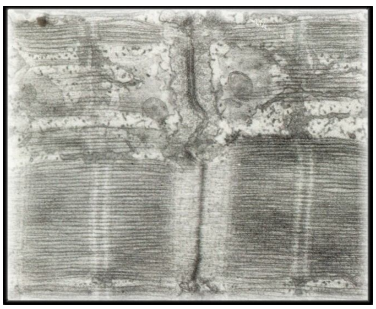
Skeletal Muscle Contraction and ATP Demand

- ***Anatomy & Structure***
- ***Contraction Cycling***
- ***Calcium Regulation***
- ***Types of Contractions***
- ***Force, Power, and Contraction Velocity***



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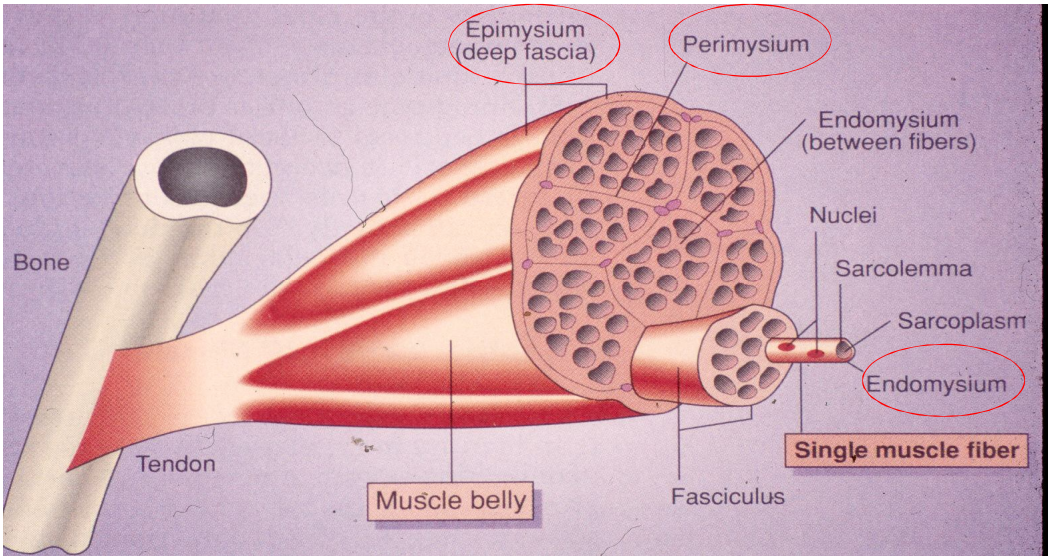
Epimysium - separates fascia and muscle
Perimysium - separates fascicles (bundle of muscle fibers
Endomysium - separates individual muscle fibers



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Definition of Structures

Fascicles - discrete bundles of muscle fibers

Muscle Fibers - muscle cells *(multiple nuclei, mitochondria, glycogen granules, lipid droplets, ribosomes, t-tubules, golgi and sarcoplasmic reticulum, contraction proteins)*

Myofibrils - longitudinal subcellular structures of muscle proteins.

Sarcomeres - contractile protein units within myofibrils.

Contractile Proteins - filamentous actin, myosin, tropomyosin, troponin, titin, nebulin.

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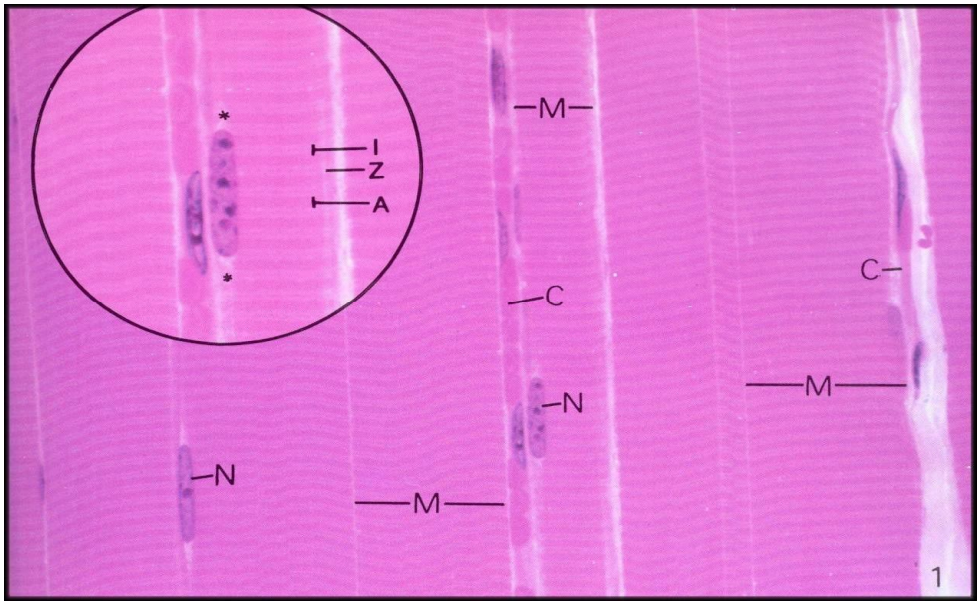

