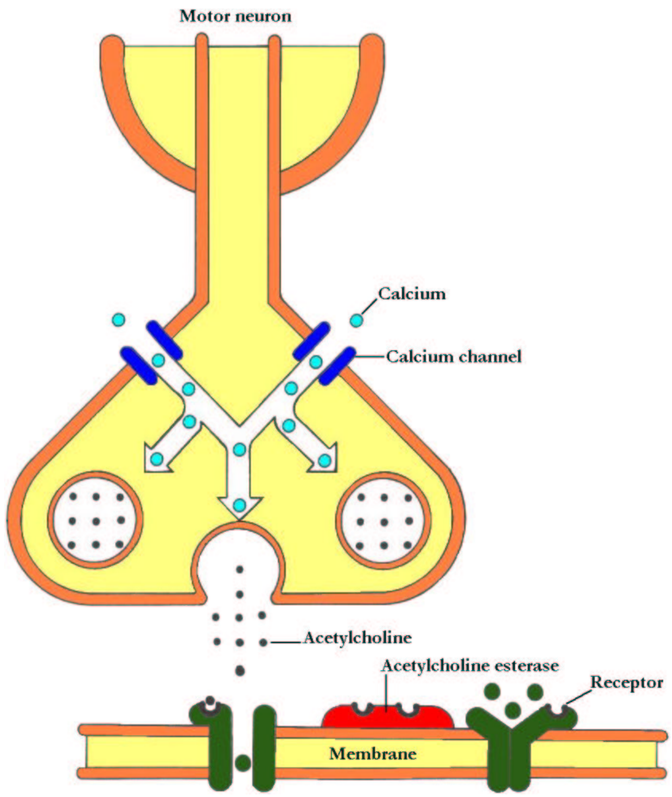
Muscular System
ANS 215
Physiology and Anatomy of
Domesticated Animals

I. Skeletal Muscle Contraction

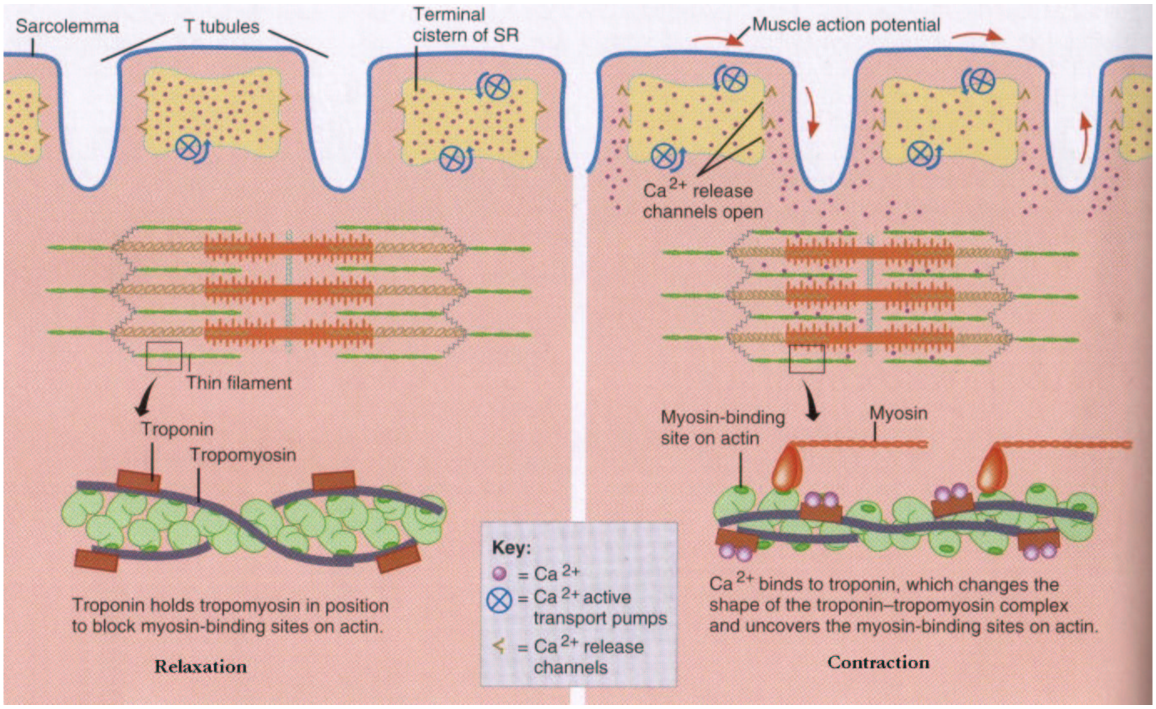
A. Neuromuscular junction functions as an amplifier for a nerve impulse
B. Arrival of a spinal or cranial nerve impulse at the neuromuscular junction results in release of acetylcholine (Ach) into the space between the nerve fiber terminal branch and the muscle fiber



