Cardiovascular Fitness

- Running is considered the most popular cardiovascular fitness program.

Learning Objectives

1. To develop an understanding of the organs and components of the human body that comprise the cardiovascular and respiratory systems.
2. To develop an understanding of physiological characteristics of the cardiovascular and respiratory systems and their functions to maintain health and optimal performance.
3. To develop an awareness of the measures used to evaluate and describe the various components of the cardiovascular and respiratory systems.
4. To develop an understanding of the effect of training on the cardiovascular and respiratory systems.
The Primary Roles of the Cardiovascular System

1. To transport oxygen from the lungs to the tissues.
2. To transport carbon dioxide from the tissues to the lungs.
3. To transport nutrients from the digestive system to other areas in the body.
4. To transport waste products from sites of production to sites of excretion.

The Heart

Structure

- Comprised of smooth muscle that serves to pump blood through the human body.
- Consists of four chambers:
  - Two ventricles (left and right) → pump blood through the body
  - Two atria (left and right) → receive blood from peripheral organs and pump blood into the ventricles
- Left ventricle → pumps blood through the entire body (are larger and with stronger muscle walls than the right ventricles)
- Right ventricle → pumps blood a short distance to the lungs

Pathway of blood flow:

- The right atrium receives deoxygenated blood from the superior and inferior vena cava.
- The blood moves from the right atrium to the right ventricle and pumps it to the lungs.
- The left atrium receives the oxygenated blood from the lungs and pumps it to the left ventricle.
- The blood is now oxygen-rich and is transported to the entire body via the aorta.
### The Heart

#### Pathway of Blood Flow:
- **RIGHT ATRIUM**: 
  - Tricuspid valve
- **RIGHT VENTRICLE**: 
  - Pulmonary valve
  - Pulmonary arteries
  - Lungs
- **PULMONARY VEINS**: 
  - Pulmonary veins
- **LEFT ATRIUM**: 
  - Bicuspid valve
- **LEFT VENTRICLE**: 
  - Aortic valve
  - Aorta
  - Inferior vena cava
  - Superior vena cava
- **Arteries**
- **Veins**
- **Capillaries**
- **Deoxygenated**
- **Oxygenated**

### The Heart

#### Function
- The heart contracts in a constant rhythm that may speed up or slow down depending on the need for blood (and oxygen) in the body.

- The beating of the heart is governed by an automatic electrical impulse generated by the **sinus node**.

- The sinus node is a small bundle of nerve fibers that are found in the wall of the right atrium.

- The sinus node generates an electrical charge called an action potential. The action potential causes the muscle walls of the heart to contract. This action potential travels through the two atria and the two ventricles via the **a-v node** and the **Purkinje fibers**.

- The atria contract before the ventricles contract, which allows for the blood to be quickly pumped into the ventricles from the atria.
The Finely Tuned Cardiac Cycle

(a) As the heart relaxes in diastole, both atria simultaneously fill with blood.
(b) The mitral and tricuspid valves open, and the atria, squeezing into systole, force blood into the ventricles.
(c) As the ventricle compartments fill with blood, they contract, thereby ejecting blood to the lungs and body.
(d) The atria again relax and refill with blood.

The Heart

Blood Pressure

- An important measure of cardiac function
- There are two components to the measure of blood pressure:
  1. Diastole: Used to describe the pressure in the heart when the ventricles are relaxed and are being filled with blood. Indicator of peripheral blood pressure (the blood pressure in the body outside the heart)
  2. Systole: The pressure in the ventricles when they are contracting and pushing blood out into the body

FYI: The normal range of pressure in the atria during diastole is about 80 mmHg, and during systole is about 120 mmHg.

Measuring Blood Pressure

- Doctor taking patient’s blood pressure
The Heart

**Stroke Volume:**
- The amount of blood pumped out of the left ventricle each time the heart beats
- Measured in milliliters
- A typical stroke volume for a normal heart is about 70 milliliters of blood per beat

**Cardiac Output:**
- The amount of blood that is pumped into the aorta each minute by the heart
- Cardiac output (L/min) = stroke volume (L/min) x heart rate (bpm)

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Measuring Heart Rate

- Taking heart rate with fingers at the neck (carotid pulse) and wrist (radial pulse)

(a) Feeling the carotid pulse  
(b) Feeling the radial pulse

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The Heart

**Heart Rate**
- The number of times the heart beats in one minute, measured in beats per minute (bpm).
- The contraction of the walls of the heart is commonly known as a heart beat
- The resting heart rate of an adult can range from 40 bpm in a highly trained athlete to 70 bpm in a normal person.
- During intense exercise, the heart rate may increase to up to 200 bpm.

