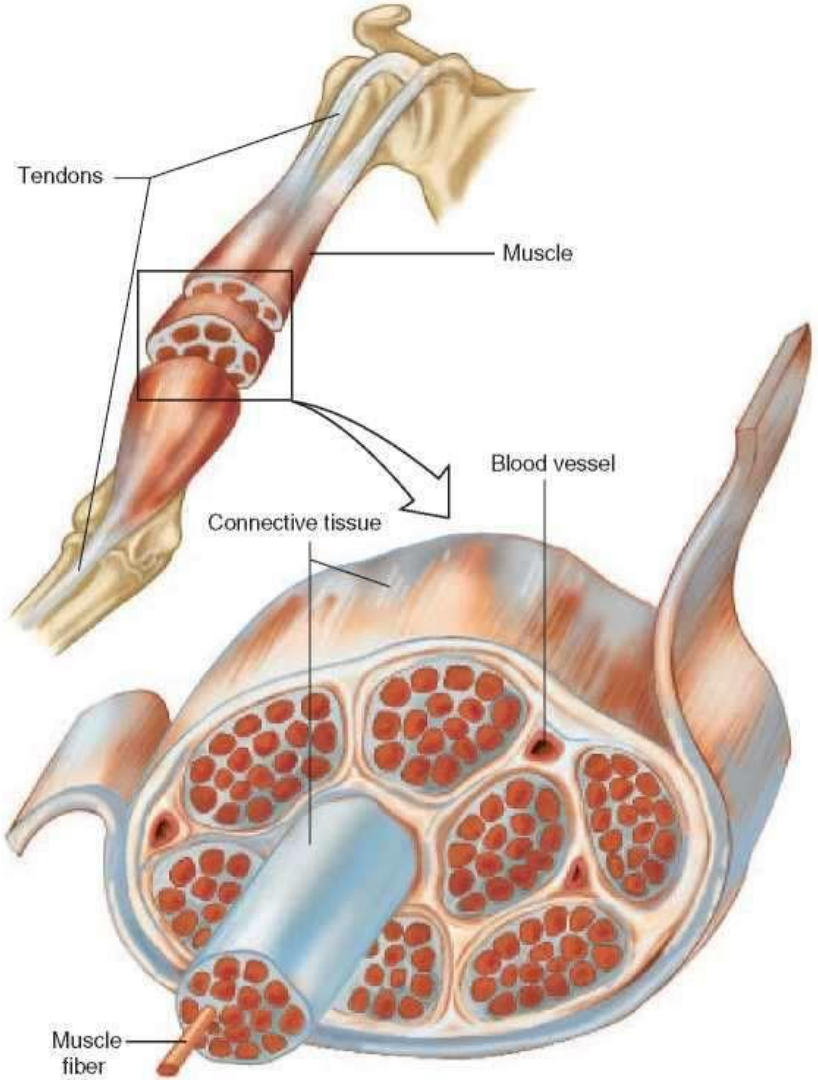
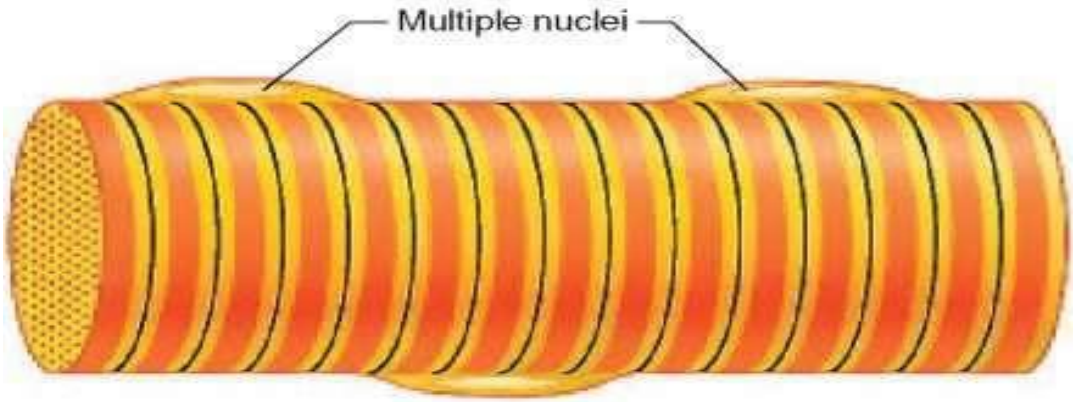
SKELETAL MUSCLES

SKELETAL MUSCLE

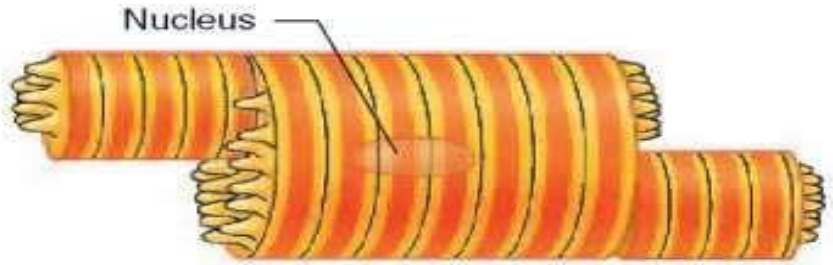
- The ability to use chemical energy to produce force and movement is present to a limited extent in most cells, but in muscle cells it has become dominant.
- **Muscles generate force and movements used in the regulation of the internal environment, and they also produce movements in the external environment**.
- In humans, the ability to communicate, whether by speech, writing, or artistic expression, also depends on muscle contractions. Indeed, it is only by controlling the activity of muscles that the human mind ultimately expresses itself.
- Three types of muscle tissue can be identified on the basis of structure, contractile properties, and control mechanisms: skeletal muscle, smooth muscle, cardiac muscle.
- Most skeletal muscle, as the name implies, is attached to bone, and its contraction is responsible for supporting and moving the skeleton. The contraction of skeletal muscle is initiated by impulses in the neurons to the muscle and is usually under voluntary control.

