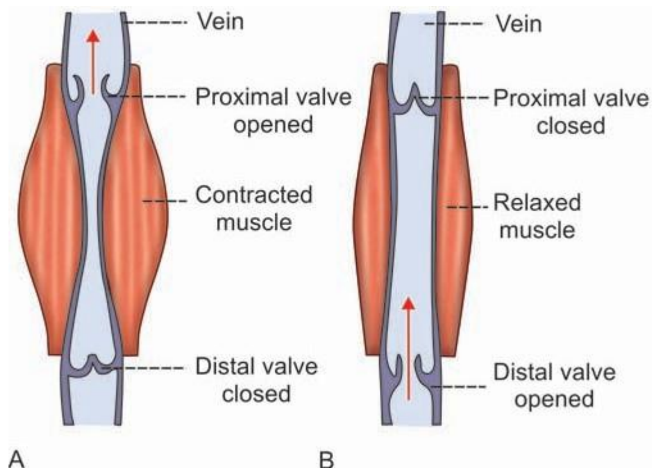


FIGURE 2: Mechanism of muscle pump. A. During contraction of the muscle; B. During relaxation of the muscle.

Thus, force of contraction of heart and cardiac output are **directly proportional** to preload.

Afterload

Afterload is the force against which ventricles must contract and eject the blood. Force is determined by the arterial pressure. At the end of isometric contraction period, semilunar valves are opened and blood is ejected into the aorta and pulmonary artery. So, the pressure increases in these two vessels. Now, the ventricles have to work against this pressure for further ejection. Thus, the afterload for left ventricle is determined by aortic pressure and afterload for right ventricular pressure is determined by pressure in pulmonary artery.

Force of contraction of heart and cardiac output are **inversely proportional** to afterload.

■ 3. HEART RATE

Cardiac output is **directly proportional** to heart rate provided, the other three factors remain constant. Moderate change in heart rate does not alter the cardiac output. If there is a marked increase in heart rate, cardiac output is increased.

If there is marked decrease in heart rate, cardiac output is decreased.

■ 4. PERIPHERAL RESISTANCE

Peripheral resistance is the resistance offered to blood flow at the peripheral blood vessels. Peripheral resistance is the resistance or load against which the heart has to pump the blood. So, the cardiac output is **inversely proportional** to peripheral resistance.

Reference:

Essentials of Medical Physiology Sixth Edition K Sembulingam PhD and Prema Sembulingam PhD