General Functions of Muscles

- **Movement**
  - Contraction of skeletal muscles produce movement of the body or its parts.

- **Heat Production**
  - Muscles produce most of the body heat produced in the body.
  - These cells (like other cells of the body) produce heat through catabolic activity.

- **Posture**
  - Skeletal muscles play a major role in maintaining posture; the muscles of the body must work together.

Functions of *Skeletal* Muscle Tissue

- *Skeletal Muscle Tissue* is composed of skeletal muscle fibers (cells) arranged in fascicles.
Functions of *Skeletal* Muscle Tissue continued

- Skeletal muscle cells have certain characteristics which allow them to carry out their functions.
  - Excitability (Irritability)
  - Contractility
  - Extensibility

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Excitability (Irritability)

- Cells can be stimulated by nerve impulses.

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Contractility

- The ability to shorten or contract
  - Allows for muscles to exert pull (never push) on the bone which results in movement of the body.
Extensibility

- The ability to stretch or extend
- Allows muscles to return to original position (the resting position)

Muscle Cells are Called Muscle Fibers

- Muscle cells are called muscle fibers because of their threadlike appearance.

Muscle Cells (Microscopic Structure)

- Have many of the same organelles as other cells, but their names differ in some cases:
  - Sarcolemma
  - Sarcoplasm
  - Sarcoplasmic reticulum
  - Mitochondria
  - Nuclei
  - Myofibrils
Sarcolemma

The plasma membrane of a muscle fiber.

Sarcoplasm

The cytoplasm of a muscle cell.

Sarcoplasmic reticulum

Similar to endoplasmic reticulum; these structures are analogous.
Mitochondria

- Each SMF Contains Many Mitochondria
- Reason: Active in Catabolism

Nuclei

- SEVERAL NUCLEI
- Located Near Sarcolemma
- Reason: SMF's Complex in Structure & Function

Myofibrils

- Each SMF Contains Numerous Myofibrils
- Microscopic Threadlike Fibers that Extend the Length of the Muscle Fiber
**Myofilaments**
- Myofibrils Composed of Myofilaments
  - UltraMicroscopic Threadlike Fibers
  - 2 Types
    - **THICK**: Myosin
      - Composed of One Kind of Protein
      - Shape: Golf Clubs
    - **THIN**: Actin, Tropomyosin, Troponin

**THIN: Actin, Tropomyosin, & Troponin**
- **THIN**: ACTIN, TROPOMYOSIN, TROPONIN
- Shapes:
  - Actin: 2 Twisted Strands of Beads
  - Tropomyosin: Long and Narrow
  - Troponin: Oval

**Thick: Myosin**
- Myosin (Cross Bridges) Are Chemically Attracted to the Active Sites of Actin
- When SMF Resting:
  - Tropomyosin Covers the Active Sites of Actin and Troponin in Place
  - Troponin Holds Tropomyosin in Place
Sarcomeres
- Contracting units of SMF’s
- Each myofibril has numerous sarcomeres lined up end to end.
  - They extend the length of the myofibril
- Sarcomeres are between successive Z lines.
- Sarcomeres are made of thick and thin myofilaments.

Sarcomeres
- The arrangement of alternating thick and thin myofilaments

T Tubules
- Transverse Tubules run at right angles to the long axis of the cells.
- They allow the impulse to travel from the sarcolemma to deeper parts of the cell.
- Sarcoplasmic reticulum also is composed of membranous tubules which pumps Ca++ ions from the sarcoplasm and stores it in its sacs.
Triad

- "Three Structures"
- T Tubule Sandwiched Between Sarcoplasmic Reticulum on Either Side

Triad

- Allows NI's Traveling Along Sarcolemma to Move Inside the SMF and Easily Stimulate Sarcoplasmic Reticulum

The Mechanism of Contraction

1. Excitation: SMF STIMULATED BY NI
   - EXCITATION: SMF STIMULATED BY NI
     - NI Travels Along the P. Membrane of Neuron
     - When NI Reaches the End of the Neuron’s Plasma Membrane, Neurotransmitters are Released and Cross the Synapse
     - Neurotransmitters Bind to Receptors in Sarcolemma, NI Begins Along Sarcolemma
     - NI Travels Along Sarcolemma, Moves Inward at T Tubules, Stimulates Sarcoplasmic Reticulum
The Mechanism of Contraction
THE SLIDING FILAMENT THEORY

2. CONTRACTION (modified from Supplement):
1. N depicts Ca2+ release
2. Ca2+ binds to troponin, causing tropomyosin to move, exposing actin active site.
3. Myosin head binds to actin active site.
4. ADP + P release causes myosin head to bend (power stroke), causing sarcomere contraction.
5. ATP binds to myosin, causing its release and bending back to original position (re-cocking).
6. Ca2+ release causes cycle to repeat.

