

CARDIOVASCULAR SYSTEM INTRODUCTION

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OBJECTIVES

1. To understand how the heart and circulatory system work
2. To measure blood pressure and cardiac output
3. To apply a mechanical energy balance to the circulatory system

INTRODUCTION

Cardiovascular system

The cardiovascular system is, in the simplest form, a system that consists of a pump, pipes, and a fluid system. The system is a closed circuit, which is elastic, thereby allowing movement and stresses to occur without damaging it. The pump in this system, or the heart, simply allows the blood to flow in. It does not pull the fluid in; therefore the only function of the heart is as a pump. As a consequence of the passive filling of the heart, the network of arteries, capillaries, and veins throughout the body regulates the rate of circulation of the blood. While this flow to the heart is constant, the actually pumping of the blood is intermittent allowing a small fraction of time for the heart to stop and rest between pumps.

Cardiac Output

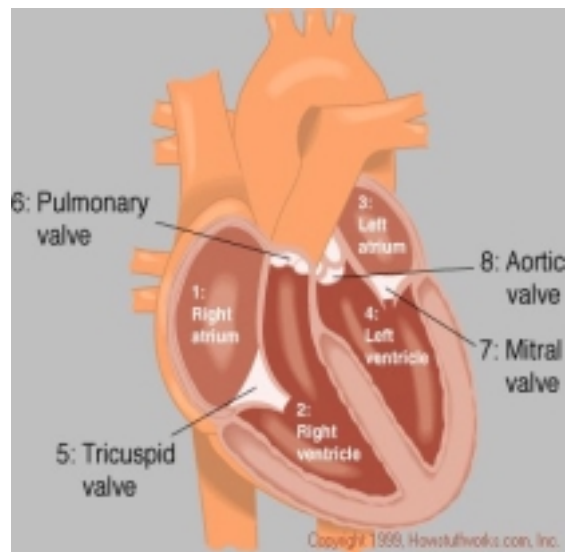
Cardiac output is the amount of blood ejected per minute by the heart (Fox, p. 250). This is closely related to the maximum VO_2 , which we measured in the previous lab. In general, the higher the maximum cardiac output, the higher the person's VO_2 . Maximum cardiac output for a physically fit male is about 30 L/min. Consequently, men who are not physically fit tend to have a maximum cardiac output of about 20-25 L/min. In women the maximum cardiac output is similar, but tend to be higher when performing work at the same level of oxygen consumption (Fox, p. 251). This is speculated to be due the lower levels of hemoglobin that exist in women, therefore reducing the amount of oxygen that a woman's blood can carry.

BACKGROUND

Heart

The heart is a pump, a four-chambered duplex pump. Functionally the heart can be considered as two separate pumps.

- **Right side:** Smaller half of the heart, receives returning blood from all parts of the body, pumps blood to the lungs for aeration by way of the pulmonary circulation
- **Left Side:** Larger half of the heart, receives oxygenated blood from the lungs, responsible for pumping blood to the rest of the body.



Valves

- The artioventricular valves in the heart provide for a one-way passage of blood from the right atrium to the right ventricle and from the left atrium to the left ventricle.
- Semilunar valves just outside the heart prevent blood from flowing back into the heart between contractions.

Pulse Rate and Heart Rate

A surge of blood enters the aorta with each contraction of the left ventricle. The peripheral vessels do not permit blood to exit the arterial system as rapidly as it is ejected from the heart; a portion of the blood pumped from the heart is stored in the aorta. This creates pressure within the entire arterial system and causes a pressure wave to travel down the aorta to the remote branches of the arterial tree. This stretch and subsequent recoil of the arterial wall during cardiac cycle can be felt readily as the characteristic pulse in any superficial artery of the body. In healthy individuals, the pulse rate and heart rate are identical.

History of Blood Pressure

The first well-documented instance of blood pressure measurement was in 1733 by Reverend Stephen Hales, who inserted a long glass tube upright into an incision made in a horse's carotid artery. The pumping action of the heart generated a pressure force, causing the blood level to rise in the tube.

Daniel Bernoulli, from which we get the Bernoulli equation, did extensive research in the field of hydrodynamics. Bernoulli inserted a tube into a pipe to measure pressure. This is the same concept Hales used to measure the pressure in the carotid artery of the horse.

THEORY

Physiologic Rationale

The force of blood against the arterial walls is defined as blood pressure. This lab you will test blood pressure non-invasively using a stethoscope and sphygmomanometer. Blood pressure is a reflection of the work of the heart; it is primarily dependent upon the volume of blood and the resistance of the blood vessels. Blood pressure is commonly measured in the brachial artery, which runs down the center of the arm close to the skin. This artery is used due its position at heart level; or when the arm is in a downward, relaxed position.