DIFFERENT TYPES OF THE MUSCLE TISSUE





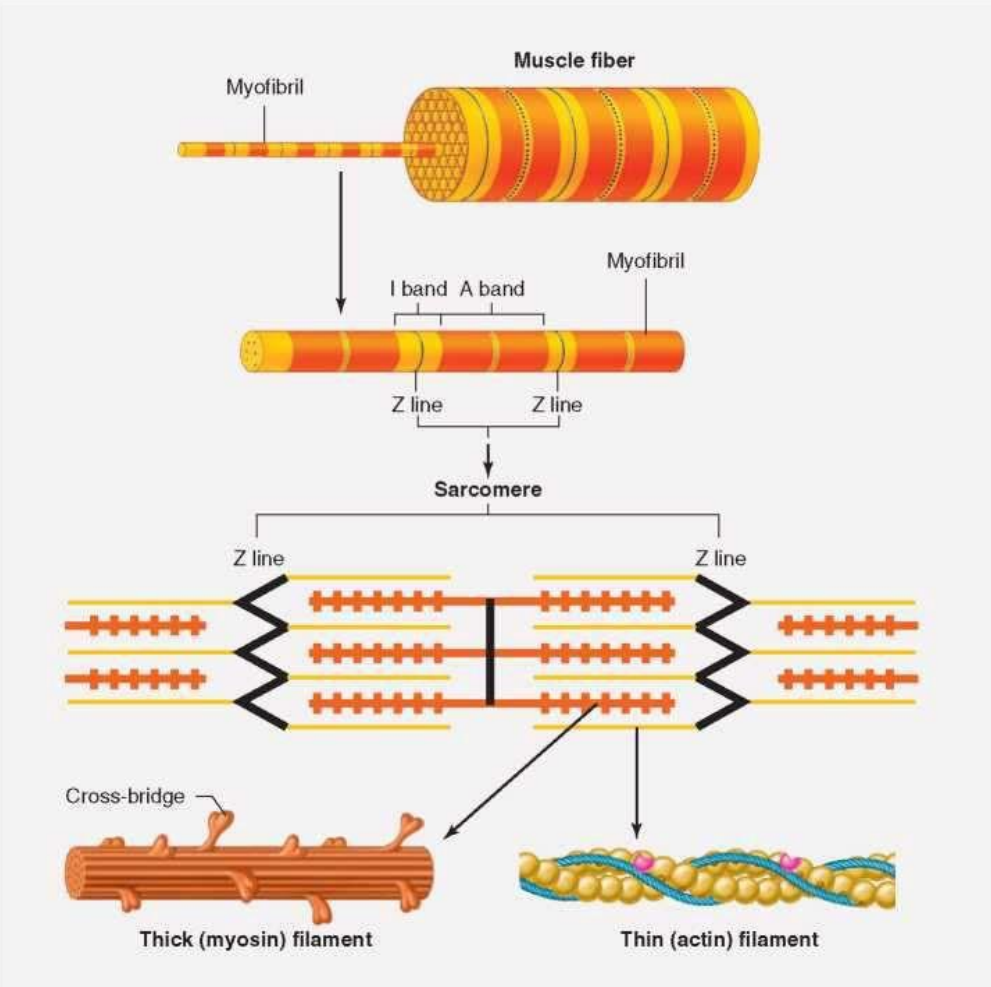
Skeletal muscle fiber



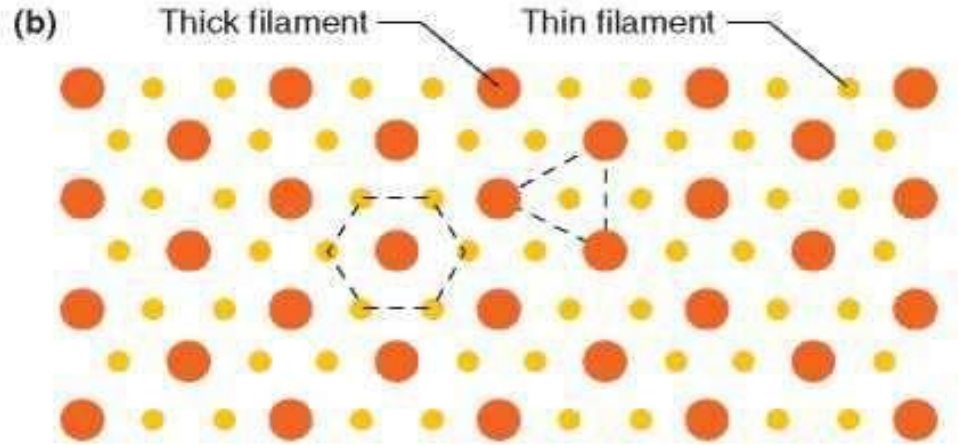
Cardiac muscle cell

Smooth muscle cell

ARRANGEMENT OF FILAMENTS IN A SKELETAL MUSCLE FIBER



When force generation produces shortening of a skeletal muscle fiber, the overlapping thick and thin filaments in each sarcomere move past each other, propelled by movements of the cross-bridges. During this shortening of the sarcomeres, there is no change in the lengths of either the thick or thin filaments. This is known as the sliding-filament mechanism of muscle contraction.