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Structure and Function Terminology

Striations -visual appearance through electron microscopy of an organized array of light and dark strands within sarcomeres.

Myofibrils -organized array of sarcomeres connected in series (end to end) along the length of a muscle fiber.

Sarcomeres -structural units of the myofiber where structural and contractile proteins are organized in a specific sequence, causing a striated appearance under electron microscopy.

Myosin - the largest of the contractile proteins

S_1 unit - the globular head region of myosin

Actin - a globular protein that forms a two stranded filament (F-actin) in vivo.

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Structure and Function Terminology, cont'd.

Tropomyosin - a rod shaped protein attached to actin in a regular repeating sequence.

Troponin - a 3 component protein that is associated with each actin-tropomyosin complex.

Sarcolemma - the cell membrane of skeletal muscle.

Motor Unit - a single α motor nerve and all the muscle fibers that it innervates.

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Protein	Function
F-Actin	Interacts with myosin during muscle contraction.
Tropomyosin	Combines with troponin to cover or expose the actin binding sites depending on the presence of calcium.
Troponin	Binds calcium to move the troponin-tropomyosin complex to expose the actin binding sites.
Meromyosin	Contains ATPase activity to break down ATP, bind to actin and induce the "power stroke" of muscle contraction.
α-actinin	Connects actin to the proteins of the z-lines.
Desmin	Connects z-line from adjacent sarcomeres to aid the structural integrity of the myofibril.
M-protein	Holds the myosin filaments in their organized array, forming the M-line.
Nebulin	Holds the actin double filament together to form F-actin
Titin	Assists M protein to anchor the meromyosin in the middle of the sarcomere. Contributes to elastic recoil of muscle relaxation.

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Skeletal Muscle Contraction

Excitability - receive and propagate an action potential.

Contractility - contract/shorten

Elasticity - rapidly return to a pre-contraction length.

The demands of exercise require that skeletal muscles must be able to,

1. contract and generate a *wide range of tensions/force*,

2. alter tension/force in small increments, and

3. do this repeatedly and rapidly for durations that may vary from a few seconds to several hours.

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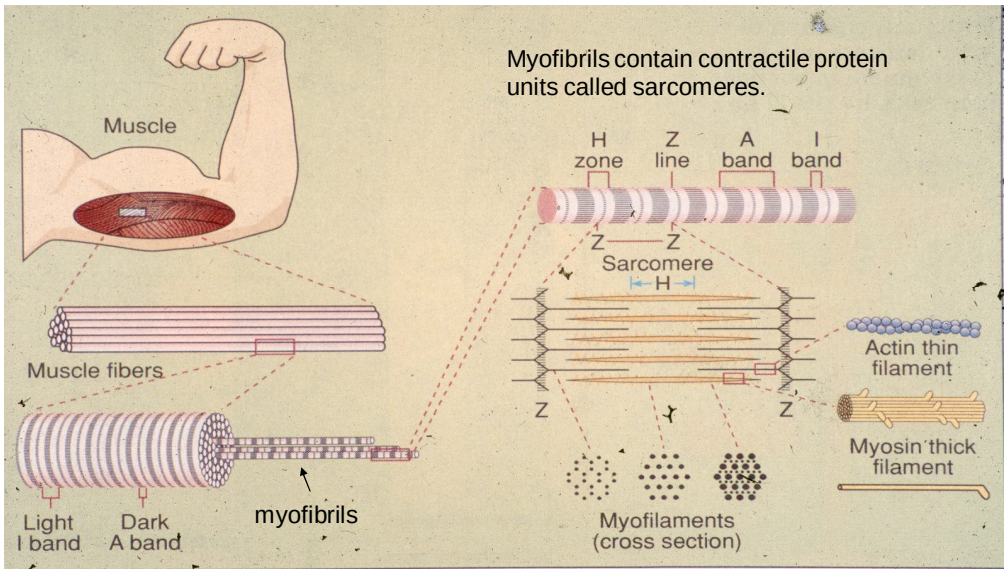
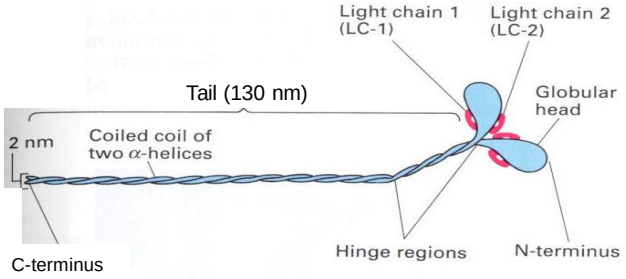
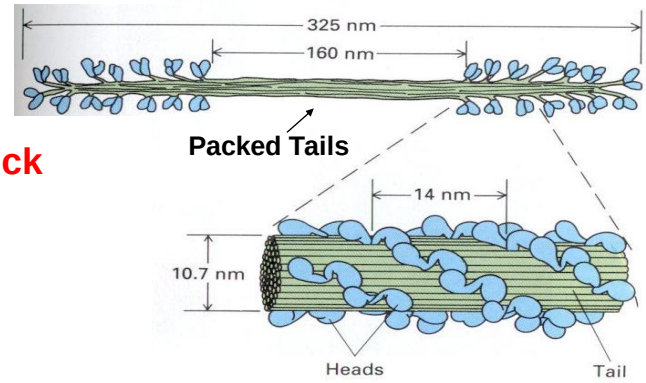
Contractile Proteins