2. CONTRACTION (repeat)
1. N depicts Ca2+ release
2. B. Ca2+ binds to troponin, causing tropomyosin to move, exposing actin active site.
3. C. Myosin head binds to actin active site.
4. C. & D. ADP + P release causes myosin head to bend (power stroke), causing sarcomere contraction.
5. A. ATP binds to myosin, causing its release and bending back to original position (re-cocking).
6. Ca2+ release causes cycle to repeat.
Muscle Contraction

http://www.sci.sdsu.edu/movies/actin_myosin.gif.html

Steps of Relaxation
- After impulse is over, the SR begins actively pumping Ca\(^{++}\) back into its sacs as the Ca\(^{++}\) is removed (stripped) from the troponin molecules in the thin myofilaments.
- Troponin returns to its original position (reattaches to tropomyosin), blocking actin’s active site.
- Myosin crossbridges are prevented from binding to actin and can no longer sustain the contraction (contraction shuts off).
- Since the thick and thin myofilaments are no longer connected, the muscle fiber returns to its long, resting position (Sarcomeres Extend).

Energy Source for Contraction
- The processes of the body have to be powered by something.
- ATP is the energy source for the muscle contraction.
- Muscle cells can only store small amounts of ATP, so the muscle cells have to resynthesize ATP.
CONTRACTION & RIGAMORTIS

- REPEAT OF EARLIER INFORMATION
- Steps 1→3
  - Myosin Cross Bridges Release From Actin, Bind to the Next Active Site, And Pull Again (Shortens Sarcomeres)
  - ATP causes the release of the myosin head AND causes it to bend back to the position where it can cause another contraction, aka ATP "cocks the gun"
- What enables myosin head to release from actin?
  - ATP

Where does ATP come from?
Nutrient Catabolism

- Glucose is used to make ATP.
- Oxygen – necessary ingredient in aerobic respiration. In muscle, the oxygen is bound to myoglobin.
- Myoglobin – similar to hemoglobin; it is a reddish pigment. Contains Fe groups which attract and hold oxygen molecules until they are needed.
- During exercise oxygen can be supplied this way.
  - Red fibers – contain large amounts of myoglobin (dark meat)
  - White fibers – contain smaller amounts of myoglobin (white meat).
- Do chickens fly?
- What color is a chicken breast?
- Do chickens walk/run?
- What color is a drumstick?

Anaerobic Respiration

- If oxygen is not available, muscle cells can switch to anaerobic respiration.
  - Lactic acid is formed during anaerobic respiration and can be dangerous.
  - Heavy breathing after exercise helps to supply the oxygen that is necessary to convert lactic acid back into a derivative of glucose.
- What effect does lactic acid have on muscles?
The All or None Principle

- Muscle fibers contract if they are sufficiently stimulated.
- I.e. IF a muscle fiber contracts, it will contract with all its force.
- Threshold stimulus – the stimulation level at which the muscle fiber will contract.
- Motor Neurons carry the stimulation to the muscle fiber.

Explanation of All-Or-None Principle

- Explanation of All-Or-None Principle
  - When Stimulated, SMF’s Either Contract Or They Don’t Contract
  - Depends Upon the Strength /Frequency of the Nerve Impulse
  - If SMF’s Contract, They Always Contract as Forcefully as Possible;
  - However, Existing Conditions Determine the Actual Strength of Contraction

Motor Unit

- Definition: A Motor Neuron + the SMF’s to Which It’s Attached
- Muscle fibers receive a stimulus from a motor neuron.
- The motor neuron and the muscle fibers attached to it are called a motor unit.
Motor Unit Generalizations

- The number of SMF’s to which a motor neuron attaches varies
  - The fewer the number of SMF’s to which a motor neuron attaches, the more precise the movements (i.e., muscles responsible for finger movements)
  - The larger the number of SMF’s to which a motor neuron attaches, the more powerful the contraction (i.e., abdominal muscles)

Basic Principles of Contraction

1. Skeletal muscles contract only if stimulated
2. Skeletal muscles produce movements by pulling on bones
3. Skeletal muscles usually lie proximal to the body part they move
4. Skeletal muscles usually work in groups rather than alone
5. Skeletal muscle contractions are of several types
   - tonic contraction (muscle tone)
   - isotonic contraction
   - isometric contraction
   - twitch contraction
   - treppe contraction
   - tetanic contraction (tetanus)
6. Skeletal muscles contract according to the graded strength principle

5. Skeletal Muscle Contractions Are of Several Types

- **a. Tonic Contraction (Muscle Tone)**
  - continued, partial contraction
  - explanation:
    - continued as long as one is awake and conscious
    - partial contraction:
      - Only a few of the total SMF’s in a muscle contract at the same time
      - SMF’s contract in relays controlled by negative feedback
      - results in firmness (tone) in a muscle rather than recognizable movement
  - tonic contractions are important in maintaining posture
5. SKELETAL MUSCLE CONTRACTIONS

