Course Name : Bachelor of Physical Education
Year : IInd
Paper Name : Kinesiology and Physiology of Exercise
Paper No. Ist
Lecture No. 10
Topic no. : Sec - D(1)
Lecture Title : Cardio – Respiratory System and Exercise Part - I

Introduction

- Immediate adjustments needed to meet metabolic demands of the body's cells to exercise as well as adaptations
- Understand how the systems of energy and substrate delivery – the respiratory and cardiovascular systems – meet the increased demand that occurs while engaging in work, exercise or physical activity.
- Brief description of the anatomy of the respiratory and cardiovascular systems
- A description of the physiology of both systems and how they work together to supply the body with oxygen
- What happens at the onset of exercise – how the cardio-respiratory system meets the increased demand that occurs while engaging in exercise or physical activity. What happens when activity is stopped
- What training adaptations occur in both systems as well as how they occur in terms of mechanism of action
- What are the long term effects of exercise on these systems

- Relate any hormonal influences of epinephrine and norepinephrine on these two systems and how this may effect the relationship between the two systems.

Anatomy of the Respiratory System

The respiratory system is responsible for gaseous exchange between the external atmosphere and the blood. It delivers oxygen to the circulatory system for distribution to all body cells and aids in the removal of carbon dioxide. The major organs of the respiratory system are the nose, pharynx, larynx, trachea, bronchi and their smaller branches, and the lungs that contain air sacs called alveoli. The alveoli are the only locations where gas exchange actually occurs; the rest of the respiratory organs function mainly as conducting passageways for air.

The nose is the external interface of the respiratory system. Air from the atmosphere enters the respiratory system through the left and right nostrils (external nares) into a nasal cavity that is divided by a midline nasal septum. The nasal passages are lined by a respiratory mucosa, composed mainly of a single layer of cilia-fringed epithelial cells, and interspersed by mucous-producing goblet cells. A bed of capillaries lie just beneath the mucous membrane near the surface of the nasal passages. Two critical functions of the nasal passages are to filter the air of contaminants and to warm and moisten incoming air protecting other respiratory system structures. Olfactory receptor cells, involved with the sense of smell, are also located in the nasal passages.

Separating the nasal cavity from the oral cavity below are hard palate (anteriorly) and the soft palate (posteriorly).

Air flows from the nasal passages to the pharynx, commonly called the throat; a short funnel shaped tube about 13cm long. It serves as a common passageway for food and air. The pharynx has a superior portion termed the nasopharynx descending through the oropharynx to the laryngopharynx. Both the nasal and oral cavities, as well as the auditory tubes, open into the pharynx. Like the nose, the pharynx is lined by ciliated mucosa to further remove impurities from the air. The tonsils are found in the pharynx, located in strategic locations, to help trap disease carrying organisms.

Air moves from the pharynx to the larynx, commonly called the voice box. The larynx routes air and food into proper channels and also functions in voice production. A leaf-like structure called the epiglottis protects the superior opening of the larynx. While a person is breathing, the epiglottis is held vertically like a trap-door, keeping the passage of air open to the lower respiratory structures. When a person swallows, a reflex causes the larynx and epiglottis to move toward each other forming a protective lid. The food and fluid are then routed to the esophagus posteriorly. Anything other than air entering the larynx causes a cough reflex to prevent any substances from entering the lungs.

The air continues on from the larynx and enters the trachea or windpipe. It is about 10-12cm long and reaches to a level of the midchest. The trachea is reinforced by c-shaped rings of hyaline cartilage keeping the structure fairly rigid. This helps hold the trachea open allowing easy passage of air at all times.

The trachea divides into the right and left primary bronchi. Each branch delivers air to the right and left lung respectively. Within each lung, the bronchi divide into smaller branches called bronchioles.

The lungs occupy the entire thoracic cavity except for the most central area called the mediastinum. This area houses the heart, the great blood vessels, bronchi, esophagus, and other organs.