**Maximum heart rate = 220 - Age (years)**

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Circuitry of the Heart and Cardiovascular System

Illustration of the entire cardiovascular system: heart, lungs, and peripheral circulation

The Heart

The Peripheral Circulatory System

- The peripheral circulatory system is comprised of the vessels that carry blood away from the heart to the muscles and organs (lungs, brain, stomach, intestines), and the vessels that return the blood to the heart.
- All of the vessels of the body are made up of smooth muscle cells that allow them to contract or relax.
- The contractile properties of smooth muscle enable the vessels of the peripheral circulatory system to regulate blood flow and alter the pattern of circulation throughout the body.

The Heart

The Peripheral Circulatory System

- Vessels that carry blood away from the heart are called arteries.
- Arteries branch into smaller and smaller vessels called arterioles.
- The arterioles branch into even smaller vessels called capillaries.

Arteries ➔ Arterioles ➔ Capillaries
Capillaries:
- allow for the exchange of oxygen and nutrients from the blood to muscles and organs
- allow blood to pick up the waste products and carbon dioxide from metabolism

As the blood begins to return to the heart, the capillaries connect to form larger and larger vessels called venules.
The venules then merge into larger vessels that return blood to the heart called veins.

In comparison to arteries, veins have valves that open as blood returns to the heart, and valves that close as blood flows away from the heart.

Blood can be pushed through veins by smooth muscle that surrounds the veins, contraction of large muscles near the veins, or to a minor extent by the pumping action of the heart.
blood flow toward the heart opens the valves

blood flow away from the heart closes the valves.

The Heart

Red Blood Cells

- Also called erythrocytes
- The primary function is to transport oxygen from the lungs to the tissues and remove carbon dioxide from the body. They are able to do this because of a substance called hemoglobin.
- Other components of blood include white blood cells and the clear fluid plasma. The percentage of the blood made up of red blood cells is called hematocrit (about 45 percent).

The Red Blood Cell

- Single red blood cell or erythrocyte
Hemoglobin

- A molecule made up of proteins and iron.
- Each molecule can bond to and transport four oxygen molecules.
- The amount of oxygen that is carried by the blood is dependent upon the partial pressure of oxygen (PO2).
- The difference in the amount of oxygen that is present in the blood as it leaves the lungs and the amount of oxygen that is present in the blood when it returns to the lungs is called the arterial-venous oxygen difference (a-v O2 difference), measured in ml of oxygen per liter of blood (ml O2/L).
- If the a-v O2 difference increases, it means that the body is using more oxygen.
- The typical a-v O2 difference at rest is about 4 to 5 ml O2/L, while during exercise the a-v O2 difference can increase to 15 ml O2/L.

New red blood cells or reticulocytes are produced in the bone marrow.

Erythropoietin (EPO), a circulating hormone, is the principal factor that stimulates red blood cell formation.

EPO is secreted in response to low oxygen levels (when one goes to altitude) and also in response to exercise, thus increasing the percentage of new red blood cells in the body.

New red blood cells contain more hemoglobin than older red blood cells and thus can carry greater amounts of oxygen.

High altitude (low oxygen level) has an effect on EPO production, which in turn generates a high production of red blood cells.
Transport of Carbon Dioxide

- CO₂ is produced in the body as a by-product of metabolism.
- CO₂ diffuses from the cells to the blood where it is transported to the lungs via one of three mechanisms:
  1. A small percentage of the produced CO₂ is dissolved in the blood plasma.
  2. CO₂ bonds to the hemoglobin molecule.
  3. The primary mechanism whereby CO₂ is transported through the body is via combining with water to form bicarbonate molecules that are then transported through the body. This happens according to the following reversible reaction:

\[
\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3
\]

Oxygen uptake

- The amount of oxygen that is consumed by the body due to aerobic metabolism.
- Measured as the volume of oxygen that is consumed (VO₂) in a given amount of time, usually a minute.
- Oxygen uptake increases in relation to the amount of energy that is required to perform an activity.
- (VO₂ max): a measure used to evaluate the maximal volume of oxygen that can be supplied to and consumed by the body.