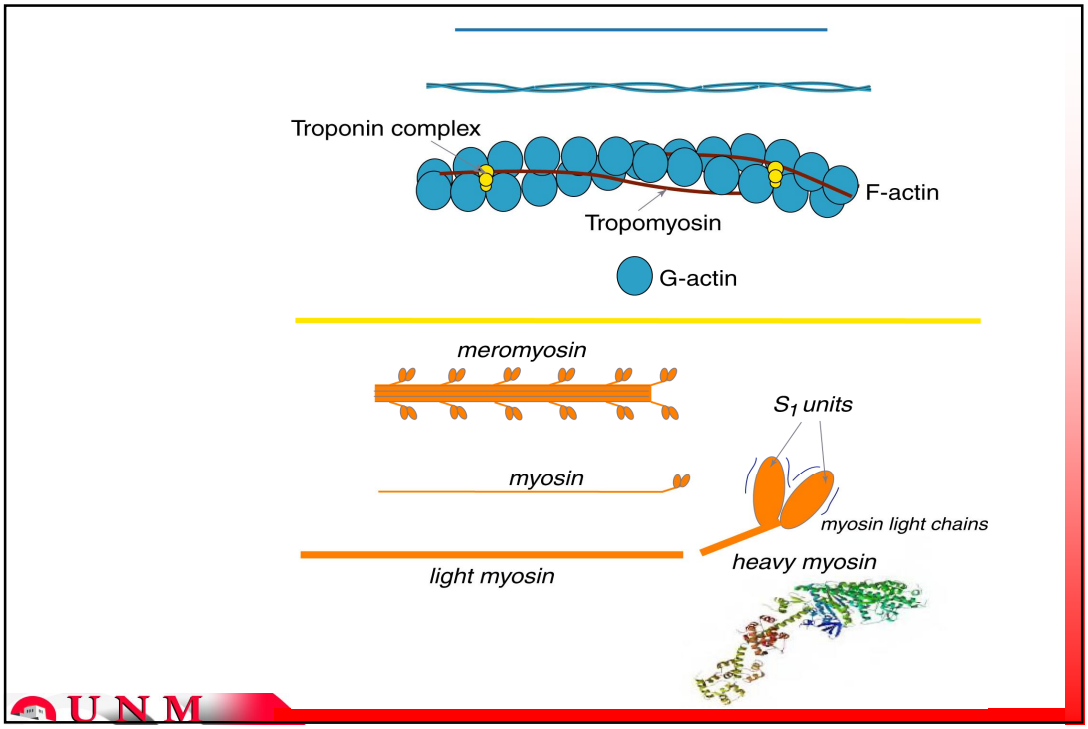
Myosin Molecule

(Two pairs of two different light chains and two identical heavy chains)