C. Release of Ach is accelerated because Ca ions from extracellular fluid enter the prejunctional membrane when the nerve impulse arrives
D. Ach is the stimulus that increases the permeability of the muscle fiber membrane for Na ions, after which depolarization begins
E. Depolarization proceeds in all directions from the neuromuscular junction
F. Impulse is conducted into all parts of the muscle fiber by the sarcotubular system (synchronizes muscle fiber contraction)
G. Low concentration of Ca in the extracellular fluid is recognized clinically in dairy cows after calving (parturient paresis) as a state of semi-paralysis caused by partial neuromuscular block.
H. Almost immediately after its release Ach is hydrolyzed by the enzyme acetylcholinesterase into acetic acid and choline
I. Next depolarization must await the arrival of the next nerve impulse

J. Tubules of sarcoplasmic reticulum have a relatively high concentration of Ca ions

K. Depolarization of these tubules results in a simultaneous release of Ca ions into the sarcoplasm, which in turn diffuse rapidly into the myofibrils



L. Presence of Ca ions within the myofibrils initiates the contraction process

M. The Ca ions are returned rapidly by active transport to the sarcoplasmic reticulum after contraction is initiated and are released again when the next signal arrives.

II. Contraction Process

A. The shortening or contraction process involves an interaction between the actin and myosin filaments

B. There is a natural attraction for actin and myosin molecules involving active sites on the actin molecule.

C. Attraction is inhibited during relaxation because the active sites are covered

D. When Ca ions enter the myofibril, the active sites are uncovered.

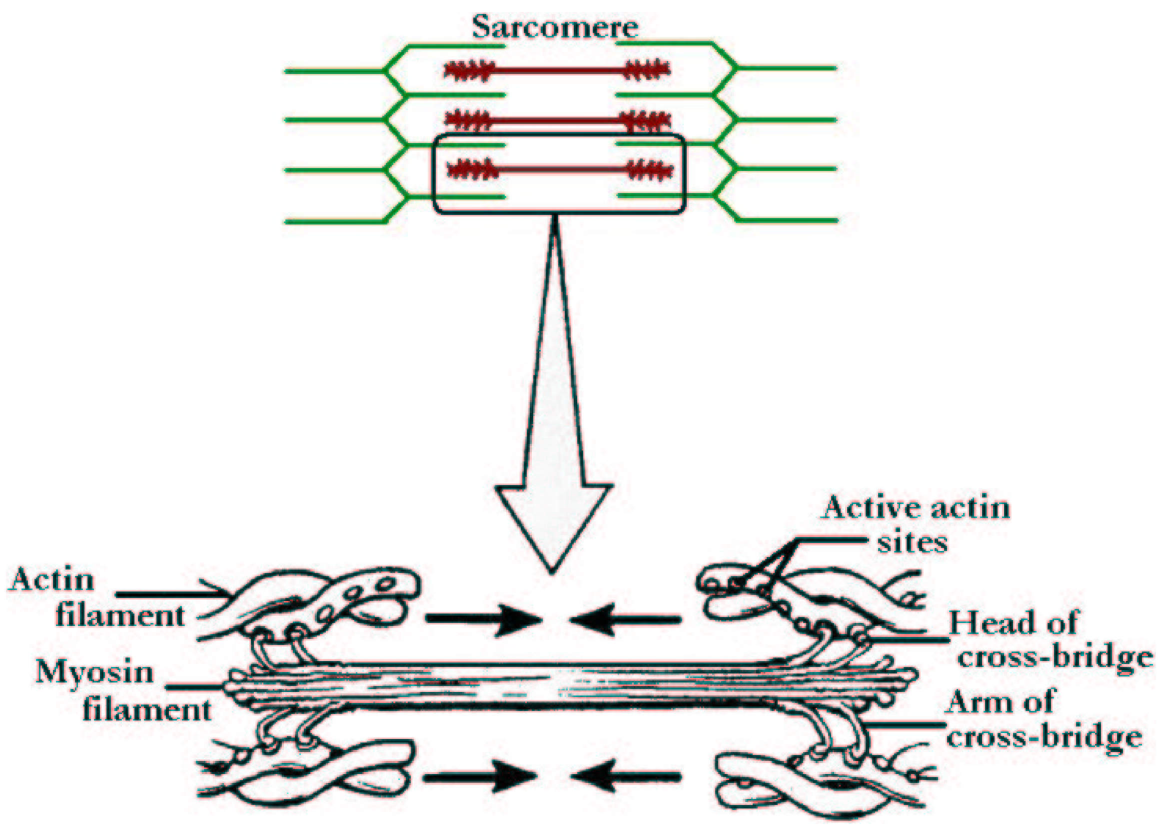
E. Projecting portions of the myosin molecules (cross bridges) attach to the active sites and bend toward the center causing the actin to slide towards the myosin molecule.

F. Actin filament has three major components (all protein)

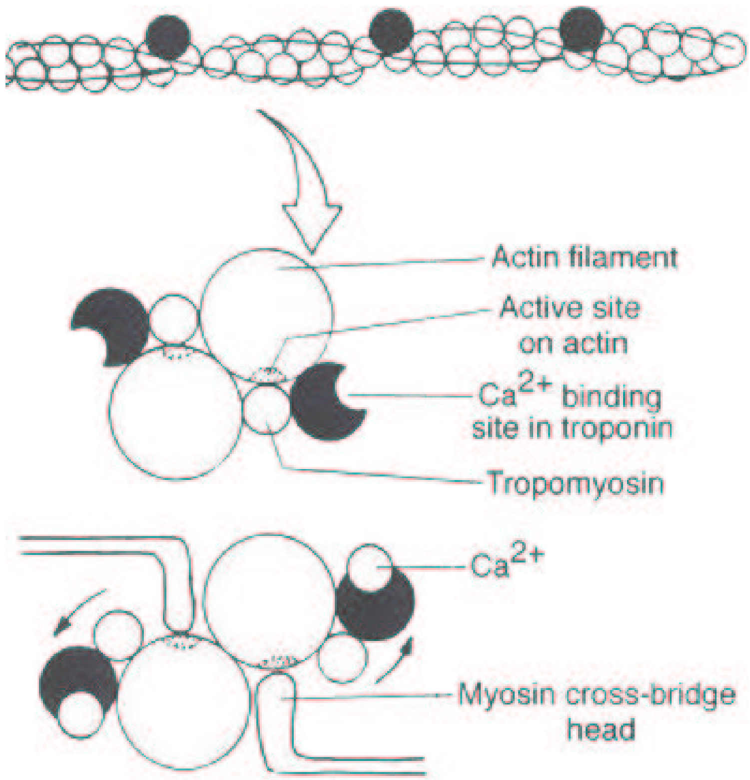
    1. Actin
    2. Tropomyosin
    3. Troponin

G. Actin and tropomyosin are arranged in helical strands interwoven with each other.

H. Troponin is located at regular intervals along the strands and contains three proteins, two which bind actin and tropomyosin together and the third which has an affinity for Ca ions.



