Chapter 1:
Exercise Physiology

ACE Personal Trainer Manual
Third Edition
Introduction

• Physiology is the study of the myriad functions in a living organism.

• Exercise physiology is the study of the ways cells and tissues of the body function during exercise.
Optimum Fitness

- Optimum fitness is the condition resulting from a lifestyle that leads to the development of an optimal level of cardiovascular endurance, muscular strength, and flexibility, as well as the achievement and maintenance of ideal body weight.
Definitions

- Cardiorespiratory Fitness - also referred to as cardiovascular or aerobic fitness; ability of the cardiovascular/cardiorespiratory system (heart, lungs, blood vessels) to deliver an adequate supply of oxygen to exercising muscles.

- Muscular Strength - maximum amount of force a muscle or muscle group can develop during a single contraction.
Definitions

• **Muscular Endurance** - number of repeated contractions a muscle or muscle group can perform against a resistance without fatiguing, or the length of time a contraction can be held without fatigue.

• **Flexibility** - amount of movement that can be accomplished at a single joint; an articulation; a range of motion about a joint.
Body Composition

Healthy body weight represents a healthy body composition.

- Healthy Body-Fat Percentage (Women): 21-24%
- Healthy Body-Fat Percentage (Men): 14-17%
Fitness Testing

• The value of fitness testing is to establish a baseline against which improvements can be measured over time.

• Fitness testing can be performed in a controlled laboratory environment or with less sophisticated “field tests.”
Physiology of the Cardiovascular System

• Cardiovascular system refers to the heart and all the vessels through which blood flows.

• Cardiopulmonary system is composed of the heart, lungs, & blood vessels.

• Three (3) types of blood vessels:
  1. Arteries
  2. Capillaries
  3. Veins
Physiology of the Cardiovascular System

Arteries
- Carry oxygenated blood away from the heart.
- Exception: Pulmonary arteries have a low O₂ content, and pulmonary veins have a high O₂ content.

Capillaries
- Narrow, thin-walled vessels across which gases, nutrients, and waste are exchanged.

Veins
- Carry blood with high levels of CO₂ and low levels of O₂ back to the heart.
The Heart

- Four (4) Chambers:
  - Right & Left Atria
  - Right & Left Ventricles
- Hemoglobin is the protein that carries O₂ in red blood cells.
- Two (2) phases of the cardiac cycle:
  - Systole (contraction)
  - Diastole (relaxation)
- The heart is supplied with O₂ through the coronary arteries.
The Heart

• The benefit of having a high level of cardiopulmonary fitness is that the heart spends more time resting (in diastole) in submaximal exercise intensity.
The Heart

- Cardiac output (Q) is the amount of blood that flows from each ventricle in one minute.

- Stroke volume (SV) is the amount of blood pumped from each ventricle each time the heart beats.

\[ Q = HR \times SV \]

For example, if the heart rate is 60bpm (HR=60), and 70mL of blood are pumped each beat (SV=70mL), the cardiac output (Q) would be:

\[ 60\text{bpm} \times 70\text{mL/beat} = 4,200 \text{mL/ min} \]
The Heart

• Ejection fraction is the percentage of the total volume of blood in the ventricle at the end of diastole that is subsequently ejected during contraction (measurement of the heart’s efficiency).

• The primary purpose of the cardiovascular system during exercise is to deliver O₂ and other nutrients to the exercising muscle cells and to carry carbon dioxide and other waste products away from the muscles.
The Heart

• The amount of $O_2$ taken from the hemoglobin and used during exercising is referred to as oxygen extraction.
Energy Production in Cells

• ATP is Adenosine Triphosphate. For our purposes, ATP is the body’s energy source, just as gasoline is the fuel/energy source for a vehicle.

• Muscle cells replenish ATP using three (3) biochemical pathways:
  1. Aerobic System
  2. Anaerobic Glycolysis
  3. Creatine Phosphate System
Energy Production in Cells

• **Aerobic** = “with oxygen”
  - Mitochondria are the site of aerobic energy (ATP) production.

• **Anaerobic** = “without oxygen”
  - Ischemia is the term for insufficient O₂ supply

• The body uses two (2) substances to produce most of the body’s ATP supply:
  1. Fat (Fatty Acids)
  2. Carbohydrates (Glucose)
Energy Production in Cells

- **Anaerobic threshold** - intensity at which adequate O$_2$ supply is unavailable.

- **Glycogen** - a large molecule made of chains of glucose; stored in the liver and muscles.

- **Creatine phosphate** - a molecule that can be quickly broken apart to help produce ATP.
Energy Production in Cells

- Kilocalorie (kcal) - unit of energy most often used in exercise science; amount of heat that will raise the temperature of 1kg of water 1°C.

- Lactic acid - by-product of anaerobic ATP production; principal cause of the immediate soreness in an exercising muscle as a result of anaerobic energy (glucose) use.
Energy Production in Cells

• **VO₂ max** - total capacity to consume O₂ at the cellular level; also referred to as maximal O₂ consumption (maximum aerobic capacity).