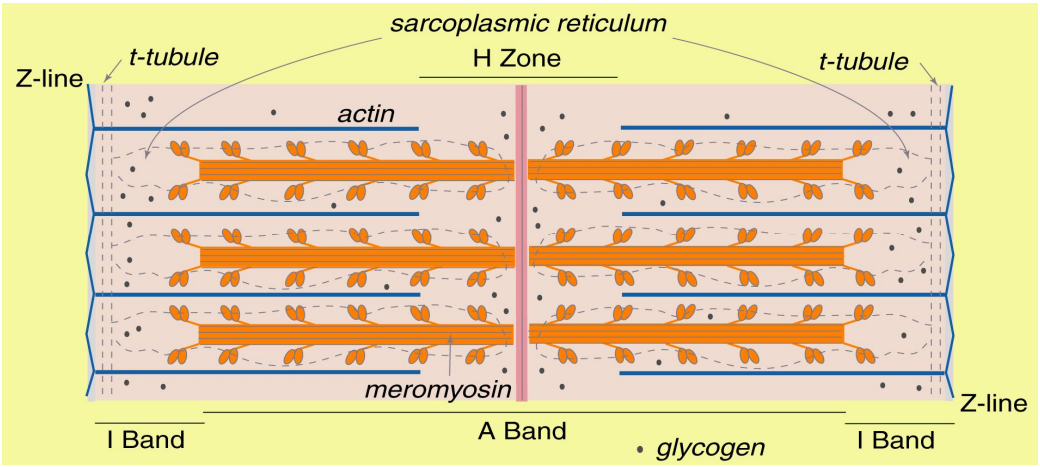


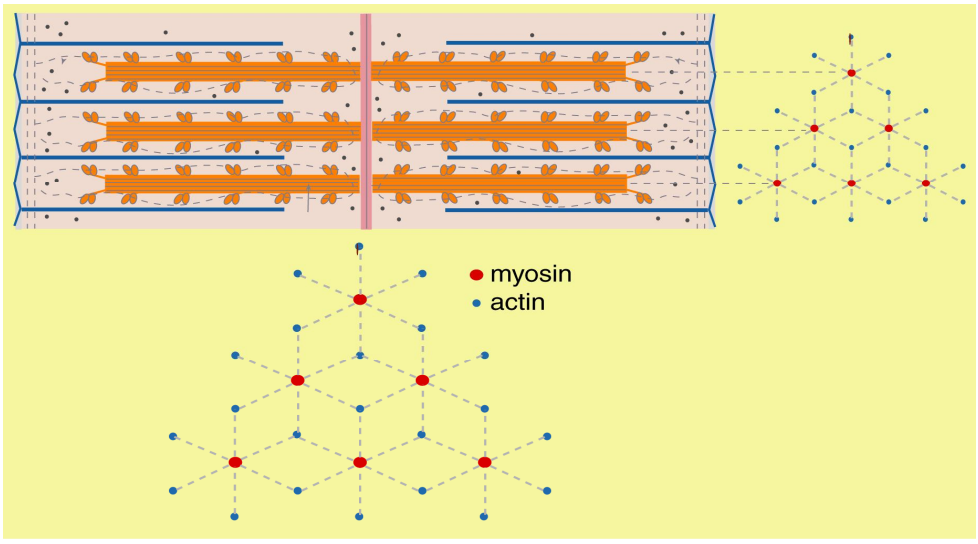


Myosin Thick Filament

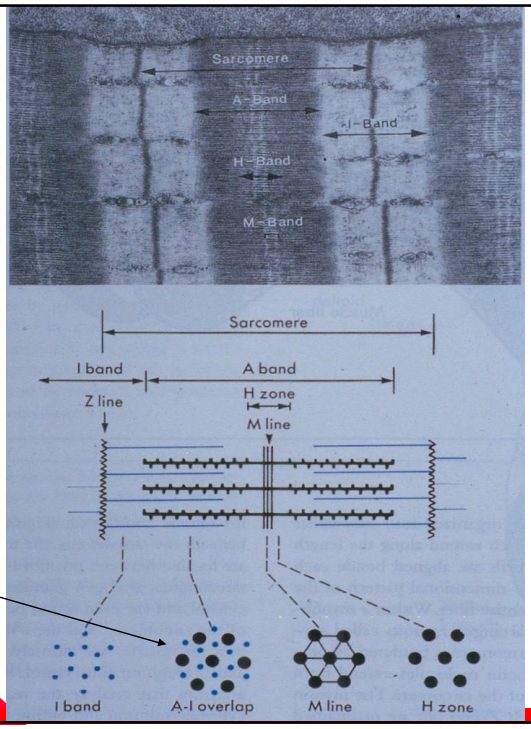

Troponin complex
F-actin
Tropomyosin
G-actin
meromyosin
S_1 units
myosin
myosin light chains
heavy myosin
light myosin


1 µm
I
M
I
Z
A
Z
0.25 µm


sarcoplasmic reticulum
t-tubule
H Zone
t-tubule
Z-line
actin
meromyosin
Z-line
I Band
A Band
glycogen
I Band


myosin
actin

Electron Micrograph



Each myosin molecule is associated with six different F-actin molecules in a hexagonal structure.