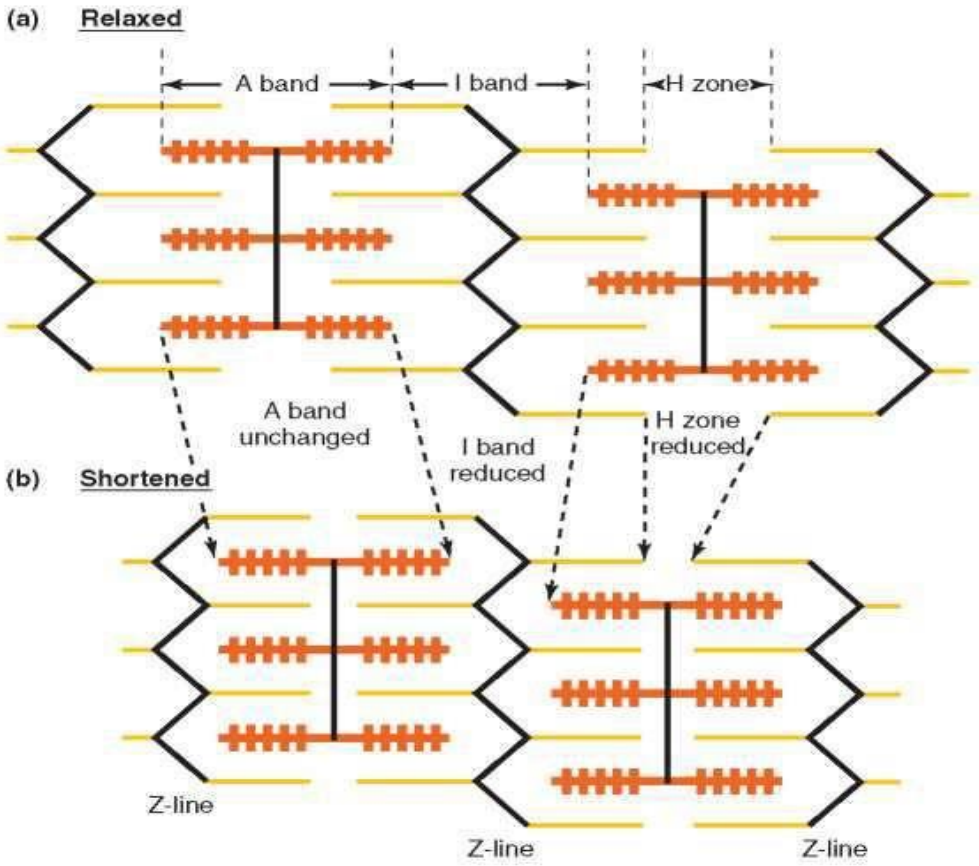


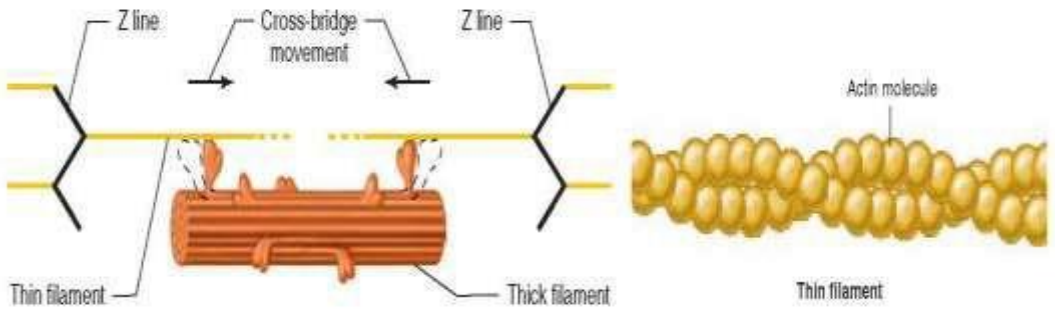
transverse section

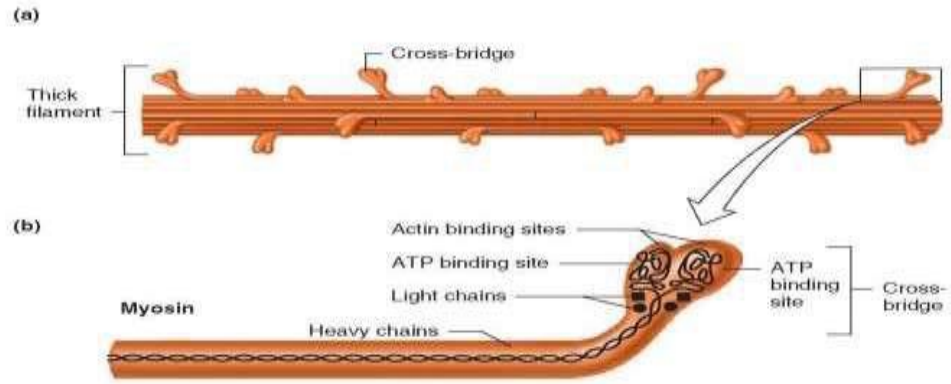
MOLECULAR MECHANISMS OF THE MUSCLE CONTRACTION

- During shortening, each myosin cross-bridge attached to a thin filament actin molecule moves in an arc much like an oar on a boat. This swiveling motion of many cross-bridges forces the thin filaments attached to successive Z lines toward the center of the sarcomere, thereby shortening the sarcomere). One stroke of a cross-bridge produces only a very small tail formed by the two intertwined heavy chains. The tail of each myosin molecule lies along the axis of the thick filament, and the two globular heads extend out to the sides, forming the cross-bridges. Each globular head contains two binding sites, one for actin and one for ATP. The ATP binding site also serves as an enzyme—an ATPase that hydrolyzes the bound ATP.
- The myosin molecules in the two ends of each thick filament are oriented in opposite directions, such that their tail ends are directed toward the center of the filament. Because of this arrangement, the power strokes of the cross-bridges move the attached thin filaments at the two ends of the sarcomere toward the center during shortening
- Cross-bridge cycling is initiated by calcium entry into the cytoplasm. The cycle begins with the binding of an energized myosin cross-bridge to a thin filament actin molecule. During the cross- bridge movement, myosin is bound very firmly to actin, and this linkage must be broken in order to allow the cross-bridge to be re-energized and repeat the cycle.