I. Active sites (places where myosin crossbridges attach) are located on the actin strands and are normally covered by the tropomyosin strands.
J. When calcium ions bind to the troponin complex a conformational change occurs between the actin and tropomyosin strands and causes the active sites to be uncovered.
K. The uncovered sites favor activation of the natural attraction that exists between actin and myosin.



III. Sequence of Events in the Heads of the Myosin Cross-bridges That Cause Muscle Contraction

A. Adenosine triphosphatase (ATPase) of the myosin cross-bridge heads hydrolyze ATP to adenosine diphosphate (ADP) + inorganic phosphorus (PÆ) bound to the heads

B. Energy from the hydrolysis of the ATP “cocks” the heads so that they increase their angle of attachment to the cross-bridge arm and become perpendicular to the active sites of the actin filaments.

C. After depolarization of the sarcotubular system, Ca ions diffuse from sarcoplasmic reticulum into myofibrils and bind to the troponin complexes, uncovering actin active sites. Ca ions are returned rapidly to the sarcoplasmic reticulum once the shortening process begins.

D. Natural attraction of myosin to actin is now permitted and the “cocked” heads bind with active sites

E. Bonds with actin cause conformational change in heads (uncocking) causing them to bend (tilt) toward cross-bridge arms (toward center of sarcomere) pulling actin with it (energy derived from previous ATP hysrolysis).

F. Tilted heads cause release of ADP + PÆ and expose sites on heads for binding new ATP.

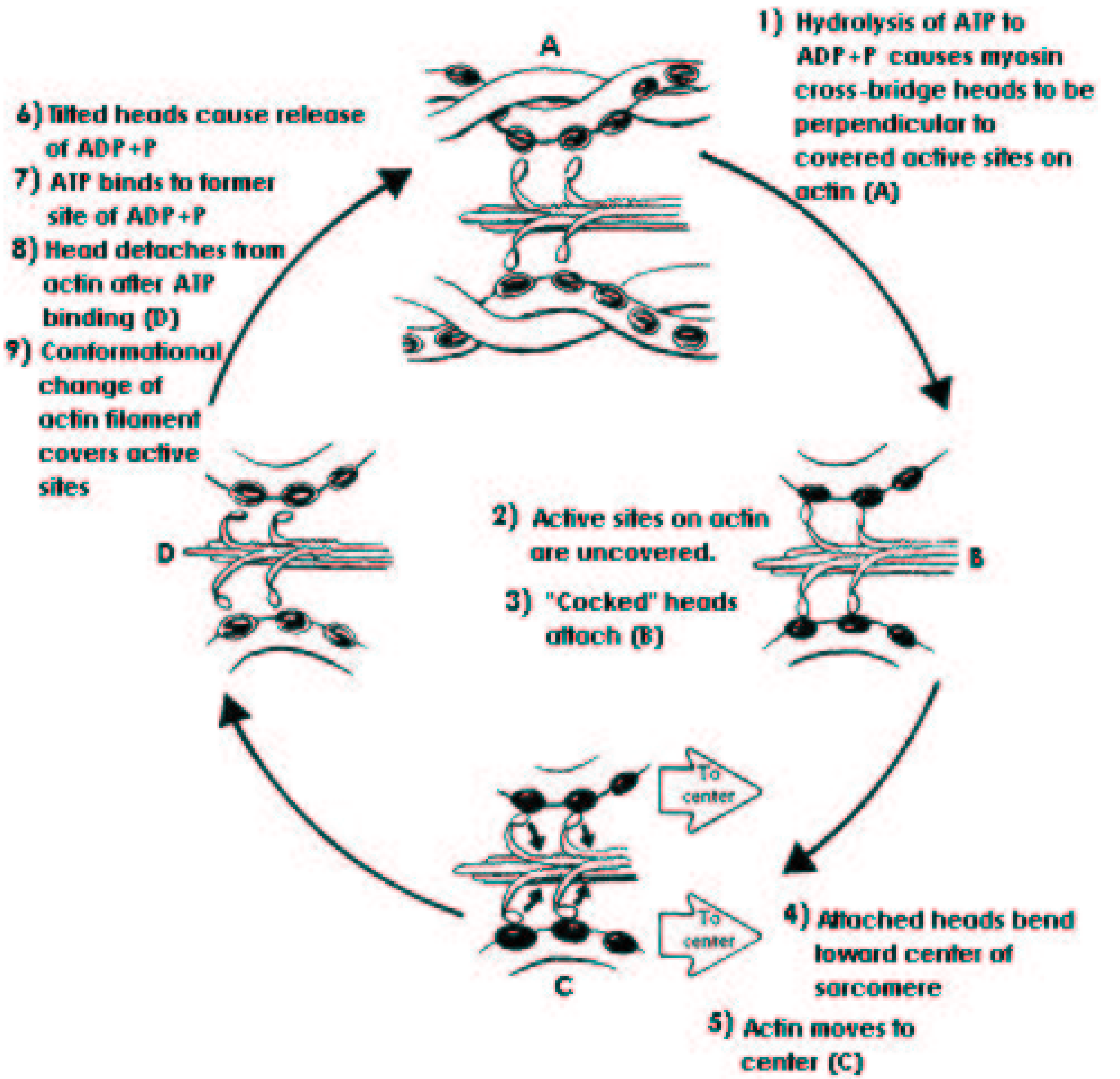
G. Binding of new ATP causes detachment of myosin cross-bridge heads from actin filaments.