The determination of blood pressure in this lab is based upon the sounds made by the vibration from the vascular walls. These sounds are referred to as *Korotkoff* sounds. If you were to place a stethoscope on the inside of your elbow right now without the pressure cuff on you are not able to hear vibrations within the artery. This is because the blood is following with little restriction. Conversely, when the flow of blood is completely blocked, there will be no vibrations to hear because little or no blood is flowing.

But, when blood flow is restricted by pressure applied by the cuff and then gently released, faint sounds can be heard. The point of the first faint sounds that are caused by vascular vibrations is called *systolic pressure*. The point at which blood starts to flow is at the peak point of blood pressure coinciding with left ventricular contraction is called *diastolic pressure*.



Figure 1 Artist's depiction of Hales' horse experiment showing that the pressure of the horse's circulation forced blood up the glass tube (Corbis-Bettman)

Systolic Pressure: the pressure in the arteries, at the height of pulsation, caused by cardiac contraction as the left ventricle pumps blood into the aorta.

Diastolic Pressure: the pressure in the arteries during ventricular relaxation between cardiac contractions.

The Korotkoff Sounds		Deflate cuff 2-3 mmHg/sec.
Phase	Blood Pressure Sounds	Duration
I	Sudden appearance of clear, regular tapping sounds (systolic pressure)	10-15 mmHg
II	A swishing softening of sounds	14-20 mmHg
III	Crisper sounds, increasing in intensity	16-25 mmHg
IV	Abrupt damping or muffling of sounds (diastolic pressure)	10-15 mmHg
V	Complete disappearance of sound	-

CARDIAC OUTPUT

The Indirect Fick Equation is a mass balance on the blood flowing through the pulmonary vein/artery past the lungs, as carbon dioxide is transferred from the blood to the lungs.

$$Q_t (C_{CO_2}^v - C_{CO_2}^a) = \dot{V}CO_2 \quad (1)$$

Cardiac Output (Q_t) is pulmonary blood flow (L/min)

$\dot{V}CO_2$ is the volumetric rate of carbon dioxide produced (L/min)

$(C_{CO_2}^v - C_{CO_2}^a)$ is the blood carbon dioxide concentration difference between inlet (venous) and outlet (arterial)

EXPERIMENTAL PROCEDURES

How to measure blood pressure

1. Put the stethoscope earpieces into your ears with the earpieces facing forward.
2. Place stethoscope disk on the inner side of the crease of your elbow.
3. Rapidly inflate the cuff by squeezing the rubber bulb to 30 to 40 points higher than your last systolic reading. Inflate the cuff rapidly; not just a little at a time. Inflating the cuff too slowly will cause a false reading.
4. Slightly loosen the valve and slowly let some air out of the cuff. Deflate the cuff by 2 to 3 millimeters per second. If you loosen the valve too much, you won't be able to determine your blood pressure.
5. As you let the air out of the cuff, you will begin to hear your heartbeat. Listen carefully for the first sound. Check the blood pressure reading by looking at the pointer on the dial. This number will be your systolic pressure.
6. Continue to deflate the cuff. Listen to your heartbeat. You will hear your heartbeat stop at some point. Check the reading on the dial. This number is your diastolic pressure.
7. Write down your blood pressure, putting the systolic pressure before the diastolic pressure (for example, 120/80).
8. Before repeating the measurement, wait 2 to 3 minutes before reinflating the cuff.

9. Repeat the measurement holding your arm straight up. Your arm must remain completely vertical throughout the test for an accurate reading to be made.

How to measure cardiac output

1. Choose one person to do the test and one person to operate the computer.
2. Set up Breeze Ex software with the person who is doing the test's name, ID, race, sex, birth date, height, and weight.
3. Click the "Return" button.
4. Now click the "VO2 Testing" button.
5. Put pneumotach in gray rubber fitting with the honeycomb design facing in.
6. Add a saliva trap on the end of the pneumotach.
7. Put pink sample wire into the rebreathing valve at the white piece. Make sure you can see the pink wire sticking through the tube.
8. Push in the black plunger.
9. Crumple the black bag so that no gas is left inside of it.
10. While holding the bag crumpled up, open the black plunger.
11. Release the bag and add the CO₂ until the bag is half full
12. Place saliva trap in mouth while holding the rest of the rebreathing valve steady.
13. Have the computer operator click the "GO/start test" button.
14. Collect 2-3 minutes of "stable" data while breathing normally and sitting still.
15. At the end of the 2-3 minutes, have the computer operator click the "NICO" button.
16. When you are ready, have the computer operator hit start while you are simultaneously pushing the black plunger.
17. **DO NOT BREATHE NORMALLY.** Breathe rapidly and deeply, about 40 breaths per minute, but not enough to hyperventilate. Do this for 20 seconds. Recall that the normal breathing rate is about 12 breaths per minute and, when hyperventilating, the breathing rate is about 100 to 120 breaths per minute.
18. At the end of 20 seconds click the "Stop Test" button and push the plunger back in.
19. Record value for blood flowrate, Qt, in L/min.

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