Cardio-Respiratory System Physiology

The respiratory and cardiovascular systems work together to deliver oxygen to the cells and to remove carbon dioxide. This two-way process of gas exchange is called respiration. Respiration involves at least four distinct stages:

a) pulmonary ventilation; the process of breathing or the movement of gases into and out of the lungs
b) external respiration; the exchange of gases between the alveoli and pulmonary blood
c) respiratory gas transport; transport of gases to and from the lungs and cells via the bloodstream involving the cardiovascular system
d) internal respiration; the exchange of gases between the blood and the cells at the capillary level.

Pulmonary Ventilation

Pulmonary ventilation or breathing is a mechanical process that creates volume changes in the thoracic cavity leading to air pressure changes, which lead to the flow of gases to equalize the pressure.

Breathing begins with the process of inspiration. The muscles that contract to increase the size of the thoracic cavity are the diaphragm and the external intercostals. The diaphragm contracts, flattens, and moves downward, elongating the thoracic cavity. The external intercostals lift the rib cage and thrust the sternum forward increasing the lateral and anterior-posterior dimensions of the thoracic cavity. The lungs expand as they adhere to the walls of the thorax. The increase in intrapulmonary volume causes the gas molecules within the lungs to spread out. This results in a decrease in gas pressure and creates a partial vacuum. Air gets sucked into the lungs through the respiratory tract until the intrapulmonary pressure equals the atmospheric pressure.

Expiration occurs as the inspiratory muscles relax. The rib cage descends and the lungs recoil causing a decrease in thoracic and intrapulmonary volume. Intrapulmonary pressure rises as the gas molecules get forced closer together. Air then flows out of the lungs to equalize the pressure inside and outside the lungs. Expiration is a predominantly passive process in healthy individuals at rest.

External Respiration

The exchange of gases between the lungs and blood, as well as gas exchange at the tissue level, progress according to the laws of diffusion. During the process of external respiration, the pressure gradients established by the relative concentrations of O_2 and CO_2 in the alveoli and pulmonary blood determine the direction of gas exchange. Movement occurs toward the area of lower concentration of the diffusing substance.

Dark red blood returning to the pulmonary capillaries from the tissue cells has a lower concentration of O_2 and a higher concentration of CO_2 than the air in the alveoli. Thus, oxygen diffuses from the alveolar air into the oxygen-poor pulmonary blood and carbon dioxide diffuses from the pulmonary blood into the alveoli for removal during expiration. Now the oxygen-rich and carbon dioxide-poor blood is ready for transport back to the tissue cells via the cardiovascular system.

Respiratory Gas Transport

Oxygen is carried in the blood in two ways:

a) oxygen binds to hemoglobin molecules in the red blood cells forming oxyhemoglobin HbO_2

b) a small amount in physical solution dissolved in the blood plasma

Carbon dioxide is carried in the blood in three ways:

a) most of the CO_2 is transported in plasma as the bicarbonate ion, which plays an important role in the blood buffer system

b) between 20-30% is carried inside the red blood cells bound to hemoglobin at a different site than O_2

c) a small amount in physical solution dissolved in the blood plasma

Carbon dioxide must be released from its bicarbonate ion form before it can diffuse out of the blood into the alveoli. The bicarbonate ions combine with hydrogen to form carbonic acid that splits to form water and carbon dioxide. Carbon dioxide then diffuses from the blood to the alveoli for removal from the lungs through the respiratory tract.

Circulation

Oxygenated blood in the pulmonary capillaries drain into one of the pulmonary veins. The oxygenated blood flows from the pulmonary vein into the left atrium of the heart. The blood passes from the left atrium to the left ventricle where it is then pumped out to the aorta. The aorta branches into the systemic arteries for distribution to body tissue capillaries where gas exchange functions with the cells occur (see internal respiration below).

The de-oxygenated blood then drains from the capillaries into the systemic vein network that transports the dark blood to the right atrium of the heart. The blood passes from the right atrium to the right ventricle where it is then pumped out through the pulmonary trunk. The pulmonary trunk branches into right and left pulmonary arteries that carry the de-oxygenated blood back to the lung capillaries where the external respiration process is repeated.