H. ATPase of heads hydrolyzes ATP as before, cocking the heads; process is repeated when the next neuromuscular transmission causes depolarization of the sarcomere system.

I. Repetition of the process causes the actin filaments to be pulled further into the center, thus shortening the sarcomere.

J. Replenishment of ATP is accomplished by transfer from creatine phosphate (CP) which is about five times more plentiful than ATP.

K. Ultimately, energy is derived from intermediary metabolism within the muscle cell and from the associated reoxidation of reduced cofactors in the electron transport chain.



L. The presence of ATP is required for relaxation, or detachment of the myosin from the actin, and also for the return of Ca ions to the sarcoplasmic reticulum

M. Muscle contraction is only about 25% efficient. Nonwork portion is dissipated as heat.

N. Generation of heat by muscle is an important source of heat for animals.

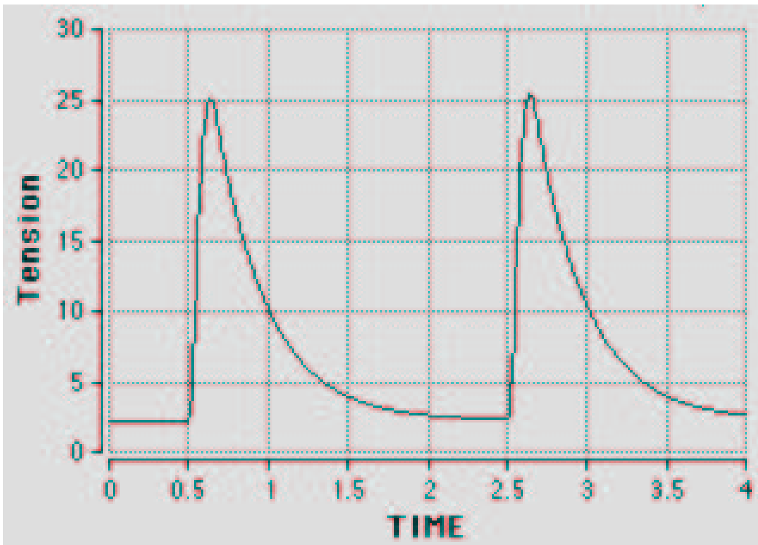
IV. Contraction vs Contracture

A. Muscle shortening can occur in the absence of action potentials.