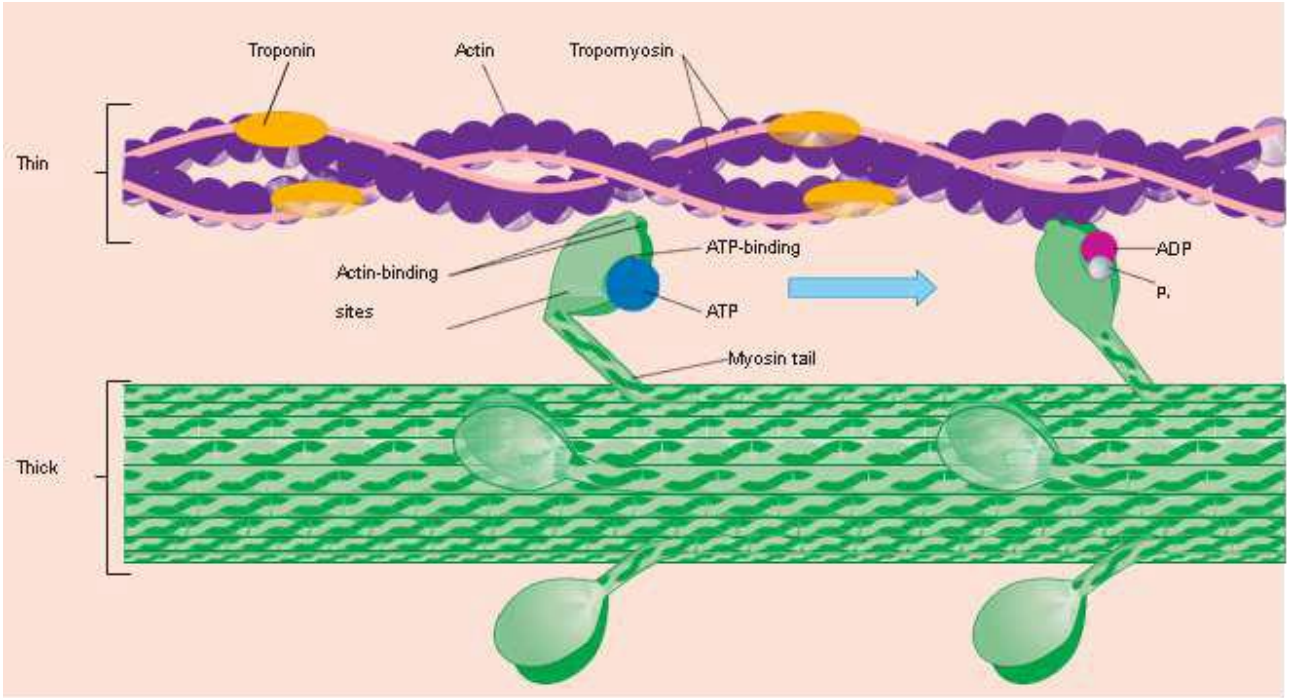
THE SLIDING MODEL OF SARCOMERE SHORTENING







THE STRUCTURE OF MYOSIN



The binding sites for ATP and actin. Once the myosin head binds to ATP, it is hydrolyzed into ADP and inorganic phosphate (Pi). This activates the myosin head, “cocking it” to put it into position to bind to attachment sites in the actin molecules.

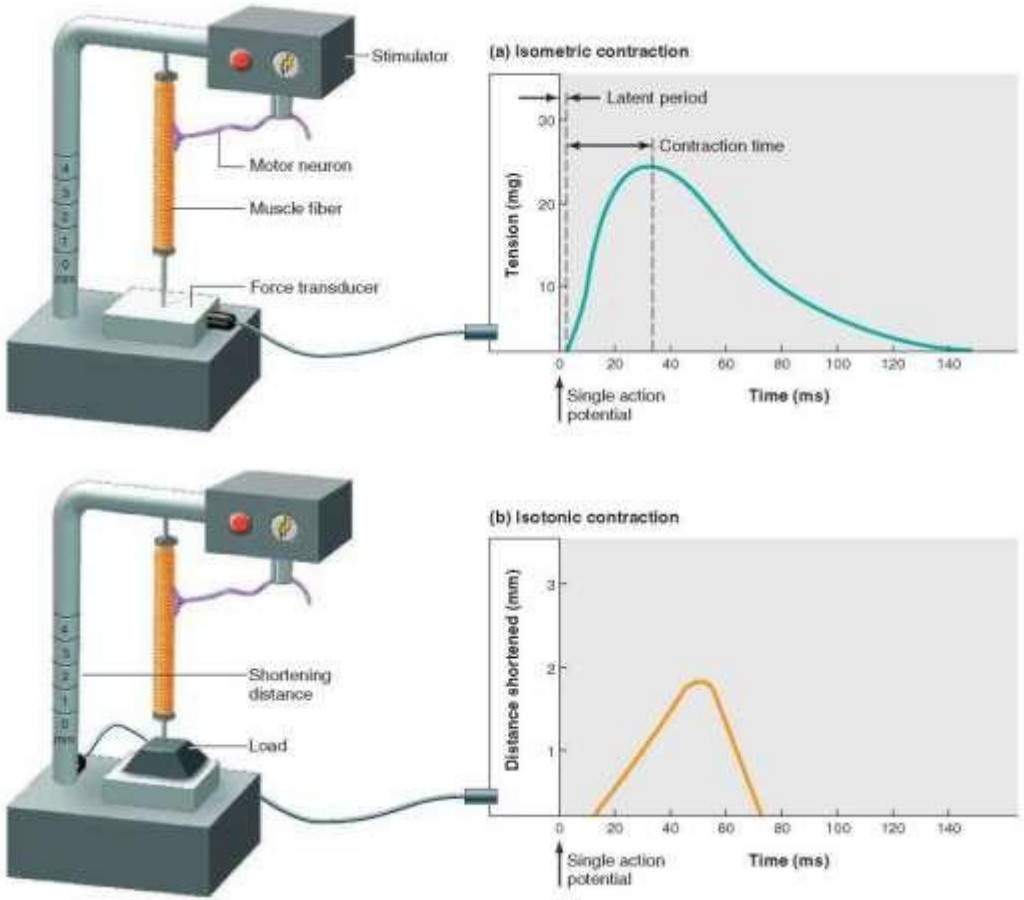
SEQUENCE OF EVENTS BETWEEN A MOTOR NEURON ACTION POTENTIAL AND SKELETAL MUSCLE FIBER CONTRACTION