Internal Respiration

Internal respiration is the exchange of gases that occurs between the blood and tissue cells. The process is the opposite of the external respiration process that takes place at the lungs. Internal respiration is a process where oxygen is unloaded from the blood in the systemic capillaries and carbon dioxide is loaded into the blood (see respiratory gas transport above). The gas molecules diffuse between the blood and cells down their concentration gradient from an area of higher concentration to lower concentration. As a result of these gas exchanges, venous blood in the systemic circulation is oxygen-poor and carbon dioxide-rich.

Effects of Exercise on the Cardio-Respiratory System

At the onset of exercise, energy requirements of the skeletal muscles increase instantly. This increased metabolic demand places additional stress on the cardio-respiratory system to deliver oxygen to the working tissue cells and to remove carbon dioxide and other waste products from the tissue cells.

In order to get more oxygen to the active muscle cells at the onset of exercise, blood flow to the tissues must increase. This means that the heart must pump more blood. Cardiac output is the amount of blood pumped out of each ventricle in 1 minute. It is the product of the heart rate times the stroke volume. Stroke volume is the amount of blood pumped out by each ventricle per heartbeat.

Cardiac output can increase from 4-8 times the resting output during maximal exercise, depending on the persons fitness level. An increase in cardiac output produces a proportionate increase in the circulation of oxygen. Both the stroke volume and heart rate increase in response to exercise. Increased cardiac filling during diastole followed by a more forceful systolic contraction is a major physiologic mechanism responsible for increasing stroke volume. Any factor that increases venous return or slows the heart produces greater cardiac filling during diastole. An increase in end-diastolic volume stretches the myocardial fibers and produces a more powerful ejection of blood during contraction. Exercise speeds venous return by activation of the muscular pump that squeezes the veins returning blood to the heart. Another factor that increases stroke volume is enhanced systolic ejection independent of increased end-diastolic volume. Catecholamine release in exercise enhances the force of heart contraction.

Another cardiovascular response to exercise is greatly increased blood flow to active muscle in proportion to other organ tissues. During exercise, arteries feeding the working muscle dilate increasing blood flow. Other blood vessels feeding tissue with less metabolic demand constrict.

The other major cardiovascular response to exercise other than increased blood flow is the increased ability of active tissue to extract more oxygen already carried in the blood. This effect is reflected by an expanded a-v O2 difference. This is a measurement of the difference in the amount of oxygen carried by the arterial and venous blood. A greater a-v O2 difference means that more oxygen is being extracted from the blood resulting in lower oxygen concentrations in the venous blood.

Maximum cardiac output and a-v O2 difference determine maximal oxygen consumption.

During exercise, pulmonary ventilation increases to augment oxygen supplies to working muscle and to remove waste products of metabolism. The volume of air breathed each minute is referred to as minute volume. Minute volume is the product of the breathing rate times the tidal volume. Tidal volume (TV) describes the volume of air moved during either the inspiratory or expiratory phase of the breathing cycle. Exercise increases both the breathing rate and the tidal volume, thus increasing minute ventilation. Exercise minute ventilation can increase about 17-20 times the resting value.

The activity of the respiratory muscles is regulated by nerve impulses transmitted from neural centers located in the medulla and pons. The brain centers send more impulses to the respiratory muscles during exercise causing a deeper more vigorous breathing pattern. The most important factor in the regulation of respiratory rate and depth are the levels of oxygen and carbon dioxide in the blood. Increased levels of carbon dioxide and decreased blood pH are the most important stimuli leading to an increase in rate and depth of breathing. Conversely, changes in the levels of oxygen in the blood are detected by receptors in the aorta and carotid artery and impulses are sent to the medulla when blood oxygen levels drop. Regulation of pulmonary ventilation is not controlled by any one factor during exercise. Rather, it is probably the combined effects of various chemical and neural stimuli that initiate and regulate exercise ventilation.

Gas exchange at the blood-alveoli level happens rapidly. Even during high-intensity exercise, the increased blood flow velocity through the pulmonary capillaries does not hamper the full loading of oxygen or the unloading of carbon dioxide.