• **VO₂ max** depends on two (2) factors:
  1. The delivery of O₂ to the working muscle by the blood (cardiac output), and
  2. The ability to extract the O₂ from the blood at the capillaries and use it in the mitochondria (oxygen extraction).

\[
VO₂ \text{ max} = (\text{cardiac output max}) \times (\text{oxygen extraction max})
\]
Energy Production in Cells

- MET - metabolic equivalent; activities are described in terms of METs.
  
  \[
  \text{MET} = \text{Resting VO}_2 \text{ of } 3.5\text{mL/ kg/ min}
  \]

  - Volleyball = 3-6 METs
  - Step Aerobics = 6-10 METs
  - Firefighter Activities = 11-13 METs
Cardiovascular Response to Exercise

- **Vasodilation** - increase in the diameter of blood vessels

- **Vasoconstriction** - decrease in the diameter of blood vessels
Cardiovascular Response to Exercise

• Blood pressure is measured in mL of pressure (mercury).

• Systolic blood pressure - amount of pressure generated by the contraction of the left ventricle (systole) to propel blood through the body.

• Diastolic blood pressure - amount of pressure left in the system when the heart muscle relaxes between beats (diastole).
Cardiovascular Response to Exercise

• During exercise, systolic blood pressure should increase as the cardiovascular system attempts to increase oxygen supply to muscles.

• In response to aerobic training, the stroke volume during exercise also becomes greater; thus, maximum cardiac output is significantly greater following training because of the increase in stroke volume.
Cardiovascular Response to Exercise

- The exchange of gases and nutrients between blood and tissues occurs in the capillaries.

- New capillaries are produced in the active skeletal muscles (increasing the area of exchange of O₂) during aerobic training.

- Mitochondrial density also increases significantly as a result of aerobic activity, which means more of a muscle cell is occupied by the mitochondria. This also results in a significant increase in the amount of aerobic enzyme activity in the cell.
Guidelines for Cardiac Fitness

• Overload principle - the principle that the system must be made to work harder than it is accustomed to working.

• To maximize overload, aerobic training should:
  1. Be the correct type;
  2. Be done at the proper intensity;
  3. Be of sufficient duration; and
  4. Occur with adequate frequency.
Guidelines for Cardiac Fitness: Type

• Principle of Specificity of Training - aerobic exercises need to be rhythmic and continuous and involve the large muscle groups.

• Muscle pump - the rhythmic squeezing action of the large muscles against the veins within them is called the “muscle pump.” This squeezing results in a substantial increase in venous return.
Guidelines for Cardiac Fitness: Intensity

Optimum exercise intensity for fitness improvement is

Maximum Oxygen Consumption of 50-85%
Or 60-90% of Maximum Heart Rate
Guidelines for Cardiac Fitness: Intensity

• “Talk Test” – utilizes the hyperventilation response to monitor exercise intensity; clients should be able to carry on a comfortable conversation while exercising.

• Borg Scale – Borg’s Rating of Perceived Exertion (RPE) is a subjective method of monitoring exercise intensity:
  
  12 to 15 on a scale of 6-20 or
  3 to 5 on a scale of 0-10
Guidelines for Cardiac Fitness: Duration

- Aerobic exercise should last for a minimum of 10 minutes per session with a goal of at least 20 minutes per day.

- Research has shown that three (3) 10-minute sessions will yield the same improvements as one (1) 30-minute session if they are done at relative intensity.
Guidelines for Cardiac Fitness: Duration

• There are two (2) types of interval training:
  1. Performance Interval Training – very high-intensity effort designed to enhance competitive performance in a specific sport.
  2. Fitness Interval Training – modest-to-vigorous intensity effort designed to improve general fitness.
Guidelines for Cardiac Fitness: Frequency

- Exercise must be done at least three (3) days per week.

- Most experts encourage even competitive athletes to take at least one (1) day per week for rest.
Guidelines for Cardiac Fitness

- Warming up brings about important physiologic changes that reduce the risk of injury, as well as make the exercise session more comfortable by:
  1. Increasing the temperature of the muscle and tissue, and
  2. Allowing the cardiovascular system to effectively adjust blood flow (blood shunt).

- Warm-up for at least 3-5 minutes.

- Cool-down until the heart rate is 108-120bpm to allow the cardiovascular system to reverse the blood shunt.
Guidelines for Cardiac Fitness

- Warm-up and cool-down periods not only reduce the potential for fatigue, but they also reduce the risk of exercise-related injuries.
Guidelines for Cardiac Fitness

- **Environmental Concerns:**
  - High altitude - less O$_2$ in the air.
  - Heat & humidity - when humidity is high, sweat does not evaporate:
    1. Drink 3-6oz of cool water every 10-15 minutes during exercise;
    2. Wear light-colored clothes that breathe;
    3. Use sunscreen
  - Cold - replenishment of body fluids is just as important when exercising in cold environments.
    1. Dress in layers;
    2. Closest layer to body should breathe & wick away moisture.
Basic Skeletal Muscle Anatomy & Physiology

• Three (3) primary types of muscle cells in the body:
  1. Cardiac cells - found only in heart;
  2. Smooth muscle cells - found in walls of arteries and intestines used to shunt blood; and
  3. Skeletal muscle cells - bound together to form skeletal muscles.