- Action potential is initiated and propagates to motor neuron axon terminals. Calcium enters axon terminals through voltage-gated calcium channels. Calcium entry triggers release of ACh from axon terminals. ACh diffuses from axon terminals to motor end plate in muscle fiber.
- ACh binds to nicotinic receptors on motor end plate, increasing their permeability to Na^+ and K^+. More Na^+ moves into the fiber at the motor end plate than K^+ moves out, depolarizing the membrane, producing the end plate potential (EPP).
- Local currents depolarize the adjacent muscle cell plasma membrane to its threshold potential, generating an action potential that propagates over the muscle fiber surface and into the fiber along the T-tubules. Action potential in T-tubules triggers release of Ca^{2+} from lateral sacs of sarcoplasmic reticulum.
- Ca^{2+} binds to troponin on the thin filaments, causing tropomyosin to move away from its blocking position, thereby uncovering cross-bridge binding sites on actin. Energized myosin cross-bridges on the thick filaments bind to actin.
- Cross-bridge binding triggers release of ATP hydrolysis products from myosin, producing an angular movement of each cross-bridge. ATP binds to myosin, breaking linkage between actin and myosin and thereby allowing cross-bridges to dissociate from actin. ATP bound to myosin is split, energizing the myosin cross-bridge.
- Cross-bridges repeat angular movements, producing sliding movement of thin filaments past thick filaments. Cycles of cross-bridge movement continue as long as Ca^{2+} remains bound to troponin.
- Cytosolic Ca^{2+} concentration decreases as Ca^{2+} is actively transported into sarcoplasmic reticulum by Ca^{2+}-ATPase. Removal of Ca^{2+} from troponin restores blocking action of tropomyosin, the cross-bridge cycle ceases, and the muscle fiber relaxes.

TYPES OF MUSCLE CONTACTION

- The force exerted on an object by a contracting muscle is known as muscle **tension,** and the force exerted on the muscle by an object is the **load.** Muscle tension and load are opposing forces. Whether or not a fiber shortens depends on the relative magnitudes of the tension and the load. In order for muscle fibers to shorten, and thereby move a load, muscle tension must be greater than the opposing load.
- When a muscle develops tension but does not shorten (or lengthen), the contraction is said to be **isometric** (constant length). A contraction in which the muscle shortens, while the load on the muscle remains constant, is said to be **isotonic** (constant tension). Shortening contractions are also referred to as **concentric contractions.**
- A third type of contraction is a **lengthening contraction (eccentric contraction).** This occurs when load acting on a muscle is greater than the tension being generated by the cross-bridges.
- It must be emphasized that in these situations the lengthening of muscle fibers is not an active process produced by the contractile proteins, but a consequence of the external forces being applied to the muscle. In the absence of external lengthening forces, a fiber will only *shorten* when stimulated; it will never lengthen.
- All three types of contractions—isometric, isotonic, and lengthening—occur in the natural course of everyday activities.