During contraction:
I band decreases
H-Zone disappears
A band retains its length.

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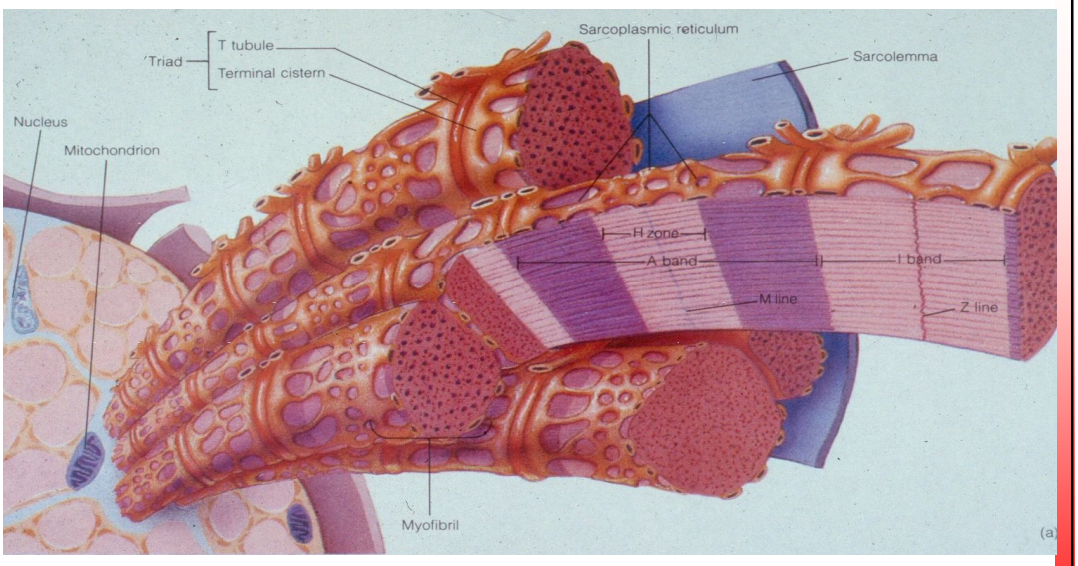