Testing for Maximal Oxygen Uptake

- Testing maximal aerobic power (VO₂ max)
Oxygen Uptake

- Changes in hematocrit (concentration of red blood cells in the blood) can also alter the oxygen uptake by increasing or decreasing the amount of oxygen that is supplied to working tissues.

- The ability of the tissues to extract oxygen (a-v O\textsubscript{2} difference) directly affects oxygen uptake.

- Increases in a-v O\textsubscript{2} difference may arise due to an increased number of mitochondria in the muscles or increased enzyme efficiency in working tissues.

Oxygen Uptake

- Increased capillarization (number of capillaries in tissue) can affect the ability of the circulatory system to place red blood cells close to the tissues that are using the oxygen.

- As a result, this increases the ability of those tissues to extract the required oxygen due to a shorter diffusion distance.

Cardiovascular Anatomy Summary

\[ \text{VO}_{\text{max}} = \text{Cardiac Output} \times (\text{a-v O}_2 \text{ difference}) \]

- The central component primarily concerns the effectiveness of the heart and the peripheral factors include:
  1. Ability of the lungs to oxygenate the blood
  2. Ability of the body to extract that oxygen

- Training can increase the maximal oxygen consumption of the human body. How this is accomplished will be presented in the next section.
The primary role of the respiratory system is to:
1. deliver oxygenated air to blood
2. remove carbon dioxide from blood, a by-product of metabolism

The respiratory system includes:
1. the lungs
2. several passageways leading from outside to the lungs
3. muscles that move air into and out of the lungs

The term respiration has several meanings:
1. Ventilation (breathing)

2. Gas exchange (occurs between the air and blood in the lungs and between the blood and other tissues of the body)

3. Oxygen utilization by the tissues for cellular respiration
The Lungs

- Located within the thoracic cavity/pectoral cavity
- The lungs are asymmetrical. The right lung is larger than the left lung because the heart takes up more space on the left side.
- The air passages of the respiratory system are divided into two functional zones:
  1. The conduction zone
  2. The respiratory zone

The Conduction Zone

- A set of anatomical structures through which air passes before reaching the respiratory zone.
- Air enters through the nose and/or mouth, where it is filtered, humidified, and adjusted to body temperature in the trachea (windpipe).

The Conduction Zone

- The trachea branches into right and left bronchi that enter the lungs and continue to branch into smaller and smaller tubes called bronchioles, and finally terminal bronchioles.
- The whole system inside the lungs looks similar to an upside-down tree that it is commonly called the “respiration tree.”
The Respiration Zone

- The region where gas exchange occurs.
- The functional units of the lungs are the tiny air sacs, known as alveoli.
- Alveoli are clustered in bunches like grapes, with a common opening into an alveolar duct called an alveolar sac.

The Structure of the Respiratory System

The Alveolus
Ventilation and the Gas Exchange

Oxygen In
Carbon Dioxide Out

Ventilation

- Ventilation includes two phases, **inspiration** and **expiration**. Gas exchange between the blood and other tissues and oxygen utilization by the tissues are collectively known as **internal respiration**.

Ventilation

Involves the movement of air into (**inspiration**) and out of (**expiration**) the lungs.

- Changes in the size of the chest/thoracic cavity, and thus of the lungs, allow us to inhale and exhale air.
- Lungs are normally light, soft, and spongy to allow for expansion of the thoracic cavity.
The muscles surrounding the thoracic cavity that cause it to shrink and expand include the:

- Diaphragm
- External Intercostal muscles (*expiration*)
- Internal Intercostal muscles (*inspiration*)

During *inspiration*, the thoracic cavity expands via muscle contractions causing the air pressure inside to be lowered. The greater outside pressure causes a flow of air into the lungs.

During *expiration*, the thoracic cavity shrinks via muscle relaxation. The greater outside pressure causes a flow of air out of the lungs.

Gas exchange between the air and blood in the lungs occurs at the **alveoli**.