• Two (2) main types of skeletal muscle fibers:
  1. Slow-Twitch (Type I)
  2. Fast-Twitch (Type II)
Basic Skeletal Muscle Anatomy & Physiology

- Myofibrils - strands of protein running the length of each muscle fiber.

- Two (2) primary proteins (contractile) in a myofibril:
  1. Actin
  2. Myosin

- Sarcomere - repeating units of myofibrils.
Basic Skeletal Muscle Anatomy & Physiology

• Three (3) types of muscle contraction:
  1. Concentric (positive) - shortens the muscle.
  2. Eccentric (negative) - lengthens the muscle.
  3. Isometric - contraction of individual fibers but no change in the length of the whole muscle.

• Two (2) factors affect the amount of force generated during muscle contraction:
  1. Size of the individual fibers contracting, and
  2. Number of muscle fibers that contract simultaneously.
Basic Skeletal Muscle Anatomy & Physiology

- Motor unit - a single motor nerve (from the spinal cord) and all the muscle fibers it stimulates constitute a motor unit.

- “All-or-None” principle - when the fibers of a motor unit are called on to contract, all of the muscle fibers in the unit contract together, and they contract with maximum force.
Adaptations to Strength Training

- **Hypertrophy** - increase in the size of a muscle; increase in the number and size of myofibrils in muscle fibers which increase in greater force generation.

- **Hyperplasia** - increase in the number of muscle fibers in the muscle; evidence is lacking for muscle fiber hyperplasia in humans. Prevailing research shows the perception of more muscle fibers is due to an increase in protein and increase in fiber diameter - not an increase in the number of fibers.
Adaptations to Strength Training

• Three (3) basic types of connective tissue:
  1. Cartilage - padding between bones that meet at a joint.
  2. Ligaments - connect bones to bones at a joint.
  3. Tendons - connect skeletal muscle to the bones.

• Golgi Tendon Organ - sensor of the nervous system used to protect against a muscle generating too much contractile force.
Adaptations to Strength Training

- It is possible to “override” the physiological Golgi protective inhibition.
  
  Ex., person lifts a car off a trapped individual

- Strength training raises the threshold of force generation at which the Golgi tendon organ is stimulated.
Guidelines for Strength Training

• Isometric (same length) - exercises that develop high-intensity contractions in the muscle with no change in the muscle length.

• Isotonic (same tone or tension) - exercises that use a given amount of external resistance that is challenged through the entire range of motion.
Guidelines for Strength Training

• Dynamic constant external resistance - recommended term for fixed amount of external resistance instead of “isotonic training”; strength-training exercises and/or equipment that provide a constant resistance throughout the movement range.

• Dynamic variable external resistance - strength-training exercises and/or equipment that automatically vary the resistance throughout the movement range.
Guidelines for Strength Training

• Isokinetic (same speed) - type of resistance exercise that causes the exercising muscles to generate a maximum amount of force throughout the entire range of movement, while keeping the speed of movement constant.
Guidelines for Strength Training

- Concentric (shortening) movements are often referred to as the positive phase of a lift.

- Eccentric (lengthening) movements are referred to as the negative phase of a lift.
Guidelines for Strength Training

• Two (2) types of exercise-related muscle soreness:
  1. Immediate soreness - directly related to build-up of lactic acid (and other by-products).
  2. Delayed Onset Muscle Soreness (DOMS) - occurs 1-3 days following a session; result of small tears in the connective tissues.
Guidelines for Strength Training

- Muscle fatigue - relates primarily to intensity and duration of the exercise session:
  - Muscle fatigue (0-30 seconds or until exhaustion) is felt when performing a power event (maximum effort) because the active muscle cells run out of ATP.
  - Muscle fatigue (40-60 minutes or until exhaustion) is felt during heavy exercise due to lactic acid accumulation.
  - Muscle fatigue (60-180 minutes or longer) occurs primarily because glycogen - the storage form of glucose - becomes depleted in the exercising muscles.
Flexibility Training

- Flexibility is the range of motion about a joint.

- Four (4) factors can limit flexibility:
  1. Elastic limits of the ligaments and tendons crossing the joint;
  2. Elasticity of the muscle tissue itself;
  3. The bone and joint structure; and
  4. The skin.
Flexibility Training

- Slow, sustained stretches can increase flexibility.

- Muscle spindles are fibers in the muscle tissue that protect against too much stretch (much like the Golgi tendon organ protects muscles against too much contractile force).

- In ballistic (rapid, bouncing) stretching, the muscle spindle is stimulated, causing the muscle to contract as a protection against the excessive stretch.