B. This type of shortening is referred to as rigor or physiologic contracture, as opposed to contraction.
C. The actin and myosin filaments remain in a continuous contracted state because sufficient ATP is not available to bring about relaxation.
D. Contracture which occurs after death is referred to as rigor mortis.
    1. Eventually autolysis of muscle results in relaxation 12–24 hrs. after death.
E. Muscles most active before death are those that develop rigor mortis first.

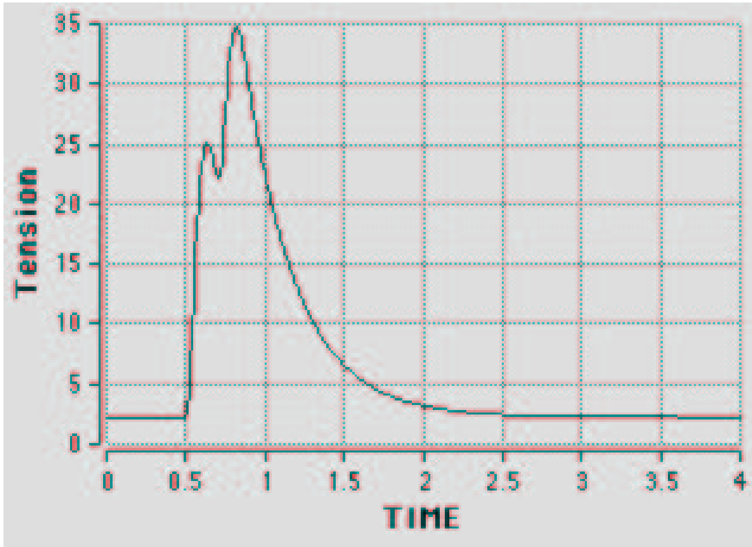
V. Contraction Strength

A. Contraction strength varies and is achieved by multiple motor unit summation or wave summation.



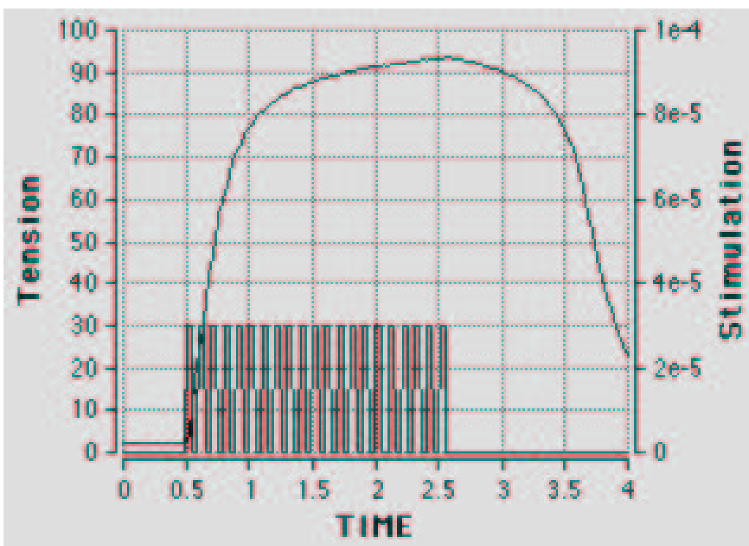
Here, and in the following two graphs, tension is a percentage.

B. Stimulation of one motor unit causes a weak contraction, whereas the stimulation of a large number of motor units develops a strong contraction.
C. Known as a motor unit summation.
D. All gradiations of contraction strength are possible, depending on the number of motor units stimulated.
E. Increasing the strength of contraction by wave summation occurs when the frequency of contraction is increased.