**ISOTONIC CONTRACTION**

- Contraction in which the length of a muscle shortens. (Muscle shortens)
- Occurs when little/no load is placed on a muscle (all the energy of contraction is used to shorten sarcomeres)

**ISOMETRIC CONTRACTION**

- Contraction in which the length of a muscle remains the same, but the tone within the muscle changes.
- Occurs when too much load is placed on a muscle (all the energy of contraction is used to try and move the load)

*NOTE: Most body movements are a combination of both isotonic and isometric contractions.*

*NOTE: Remaining contractions are experimental contractions (can be induced in the lab, but don’t occur in the body the same way they occur in the lab). However, principles have been developed from them.*
Twitch Contraction

- A quick jerk of a muscle that occurs when an entire muscle (all motor units are) is stimulated simultaneously.
- Similar situation occurs in the body under abnormal conditions:
  - Seen as muscle twitches/spasms/cramps.
  - May be due to muscle irritation/inflammation.
  - Fluid/electrolyte imbalances.
  - Overactivity of the nervous system, etc.

Treppe (Staircase Phenomenon)

- A gradual, step-like increase in the strength of muscle contraction.
- Occurs when an entire muscle is repeatedly stimulated at brief, constant intervals.
- Generalization that developed from Treppe:
  - A muscle contracts more forcefully after it has contracted a few times.
  - Application: Athletes "warm up" before beginning an athletic event.
  - If Treppe continues:
    - Strength of muscle contraction gradually decreases.
    - Muscle exhibits fatigue.

Tetanic Contraction (Tetanus)

- A prolonged contraction of a muscle resulting from rapidly repeated motor impulses.
- This is called multiple wave summation.
- Smooth, sustained contraction:
  - Occurs when an entire muscle is repeatedly stimulated in rapid succession.
  - Muscle doesn't have time to relax before the next contraction.
  - Creates a series of twitches close together.
- This type of contraction is exhibited by most skeletal muscles most of the time.
  - However, it is carefully co-ordinated, unlike a twitch.
SKELETAL MUSCLES CONTRACT ACCORDING TO THE GRADED STRENGTH PRINCIPLE

**DEFINITION**
- Skeletal Muscles Contract With Varying Degrees of Strength At Different Times

FACTORS THAT AFFECT GRADED STRENGTH PRINCIPLE: LOAD

- **AMOUNT OF LOAD IMPOSED ON THE MUSCLE (STRETCH REFLEX)**
  - Within Limits, the More Load That's Placed On a Muscle
  - The Stronger the Contraction
  - D/T Stretch Reflex (Neg. FB)

FACTORS THAT AFFECT GRADED STRENGTH PRINCIPLE: NUMBER OF SKELETAL MUSCLE FIBERS CONTRACTING SIMULTANEOUSLY

- The More SMF's That Contract At the Same Time the Stronger The Contraction

Depends On:
- **NUMBER OF MOTOR UNITS RECRUITED** (Activated) Which in Turn Depends On:
  - INTENSITY AND FREQUENCY OF STIMULATION (How Strong/How Often the Nerve Impulses
  - *The More Intense and Frequent the Stimulation*
  - *The More Motor Units That Are Activated*
  - *The More SMF's Contracting At The Same Time*
  - *The a Stronger Contraction*
FACTORS THAT AFFECT GRADED STRENGTH PRINCIPLE:
METABOLIC CONDITION OF SKELETAL MUSCLE FIBERS

ATP Available to SMF's
Since a Skeletal Muscle is Composed of SMF's, Amount of ATP Available to SMF's Affects Strength of Contraction

INITIAL LENGTH OF SKELETAL MUSCLE FIBERS (LENGTH/TENSION RELATIONSHIP)

SMF's Must Be of Optimal Length At the Beginning of The Contraction to Produce The Strongest Contraction

Summary of Muscle Contractions

- **Tonic**: Muscle Tone
- **Isotonic**: Same tone, changing length
- **Isometric**: Same length, changing tone
- **Twitches**: Cramps, etc.
- **Treppe**: The Staircase Phenomenon a.k.a. Warm Up
  - A gradual, step-like increase in the twitch contraction occurring about 1 sec apart.
  - The muscle contracts more forcefully with every contraction
  - This may lead to muscle fatigue.

- **Tetanic**: Typical muscle contraction
  - More sustained than a twitch
  - Stimulus is rapid enough that the muscle does not have time to sufficiently relax.
  - This is called multiple wave summation.

- The **Graded Strength Principle** explains how muscle organs contract.
  - Skeletal muscle organs do not contract by the "all or none" principle.
  - They can contract with varying degrees of strength.
  - The more muscle fibers that are recruited, the stronger the contraction.