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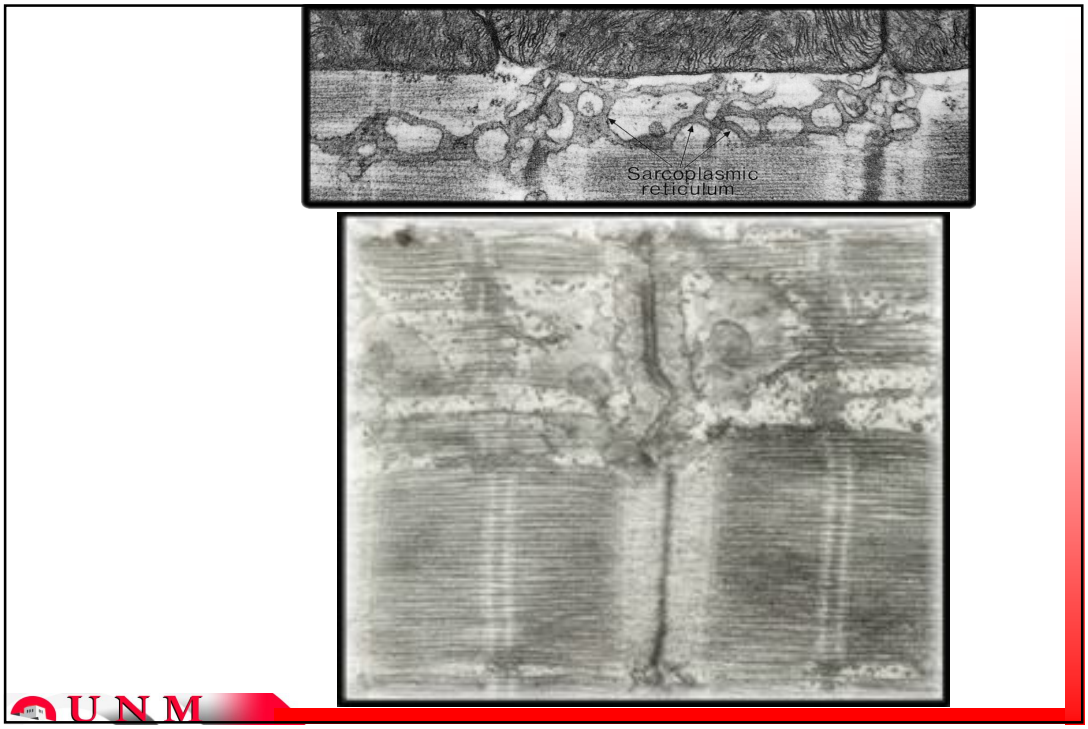
Sarcoplasmic reticulum
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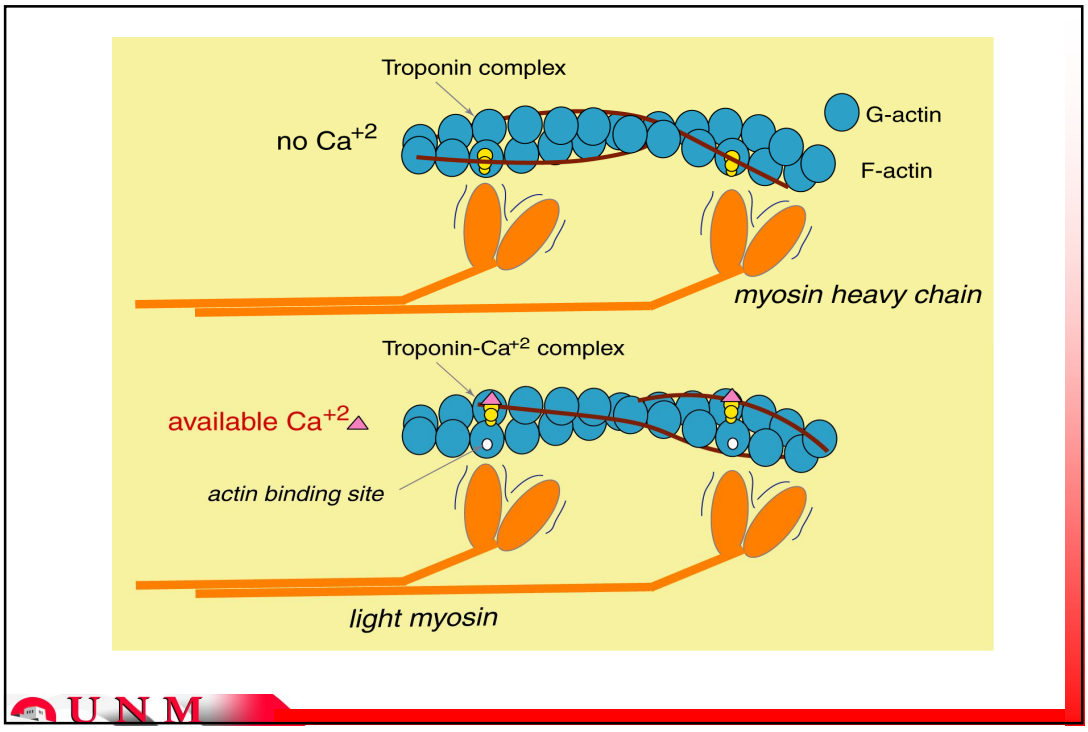
Troponin complex
no Ca+2
G-actin
F-actin
myosin heavy chain
Troponin-Ca+2 complex
available Ca+2
actin binding site
light myosin
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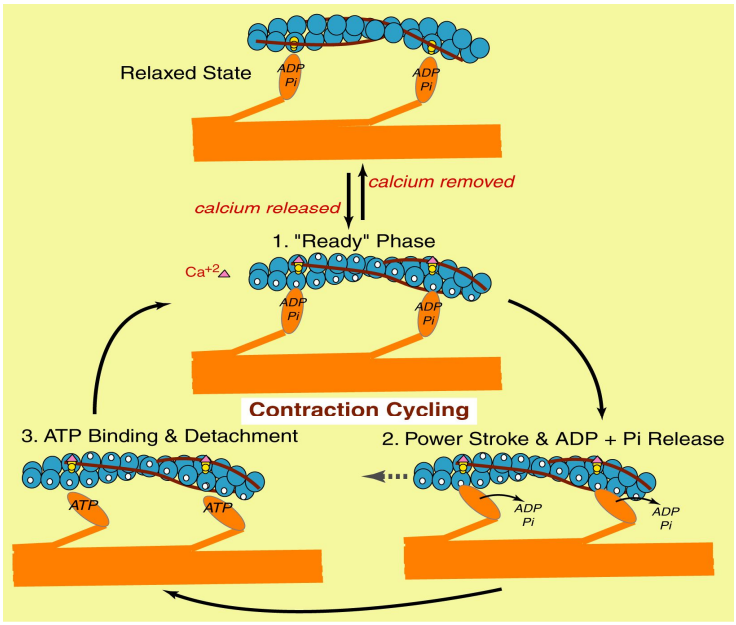
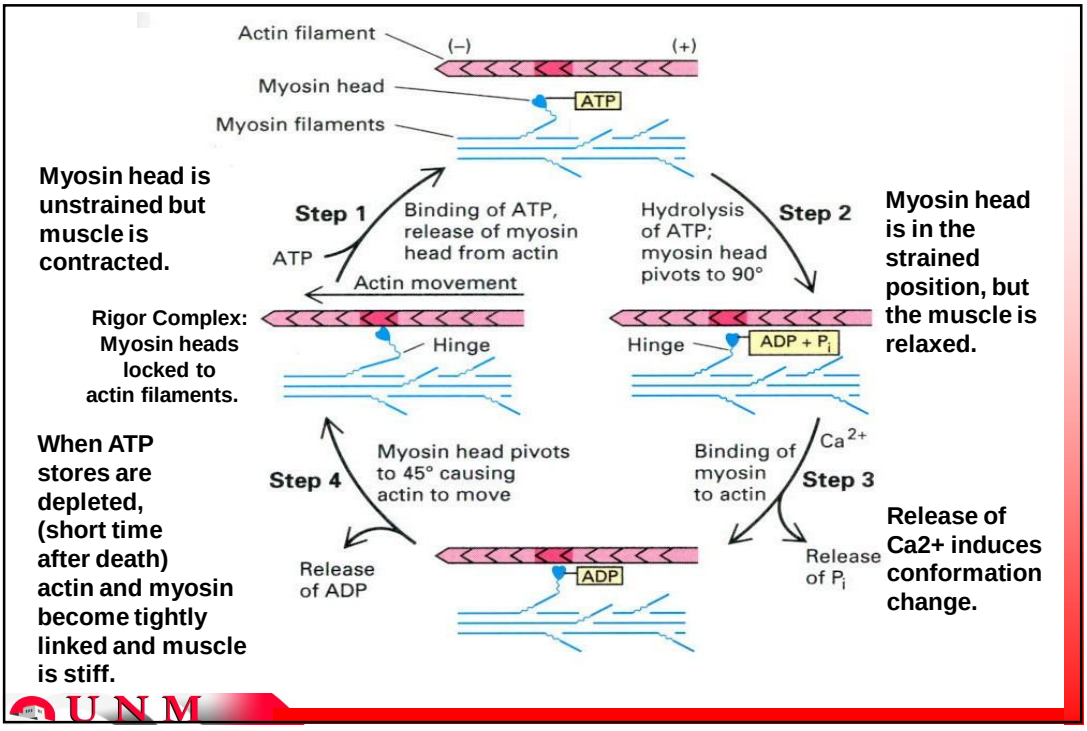