F. When a muscle is stimulated to contract before the muscle has relaxed the strength of the subsequent load is increased.

G. When the frequency is sufficient such that the individual muscle twitches become fused into a single prolonged contraction, the strength is at maximum, this is known as tetany.

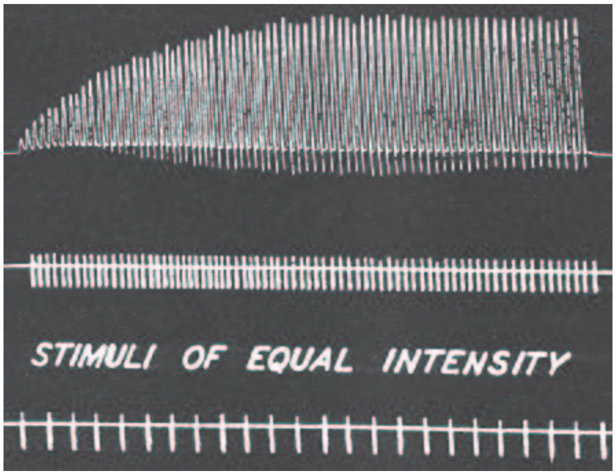


VI. Tetanus

A. Tetanus is a bacterial disease caused by a potent neurotoxin elaborated by the organism *Clostridium tetani*.
B. The neurotoxin reaches the central nervous system and prevents release of an inhibitory transmitter (glycine).
C. The resultant sensitivity to excitatory impulses, unchecked by inhibitory impulses, produces generalized muscle spasms (tetany).
D. Tetanus has also been called lockjaw, because the masseter muscles that close the mouth are stronger than the muscles that open the mouth and the jaw remains in a closed (locked) position

VII. Treppe

A. Muscles appear to "warm up" to a maximum contraction state.
B. This can be demonstrated by applying stimuli of equal intensity a few seconds apart to a muscle.
C. Each successive muscle twitch has slightly more strength than the previous until maximum contraction strength is reached.
D. This is called treppe, or a staircase phenomenon
E. Successive stimulations are believed to provide for an increasing concentration of Ca ions in the sarcoplasm during the beginning contractions of rested muscles.



VIII. Comparison of Contraction Among the Three Muscle Types

A. The contraction process is similar in all three in that actin filaments slide between myosin filaments and cause a shortening of the cell.
B. There is a greater similarity in arrangement of these filaments between cardiac and skeletal muscle (hence their common description as striated).
C. The myofibrils of cardiac muscle constitute most of the muscle fiber, but instead of being discrete and cylindric, as in skeletal muscle, they join together and are variable in diameter.
D. This may be related to more circular contraction of cardiac muscle compared to skeletal (linear) contraction.

E. Whereas the work of skeletal muscle fibers is harnessed to connective tissue elements, cardiac muscle fibers anastomose with each other.

F. Each skeletal muscle fiber receives separate stimulation through a spinal or cranial nerve and neuromuscular junction.

G. Cardiac muscle receives its stimulus from rhythmic, contractile, and specialized cardiac muscle cells known as pacemakers.

H. The autonomic nervous system regulates the pacemakers.

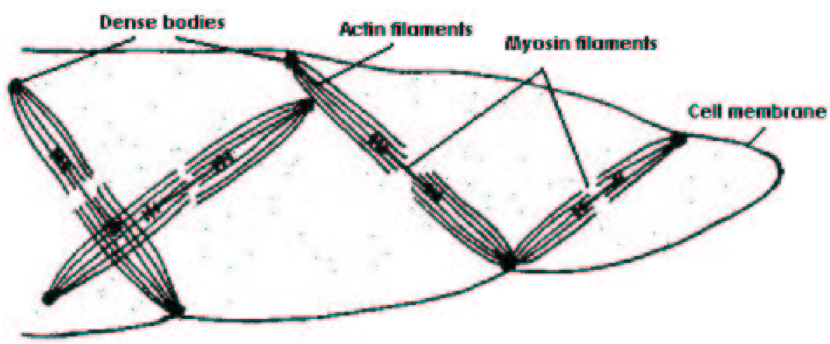
I. Conduction of stimulation is from cell to cell (through intercalated disk) and from special conduction fibers (Purkinje fibers) in the ventricular walls.

