

Sports physiology

Muscles in Exercise

What Are Muscles?

- Muscles are soft tissues found in most animals, including humans. They are primarily responsible for producing **movement** by contracting and relaxing.
- Muscles work in coordination with the **skeletal system** to facilitate motion.
- There are three main types of muscles:
 - **Skeletal Muscles:** These are voluntary muscles attached to bones via tendons. They're responsible for movement and posture. They are striated (striped appearance under a microscope).
 - **Cardiac Muscles:** Found only in the heart, involuntary and striated. They pump blood through the circulatory system.
 - **Smooth Muscles:** Found in internal organs (e.g., stomach, intestines, blood vessels). They are involuntary and non-striated.
- In sports physiology, our focus is primarily on skeletal muscles because these are the ones engaged during physical activity.

Muscle Structure and Function

- Each skeletal muscle is made of muscle fibers, which are long cylindrical cells.
- Each fiber contains:
 - **Myofibrils:** Thread-like structures running along the length of the muscle fiber.
 - **Sarcomeres:** The functional units of a myofibril, made of proteins actin (thin filament) and **myosin** (thick filament).
 - **Motor units:** A motor neuron and the muscle fibers it controls.
- When the brain sends a signal through motor neurons, it causes muscle contraction through a process called the Sliding Filament Theory, where:
 - Myosin heads bind to actin
 - ATP (energy molecule) helps the myosin pull the actin, shortening the sarcomere
 - This generates force or movement

Types of Muscle Fibers

There are two primary types:

A. Type I (Slow-Twitch) Fibers

- High in mitochondria
- High resistance to fatigue

- Used for **endurance** activities like marathon running
- Contracts slowly but can maintain activity for long durations

B. Type II (Fast-Twitch) Fibers

Subdivided into:

- **Type IIa** (Fast oxidative): Intermediate resistance to fatigue, used in mid-duration sports like 400m sprint
- **Type IIb/x** (Fast glycolytic): Low resistance to fatigue, used in short, high-intensity bursts like powerlifting or 100m sprint

Skeletal muscles contain different **fiber types** with different properties:

Fiber Type	Contraction Speed	Fatigue Resistance	Energy System	Usage
Type I (Slow-Twitch)	Slow	High	Aerobic	Endurance sports (e.g., marathon)
Type IIa (Fast-Twitch Oxidative)	Fast	Moderate	Aerobic + Anaerobic	Mixed activities (e.g., 400m)
Type IIb/x (Fast-Twitch Glycolytic)	Very Fast	Low	Anaerobic	Explosive sports (e.g., sprinting, weightlifting)

Muscle Contraction During Exercise

- During exercise, muscles contract in different ways:
 - **Isometric**: No change in length, but tension increases (e.g., wall sit)
 - **Isotonic**: Muscle changes length:
 - **Concentric**: Muscle shortens (e.g., lifting a dumbbell)
 - **Eccentric**: Muscle lengthens (e.g., lowering a dumbbell)
- Muscle contraction requires energy, primarily in the form of ATP, which can be generated by:
 - **Aerobic metabolism** (with oxygen) – long-duration, low/moderate intensity
 - **Anaerobic metabolism** (without oxygen) – short-duration, high-intensity

Muscle Contraction: The Sliding Filament Theory

- Muscles contract via a microscopic interaction between actin and myosin in a process called the Sliding Filament Theory.

Steps in Muscle Contraction:

1. A signal from a motor neuron causes the release of acetylcholine at the neuromuscular junction.

2. This triggers the release of calcium ions (Ca^{2+}) from the sarcoplasmic reticulum.
3. Myosin heads bind to actin, forming cross-bridges.
4. Using ATP, the myosin heads perform a power stroke, pulling the actin filaments inward, which shortens the sarcomere and causes contraction.
5. When ATP or calcium levels drop, the myosin heads detach, and the muscle relaxes.

Energy Systems in Muscular Work

Muscles need ATP (Adenosine Triphosphate) to contract. The body uses three main energy systems to produce ATP:

A. Phosphagen System (ATP-PC System):

- Used in the first 0–10 seconds of high-intensity effort.
- Anaerobic (no oxygen required).
- Utilizes creatine phosphate to rapidly regenerate ATP.
- Best suited for explosive activities (e.g., sprinting, jumping, shot put).