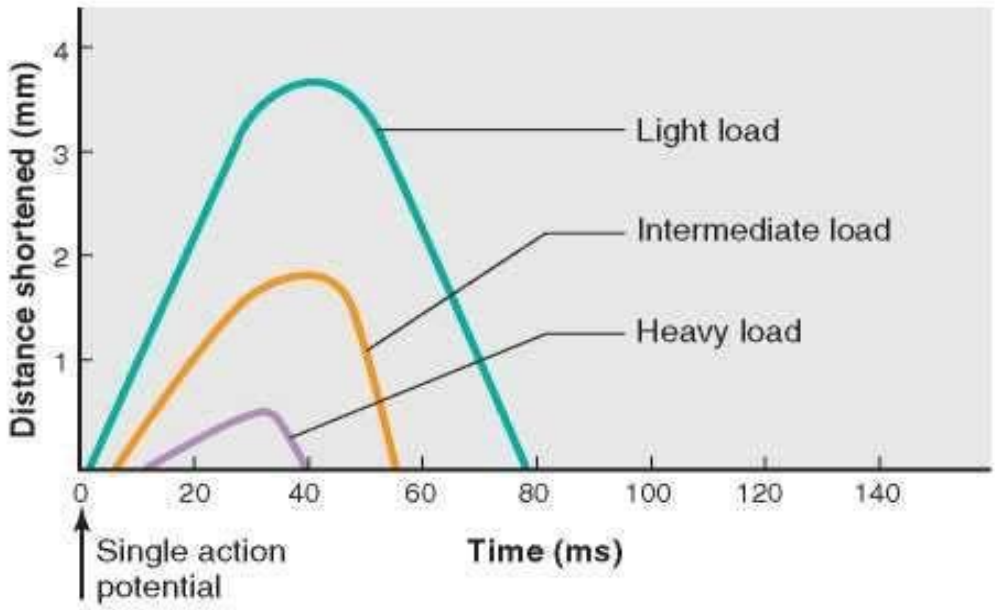
MECHANICS OF SINGLE-FIBER CONTRACTION



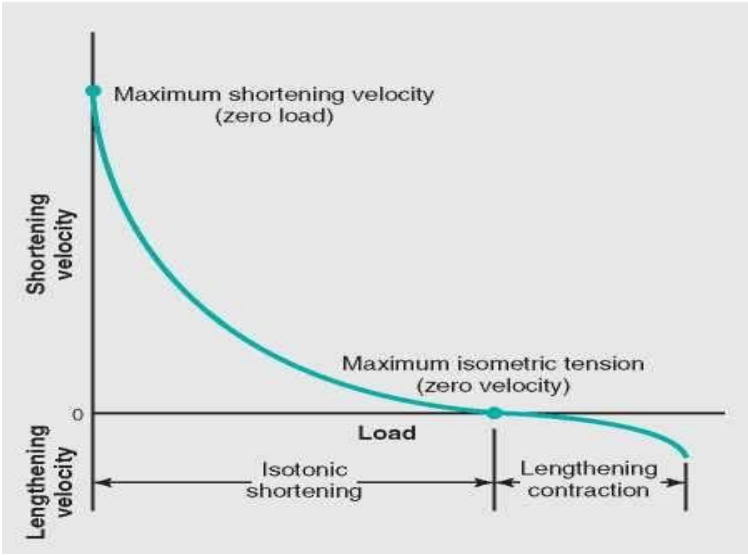
(a) Measurement of tension during a single isometric twitch of a skeletal muscle fiber. (b) Measurement of shortening during a single isotonic twitch of a skeletal muscle fiber.

The mechanical response of a single muscle fiber to a single action potential is known as a **twitch.** Following the action potential, there is an interval of a few milliseconds, known as the **latent period,** before the tension in the muscle fiber begins to increase. During this latent period, the processes associated with excitation-contraction coupling are occurring. The time interval from the beginning of tension development at the end of the latent period to the peak tension is the **contraction time.** Not all skeletal muscle fibers have the same twitch contraction time. Some fast fibers have contraction times as short as 10 ms, whereas slower fibers may take 100 ms or longer.

SHORTENING (CONCENTRIC) CONTRACTIONS

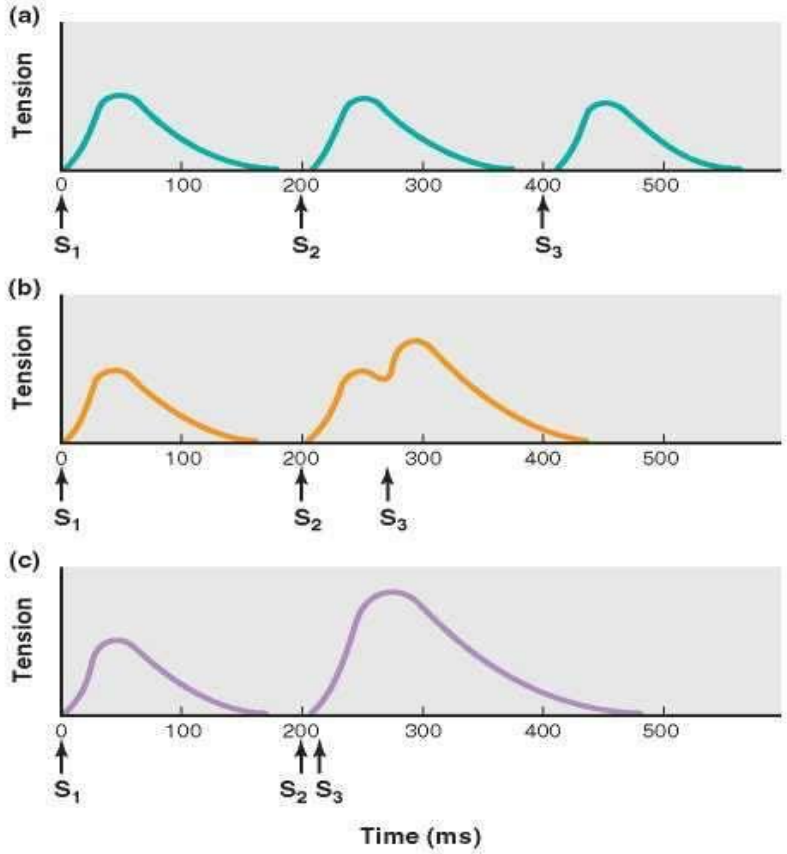


ISOTONIC TWITCHES WITH DIFFERENT LOADS.
The movement amplitude, velocity of shortening, and duration of shortening all decrease with increased load, whereas the time from stimulation to the beginning of shortening increases with increasing load.

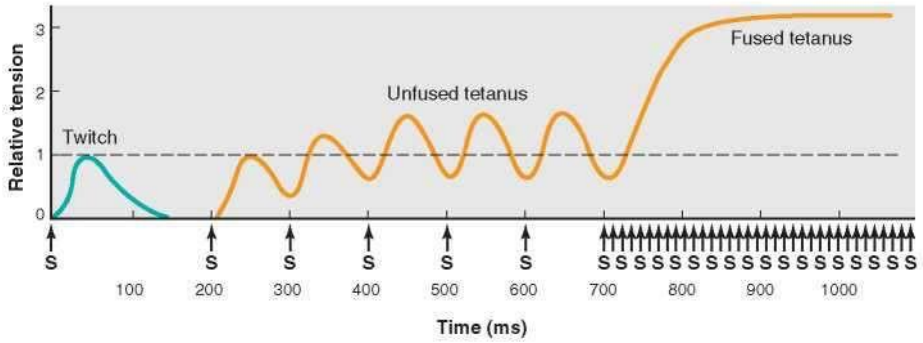


LOAD-VELOCITY RELATION
It is a common experience that light objects can be moved faster than heavy objects. That is, the velocity at which a muscle fiber shortens decreases with increasing loads. The shortening velocity is maximal when there is no load and is zero when the load is equal to the maximal isometric tension. At loads greater than the maximal isometric tension, the fiber will *lengthen* at a velocity that increases with load.