- Each bubble-like alveolus is surrounded by a vast network of pulmonary capillaries.
- The atmospheric air that makes its way into each alveolus is rich in oxygen.
Gas Exchange in the Lungs

The blood in the pulmonary capillaries is loaded with the waste product carbon dioxide. This difference in concentration of CO₂ and O₂ gases sets up ideal conditions for gas diffusion to occur.

- **Diffusion** is the movement of molecules (in this case, gases) from a higher concentration to a lower concentration.

Therefore, oxygen diffuses through the alveolar membrane into the deoxygenated pulmonary capillaries.

Gas Exchange in the Lungs

- **Carbon dioxide** diffuses in the opposite direction, from the carbon dioxide-rich pulmonary blood into the alveoli.

The oxygenated blood follows the pulmonary circulation to reach the heart (right ventricle) and is distributed through systemic circulation.

- Carbon dioxide is exhaled out.

Gas Exchange at the Alveolus
Exercise Effects on the Cardiovascular and Respiratory Systems

The cardiovascular system ensures that an adequate blood supply to the working muscles, the brain, and the heart is maintained.

- Heat and waste products generated by the muscles are dissipated and removed.

Aerobic Training Effects on the Cardiovascular and Respiratory Systems

Cardiac Output

- An increase in heart size is one of the benefits that may arise from endurance training.

1. Larger atria and ventricles allow for a greater volume of blood to be pumped each time the heart beats.

2. Increased thickness of the walls of the heart (cardiac muscle) allows for increased contractility (rate of contraction).
Exercise Effects on the Cardiovascular and Respiratory Systems

Capillary Supply

- Increased capillarization is another benefit of endurance training.
- Increased capillarization:
  1. provides a greater surface area and reduced distance between the blood and surrounding tissues
  2. increases the diffusion capacity of oxygen and carbon dioxide
  3. eases transport of nutrients to cells

Exercise Effects on the Cardiovascular and Respiratory Systems

Capillary Supply

- The a-v O₂ difference of the body can be also improved by endurance training.
- Endurance training increases circulation (blood flow) in the capillaries that are next to muscle fibers.
- Capillarization also occurs in cardiac muscle, reducing the possibility of cardiac disease and heart attacks.

Exercise Effects on the Cardiovascular and Respiratory Systems

Blood Volume

- Increase in total blood volume along with the number and total volume of red blood cells.
- This is achieved through stimulation of erythropoiesis (formation of new red blood cells) in the bone marrow.
Exercise Effects on the Cardiovascular and Respiratory Systems

Ventilation
- Increases with exercise to meet the increased demand of gas exchange.
- During exercise, ventilation can increase from 6 L/min at rest to over 150 L/min during maximal exercise and to more than 200 L/min during maximal voluntary breathing.
- With exercise/endurance training, the lungs become more efficient in gas exchange.

Exercise Effects on the Cardiovascular and Respiratory Systems

Oxygen Extraction
- Similar to ventilation in that increased air flow allows for more gas exchange.
- During exercise, body temperature also increases. Increased body temperature promotes oxygen extraction, known as the Bohr effect.

Exercise Effects on the Cardiovascular and Respiratory Systems

Summary
- Endurance training stimulates many positive adaptations in the cardiovascular system.
- It is crucial that health professionals understand these adaptations in order to impart this knowledge to the general population to promote better health and quality of life.
Cardiovascular Anatomy and Physiology

Discussion Questions

1. Describe the path and all related steps that a molecule of oxygen would take from the air in the lungs to a muscle cell.
2. Describe the path and all related steps that a molecule of carbon dioxide could take from a muscle cell to the air in the lungs.
3. Define and provide the units for blood pressure, heart rate, cardiac output, stroke volume, and arteriovenous oxygen (a-v O₂) difference.
4. List the ways in which training improves the effectiveness of the cardiovascular system.

5. Describe the two components of blood pressure. What do they measure?
6. What is hemoglobin, where is it found, and what is its purpose?
7. What are erythrocytes and reticulocytes? Where are they produced?
8. What is hematocrit?
9. Describe the ways in which carbon dioxide can be transported through the blood.
10. What is VO₂max? What factors influence this measure? How is it affected by training?