Relaxed State
ADP Pi
ADP Pi
calcium removed
calcium released
1. "Ready" Phase
Ca+2
ADP Pi
ADP Pi
Contraction Cycling
3. ATP Binding & Detachment
2. Power Stroke & ADP + Pi Release
ATP
ATP
ADP Pi
ADP Pi


Actin filament
(–)
(+)
Myosin head
ATP
Myosin filaments
Myosin head is unstrained but muscle is contracted.
Step 1
Binding of ATP, release of myosin head from actin
ATP
Actin movement
Hydrolysis of ATP; myosin head pivots to 90°
Step 2
Myosin head is in the strained position, but the muscle is relaxed.
Rigor Complex: Myosin heads locked to actin filaments.
Hinge
Hinge
ADP + Pi
When ATP stores are depleted, (short time after death) actin and myosin become tightly linked and muscle is stiff.
Step 4
Myosin head pivots to 45° causing actin to move
Binding of myosin to actin
Ca2+
Step 3
Release of Ca2+ induces conformation change.
Release of ADP
ADP
Release of Pi

The sequence of events during muscle contraction

When "relaxed" ADP and Pi are bound to the S_1 unit of myosin, and the unit is in the vertical "strained" position

1. depolarization of the sarcolemma and propagation of the depolarization down t-tubules to the sarcoplasmic reticulum.