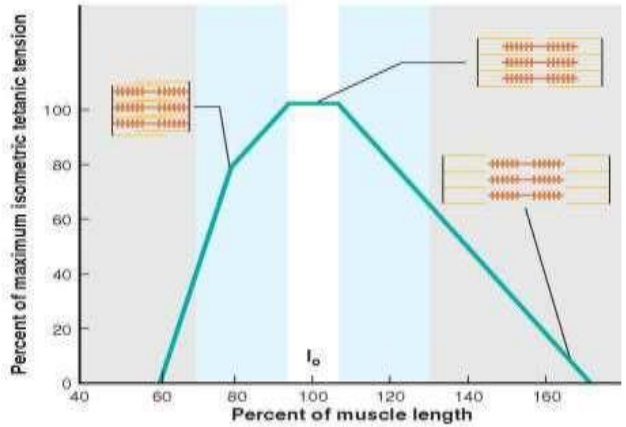
FREQUENCY-TENSION AND LENGTH-TENSION RELATIONS



Summation of isometric contractions produced by shortening the time between stimuli S_2 and S_3.

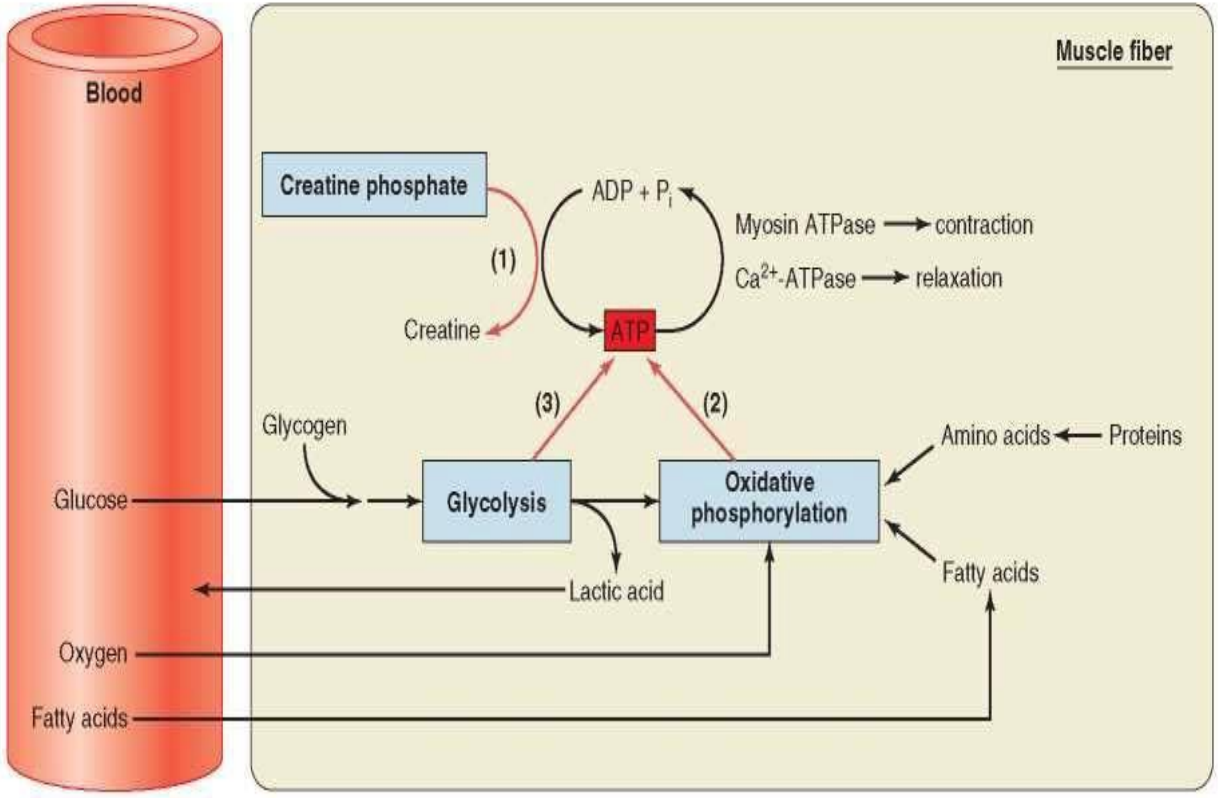


Isometric contractions produced by multiple stimuli(**S**) at 10 stimuli per second (unfused tetanus) and 100 stimuli per second (fused tetanus).



Variation in active isometric tetanic tension with muscle fiber length. The blue band represents the range of length changes that can normally occur in the body.