B. Glycolytic (Anaerobic) System:

- Dominant between 10 seconds to 2 minutes of intense effort.
- Breaks down glucose into pyruvate, which is then converted into lactic acid if oxygen is insufficient.
- Produces ATP without oxygen but results in lactic acid accumulation, leading to fatigue.
- Used in high-intensity efforts like a 400m sprint.

C. Oxidative (Aerobic) System:

- Dominates in activities lasting longer than 2 minutes.
- Requires oxygen to metabolize carbohydrates and fats.
- Produces the most ATP, but at a slower rate.
- Used in endurance sports like marathon running.

Neuromuscular Activation

A **motor unit** is composed of a **motor neuron** and the **muscle fibers** it controls.

Size Principle of Motor Unit Recruitment:

- Smaller, slow-twitch motor units are recruited first.
- As exercise intensity increases, larger, fast-twitch units are activated.
- Training improves the nervous system's ability to recruit more motor units efficiently, enhancing force production and performance.

Muscle Fatigue and Recovery

Muscle Fatigue:

- Occurs when a muscle's ability to generate force declines due to:
 - **Accumulation of lactic acid**
 - **Depletion of ATP and glycogen stores**
 - **Impaired neural activation**

Recovery:

- Following exercise, recovery involves:
 - Replenishment of ATP and glycogen stores
 - Removal of lactic acid
 - Muscle repair and growth, especially during rest and after training sessions

Effect of Athletic Training on Muscles and Muscle Performance

Hypertrophy and Muscle Growth

Definition of Hypertrophy:

- Hypertrophy refers to the increase in muscle fiber size (not number).
- Most noticeable in Type II (fast-twitch) fibers.

Causes of Hypertrophy:

- **Mechanical tension** from heavy lifting
- **Muscle micro-damage**, especially during eccentric contractions
- **Metabolic stress** from intense/high-rep training

Training Leads To:

- Increased muscle cross-sectional area
- Greater force production
- More actin and myosin filaments
- Increased sarcoplasmic volume (fluid in muscle cells)

Muscle Repair and Growth Process:

- Resistance training causes **micro-tears** in fibers.
- The body repairs these fibers and builds them back **stronger and thicker**.
- **Satellite cells** are activated to:
 - Repair damaged fibers
 - Donate nuclei to growing muscle cells

- Support long-term muscle adaptation

Neural (Neuromuscular) Adaptations

Early-Stage Adaptations:

- In early training, strength increases mostly due to **neural changes**, not muscle growth.

Key Neuromuscular Adaptations:

- **Improved motor unit recruitment:** More muscle fibers are activated
- **Better synchronization:** Muscle fibers contract more efficiently
- **Reduced inhibition:** Less resistance from Golgi tendon organs allows greater force output
- **Increased firing frequency:** Faster signals from nerves to muscles
- **Improved intermuscular coordination:** Muscles work better together

Result: Enhanced strength, control, and performance, even before noticeable size gains.

Muscle Fiber Transformation

Functional Shifts in Fiber Types:

- With training, muscle fibers can adapt their characteristics:
 - **Type IIx → Type IIa:** Common transition with both endurance and resistance training
 - Fast-twitch fibers can develop greater oxidative capacity
 - **Type I fibers** may become more efficient
- **Endurance training** promotes oxidative adaptations in both slow and fast fibers.
- **Resistance training** emphasizes fast-twitch characteristics like power and speed.

Muscle Endurance Improvement

Adaptations from Endurance Training:

- Increased **mitochondrial density**
- Enhanced **capillary density** (see section 6)
- Improved **oxygen delivery and utilization**
- Greater **fat oxidation capacity**

Result: Improved endurance performance and reduced fatigue during prolonged activities.

Metabolic and Enzymatic Adaptations

- Athletic training enhances the function and quantity of key metabolic enzymes, increasing the muscle's capacity to generate and recycle ATP.

Key Enzymes Upregulated:

- **Creatine kinase:** Supports ATP-PC energy system



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