2. depolarization of the triad region initiates the release of calcium into the cytosol.

3. calcium binds to troponin.

4. the troponin-calcium complex induces a conformational change in the actin-tropomyosin interaction, allowing myosin to bind to actin.

5. the actin-myosin binding allows the S_1 unit to move to the "unstrained" position, causing muscle contraction. During this process, ADP and Pi are released.

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The sequence of events during muscle contraction, cont'd

The binding of ATP to the S1 unit, and the immediate reaction producing ADP and Pi provides the free energy to move the S_1 unit into the "strained" position.

6. muscle contraction results from the shortening of every sarcomere in every muscle fiber of the motor units that are recruited.

7. if ATP is replenished and available, ATP binds to the S_1 unit, is broken down to ADP and Pi, and causes the S_1 unit to move to the "strained" position. ADP and Pi remain attached to the S_1 unit.

8. if calcium is still present in the cytosol due to continued neural stimulation, steps 1-7 will continue – termed *contraction cycling*.

9. Relaxation occurs when action potentials are not received at the neuromuscular junction, causing calcium to be actively pumped back into the sarcoplasmic reticulum.

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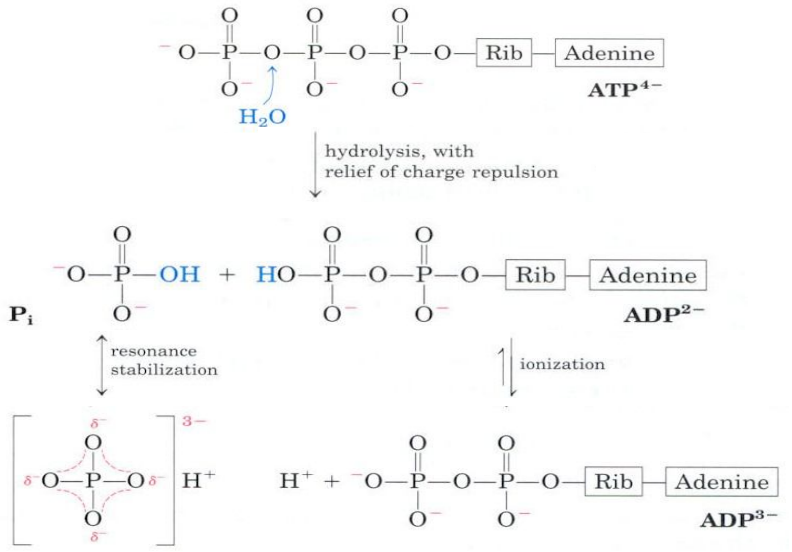
ATP Hydrolysis Releases Protons



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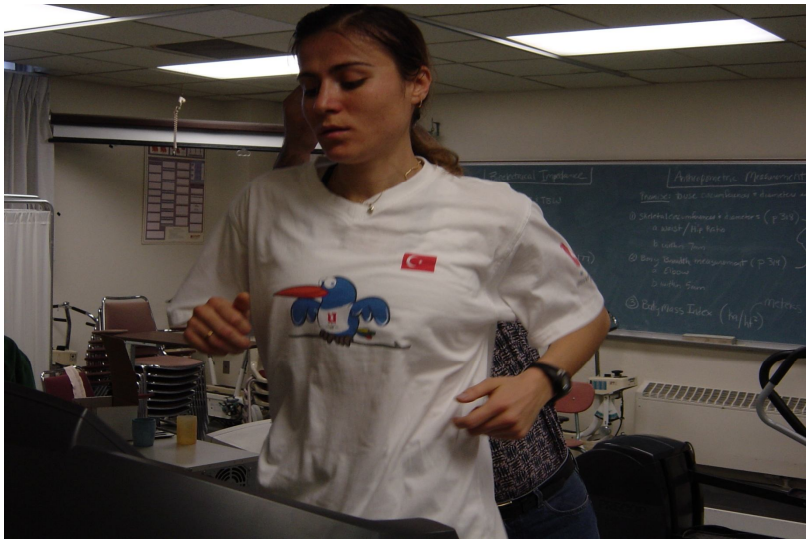
ATP Demand of Muscle Contraction Drives Cellular Energy Metabolism During Exercise



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