SKELETAL MUSCLE ENERGY METABOLISM

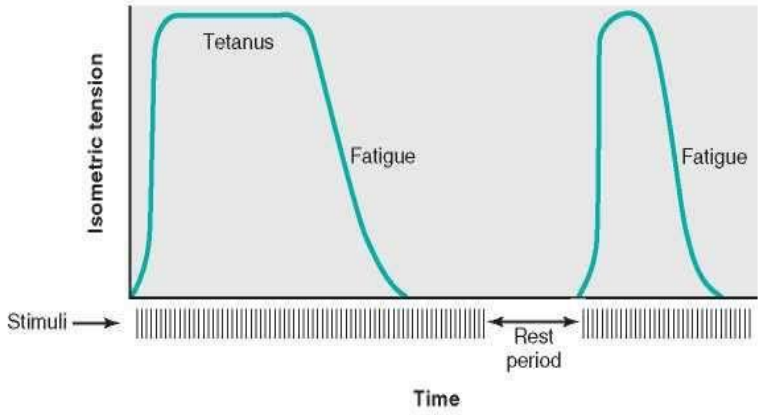


The three sources of ATP production during muscle contraction: (1) creatine phosphate, (2) oxidative phosphorylation, and (3) glycolysis.

Phosphorylation of ADP by creatine phosphate provides a very rapid means of forming ATP at the onset of contractile activity. When the chemical bond between creatine and phosphate is broken, the amount of energy released is about the same as that released when the terminal phosphate bond in ATP is broken. This energy, along with the phosphate group, can be transferred to ADP to form ATP in a reversible reaction catalyzed by creatine kinase.

Although creatine phosphate is a high-energy molecule, its energy cannot be released by myosin to drive cross-bridge activity. During periods of rest, muscle fibers build up a concentration of creatine phosphate contributing approximately equally; beyond this period, fatty acids become progressively more important, and glucose utilization by muscle decreases.

MUSCLE FATIGUE

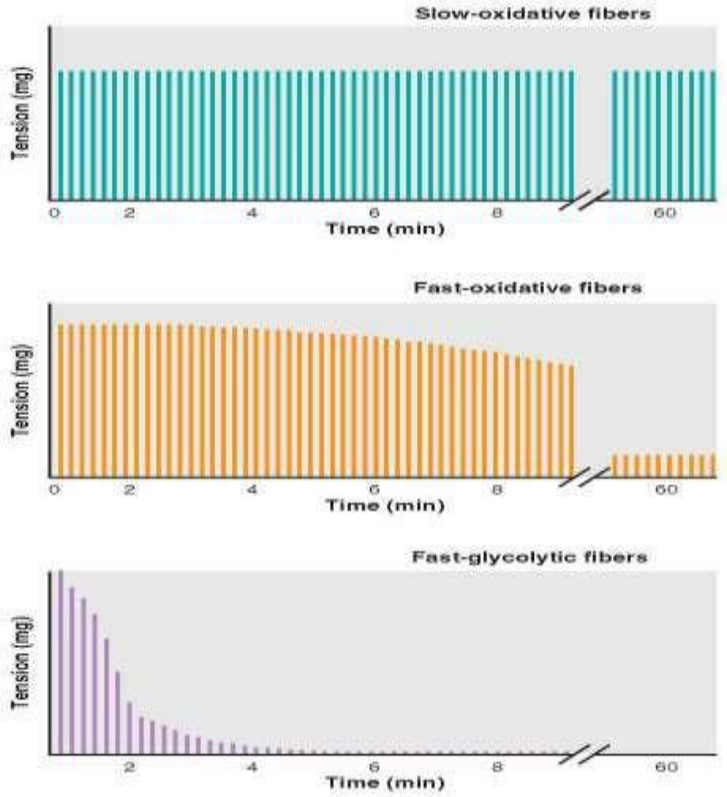


When a skeletal muscle fiber is repeatedly stimulated, the tension developed by the fiber eventually decreases even though the stimulation continues. This decline in muscle tension as a result of previous contractile activity is known as **muscle fatigue.** Additional characteristics of **fatigued muscle** are a decreased shortening velocity and a slower rate of relaxation. The onset of fatigue and its rate of development depend on the type of skeletal muscle fiber that is active, the intensity and duration of contractile activity, and the degree of an individual's fitness.

Conduction Failure.
Lactic Acid Buildup.
Inhibition of Cross-Bridge Cycling.

TYPES OF SKELETAL MUSCLE FIBERS

Skeletal muscle fibers do not all have the same mechanical and metabolic characteristics. Different types of fibers can be identified on the basis of (1) their maximal velocities of shortening—fast or slow— and (2) the major pathway used to form ATP—oxidative or glycolytic.



CHARACTERISTICS OF THE THREE TYPES OF SKELETAL MUSCLE FIBERS

	SLOW - OXIDATIVE FIBERS	FAST - OXIDATIVE FIBERS	FAST- GLYCOLYTIC FIBERS
Primary source of ATP production	Oxidative phosphorylation	Oxidative phosphorylation	Glycolysis
Mitochondria	Many	Many	Few
Capillaries	Many	Many	Few
Myoglobin content	High (red muscle)	High (red muscle)	Low (white muscle)
Glycolytlc enzyme activity	low	Intermediate	High
Glycogen content	Low	Intermediate	High
Rate of fatigue	Slow	Intermediate	Fast
Myosin-ATPase activity	Low	High	High
Contraction velocity	Slow	Fast	Fast
Fiber diameter	Small	Intermediate	Large
Motor unit size	Small	Intermediate	Large
Size of motor neuron innervating fiber	Small	Intermediate	Large

REVIEW QUESTIONS

- List the three types of muscle cells and their locations.
- Diagram the arrangement of thick and thin filaments in a striated muscle sarcomere, and label the major bands that give rise to the striated pattern.
- Describe the organization of myosin and actin molecules in the thick and thin filaments.
- What prevents cross-bridges from attaching to sites on the thin filaments in a resting skeletal muscle? What is an end-plate potential, and what ions produce it?
- Describe isometric, isotonic, and lengthening contractions.
- What effect does increasing the frequency of action potentials in a skeletal muscle fiber have upon the force of contraction? Explain the mechanism responsible for this effect.
- Describe the length-tension relationship in striated muscle fibers.