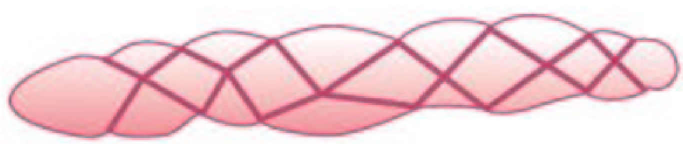
J. Sarcotubular system of cardiac muscle is not as well developed in cardiac muscle as in skeletal muscles.

K. Smooth muscle myofilaments are not aligned into myofibrils as in cardiac and skeletal muscles.

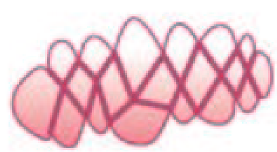
L. A higher ratio of actin to myosin exists (15:1 versus 2:1).

M. Actin filaments are attached to dense bodies which are dispersed inside the cell, and some are attached to cell membrane.





Relaxed smooth muscle cell



Contracted smooth muscle cell

N. Dense bodies correspond to the Z lines of skeletal muscle and are held in place by framework of structural proteins that link one dense body to another.

O. The actin filaments from two separate dense bodies extend toward each other and surround a myosin filament, thereby providing a contractile unit that is similar to a contractile unit of skeletal muscle.

P. Cycle of attachment and detachment of cross-bridge heads that extend from myosin to actin is much slower in smooth muscle.

Q. This provides for a prolonged contraction.

R. The slower cycles are a result of the much lower ATPase activity on the myosin cross-bridge heads than in skeletal muscle.

S. The heads remain in an “uncocked” position for a longer time.

T. Coupled with the slower frequency of attachment-detachment cycling is the lower energy requirement for sustaining the same tension of contraction in smooth muscle as in skeletal muscle.

U. Neuromuscular junctions associated with smooth muscle are diffuse junctions. The autonomic nerve fibers that innervate smooth muscle do not make direct contact with the muscle fibers, but from diffuse junctions that secrete their transmitter substance into interstitial fluid.

V. The vesicles of the terminal axons contain either Ach or norepinephrine depending of whether the postganglionic terminal fiber is parasympathetic or sympathetic.

W. The vesicle secretion may be excitatory or inhibitory depending on the receptors that are located on the smooth muscle membrane.

X. The sarcotubular system of smooth muscle fibers is poorly developed.

IX. Changes in Muscle Size

A. An increase in individual muscle fiber size is referred to as hypertrophy.
   1. Common in skeletal, cardiac, and smooth muscle

B. Postnatal growth of skeletal muscle fibers is not accomplished by an increase in the number of muscle fibers, but rather by the addition of myofibrils to the periphery and of sarcomeres to the tendonous ends.

C. An increase in the number of muscle fibers is called hyperplasia.

D. Regeneration of skeletal muscle fibers is possible from so-called satellite cells.
   1. Requires an intact endomysium for successful repair

E. Increase in cardiac muscle size is similar to that of skeletal muscles in that it involves hypertrophy and not hyperplasia.

F. Regeneration of cardiac muscle does not occur.

G. Smooth muscle organs can increase their size by hypertrophy and by hyperplasia.

H. A decrease in size of a muscle is referred to as atrophy – when a body part has been immobilized for a period of time.

I. Loss of the nerve supply to a muscle results in denervation atrophy.