

Overview of Human Anatomy and Physiology: Cardiac Output

Introduction

Welcome to the Overview of Human Anatomy and Physiology course on the Cardiac System. This module, Cardiac Output, discusses measurement of heart activity and factors that affect activity.

After completing this module, you should be able to:

1. Define stroke volume and cardiac output.
2. Discuss the relationship between heart rate, stroke volume, and cardiac output.
3. Identify the factors that control cardiac output.

Measurement

Cardiac Output

The activity of the heart can be quantified to provide information on its health and efficiency. One important measurement is cardiac output (CO), which is the volume of blood ejected by the left ventricle each minute. Heart rate and stroke volume determine cardiac output. Heart rate (HR) is the number of heartbeats in one minute. The volume of blood ejected by the left ventricle during a heartbeat is the stroke volume (SV), which is measured in milliliters.

Equation

Cardiac output is calculated by multiplying the heart rate and the stroke volume.

Average Values

Cardiac output is the amount of blood pumped by the left ventricle--not the total amount pumped by both ventricles. However, the amount of blood within the left and right ventricles is almost equal, approximately 70 to 75 mL. Given this stroke volume and a normal heart rate of 70 beats per minute, cardiac output is 5.25 L/min.

Relationships

When heart rate or stroke volume increases, cardiac output is likely to increase also. Conversely, a decrease in heart rate or stroke volume can decrease cardiac output.

What factors regulate increases and decreases in cardiac output?

Regulation

Factors Regulating Cardiac Output

Factors affect cardiac output by changing heart rate and stroke volume. Primary factors include blood volume reflexes, autonomic innervation, and hormones. Secondary factors include extracellular fluid ion concentration, body temperature, emotions, sex, and age.

Primary Factors

Blood Volume Reflexes

Primary Factors

Two heart reflexes respond to changes in blood volume: the atrial reflex and the ventricular reflex. How does the atrial reflex affect heart rate?

Atrial/Bainbridge Reflex

The atrial reflex, also referred to as the right heart reflex or Bainbridge reflex, is triggered by an increase in venous return to the heart. Baroreceptors in the superior and inferior venae cavae sense pressure changes and send impulses to the SA node, increasing heart rate.

Ventricular Reflex

Whereas the atrial reflex affects heart rate, the ventricular reflex affects stroke volume. The amount of blood ejected is dependent on the amount of blood filling the ventricle during diastole, called the end-diastolic volume, and the amount of blood left in the ventricle after systole, which is the end-systolic volume.

Frank-Starling Law

Overview

When the blood volume in the ventricle increases, cardiac muscle fibers stretch and then contract.

The amount of blood in the ventricles, the amount of stretching, and the force of contraction are directly proportional--an increase in blood volume results in greater fiber stretching and then a more powerful contraction. This relationship is referred to as the Frank-Starling law.

Analogy

The action of the cardiac muscle fibers is analogous to that of a rubber band. Stretching a rubber band longer results in a more forceful snap when it is released.

How does the nervous system affect heart rate?

Autonomic Innervation

Role of the Autonomic Nervous System

Although heart rate is established by the SA nodal cells, it can be affected by the autonomic nervous system. Changing heart rate is the body's principal short-term mechanism of controlling cardiac output and blood pressure. When stroke volume decreases, the body attempts to maintain adequate cardiac output by increasing the rate and strength of cardiac contraction. The most important control of heart rate and strength of contraction is autonomic innervation.

Cardioacceleratory Center

The medulla oblongata, located in the brain, includes a cluster of neurons that make up the cardioacceleratory center (CAC). Sympathetic fibers that begin in the CAC innervate the SA node, the AV node, and parts of the myocardium. CAC stimulation causes these fibers to release norepinephrine, thereby increasing heart rate and contraction strength.

Cardioinhibitory Center

The medulla oblongata also contains an opposing cardioinhibitory center (CIC). Parasympathetic fibers that begin in the CIC also innervate the SA node and AV node. CIC stimulation results in the transmission of nerve impulses along the parasympathetic fibers and the release of acetylcholine, which decreases heart rate.

How do norepinephrine, acetylcholine, and other hormones exert their effects on heart rate?

Hormones

Overview

When norepinephrine, epinephrine, and acetylcholine are released, the force of myocardial contraction is altered, thus affecting stroke volume.

Norepinephrine and Epinephrine

In response to sympathetic stimulation, norepinephrine is released in the myocardium, and norepinephrine and epinephrine are released by the adrenal medullae. Norepinephrine increases heart rate and myocardial contractility. Epinephrine excites the SA node, thereby increasing the rate and strength of myocardial contraction.

Clinical Correlation: Fight-or-Flight Response

The fight-or-flight response is a physiological and psychological response to danger or stress. During this automatic involuntary response, norepinephrine is released by the medulla oblongata, and norepinephrine and epinephrine are released by the adrenal glands, resulting in a faster heart rate and a more forceful contraction of the heart. Additional effects of the fight-or-flight response include an increase in respiration rate, shunting of blood away from the digestive tract and towards muscles and limbs, release of blood sugar, dilation of pupils, and decreased sensitivity to pain. The fight-or-flight response protects humans from dangers faced in the physical environment--for example, encountering an adversary--and prepares the body to fight the threat or flee from it.

Acetylcholine

Parasympathetic stimulation results in the release of acetylcholine, which inhibits heart activity by decreasing the force of cardiac contractions.

What are some other factors that affect heart rate?

Secondary Factors

ECF Ion Concentration

Elevated levels of extracellular potassium or sodium ions can decrease heart rate and stroke volume. Abnormal potassium levels interfere with the SA node, affecting heart rate. Too much potassium causes cardiac contractions to become weak and irregular, and too little potassium decreases the heart rate. High concentrations of sodium interfere with calcium activity in muscle contractions, reducing contractility.

How do changes in calcium concentration affect heart rate?

Calcium Ion Concentrations

Abnormal calcium ion concentrations affect the strength and duration of cardiac contractions, which then affects stroke volume. High calcium levels cause strong and lengthy contractions. Low calcium levels weaken contraction strength.

Temperature and Emotions

Other Factors

Changes in body temperature can also affect heart rate and contractility. Increased body temperature results in increased heart rate. Decreased body temperature slows heart rate and results in less powerful contractions.

Strong emotions, such as anger, fear, and anxiety, tend to increase heart rate, making you feel like your “heart is pounding.” Other mental states, such as depression and grief, probably stimulate the cardioinhibitory center, resulting in a slower heart rate.

Sex and Age

Sex and age also affect heart rate. The heartbeat of females is generally faster than that of males. Finally, heart rate is fastest at birth and decreases throughout life.

Key Points

- The volume of blood ejected by the left ventricle during a heartbeat is the stroke volume (SV).
- The volume of blood ejected by the left ventricle in each minute is the cardiac output (CO), which is equal to the heart rate (HR) multiplied by the stroke volume and therefore is measured in liters per minute.
- Cardiac output is controlled and affected by many different factors, including the atrial and ventricular reflexes, the autonomic nervous system, hormones, blood ion concentrations, and emotions.