

INTRODUCTION

System Concept

1. Skeletal muscles -- only organs in *muscular system*
2. Heart
 - _ Essentially a muscular organ -- unique cardiac muscle
 - _ But, part of cardiovascular system
3. Smooth muscles
 - _ Not in same conceptual category as skeletal or cardiac
 - _ Always considered a secondary tissue in diverse organs

Functions

1. Movements
 - _ Most body movements
 - _ Exceptions
 - _ cilia -- e.g. tracheal lining epithelium
 - _ flagella -- sperm
 - _ amoiboid -- e.g. phagocytes
2. Prevention or limiting of movements
 - a. Prevention -- e.g. posture maintenance
 - b. Stabilization -- e.g. limiting joint movements
 - c. Blocking an opening -- e.g. sphincters
3. Heat production
 - _ Secondary importance
 - _ Greatest contributor of body heat
 - _ Highest energy requirement
 - _ Skeletal muscle produces 50% total body ATP

- _ Unique myoglobin
- _ Shivering -- only isolated example

Tissue Characteristics & Features

1. Contractility

- _ All cells can contort & shrink
- _ Muscle cells carry this to extreme -- unique
- _ Cellular linearity reflects this
- _ Highly organized intracellular components necessary

2. Conductivity

- _ All cells exhibit irritability -- respond to stimuli
- _ Muscle & nervous more highly developed
 - _ Very excitable
 - _ Respond with useful ionic changes at cell membrane
 - _ Conducted -- travels over membrane

Types of Muscle Tissue

1. Skeletal

- _ Often termed striated -- not unique
- _ Usually attach to various skeletal parts
- _ Voluntary
 - _ Under absolute nervous control
 - _ Paralyzed if controlling nerves lost

2. Cardiac

- _ Also termed heart muscle
- _ Only found in heart
- _ Striated cells, as in skeletal

- _ Involuntary
 - _ Under nervous influence only -- action only modified
 - _ Can function independently of nerves

3. Smooth

- _ Also termed visceral -- in viscera (internal organs)
- _ Also termed smooth -- cells lack striations
- _ Involuntary

GENERAL STRUCTURAL FEATURES

Skeletal Emphasis

- *Unless otherwise specified from now on only skeletal muscle will be considered*

Concepts

1. Numbers

- _ 600⁺ muscles in entire body
- _ Not all unique
 - _ Right & left for all but a few
 - _ Some repeated -- e.g. intercostals

2. Volume

- _ Women -- avg. 36% body mass
- _ Men -- avg. 42% body mass

3. Variability -- permits functional diversity

- _ Size
- _ Shape
- _ Number of parts

- _ Attachment method or angle
- _ Power
- _ Speed
- _ Skeletal cell type variations

Gross Structure

[*A muscle as an organ*]

1. Fibers

- _ Special descriptive name for muscle cells
- _ Linear & fiber-like
- _ Parallel arrangement

2. Fasciculus

- _ Bundles of fibers
- _ Subdivisions of entire muscle
- _ Size variation

3. Connective tissues

a. Endomysium

- _ Surrounds individual fibers
- _ Delicate fibrous
- _ Holds fibers in place & contains blood vessels

b. Perimysium

- _ Surrounds & separates fasciculi
- _ Fibrous, denser than endomysium

c. Epimysium

- _ Covering of entire muscle -- sheathing
- _ Dense irregularly arranged collagenous

4. Belly

- _ Muscle portion containing fibers
- _ Excludes tendons
- _ Where contractile power developed

5. Tendon

- _ For attachment of muscle ends
- _ Continuation of epi-, peri- & endomysia
 - _ Important structural & functional integrity
 - _ Direct harnessing of forces by fibers' contraction
- _ Receives force of contraction -- transmits to attachments
- _ Technically not present in some muscles [*details later*]

6. Vascular supply

- _ Abundant
- _ Necessitated by extremely high cellular respiratory needs
- _ Other related special features
 - _ Myoglobin -- carries O₂ -- similar to hemoglobin
 - _ Glycogen -- few other tissues store glucose

7. Nerve supply

- _ More extensive for voluntary muscles
- _ Contained within peri- & endomysia

8. Proprioceptor

- _ Receptor (sense organ)
- _ Relays information on contractile status to nervous system

Attachments

1. Locations

a. Bone

- _ To periosteum
- _ Majority of muscles

b. Cartilage

- _ To perichondrium
- _ e.g. pectoralis to costal cartilages

c. Skin

- _ To subcutaneous tissue
- _ e.g. orbicularis oculi

d. Mucous membrane -- e.g. orbicularis oris

e. Fascia

- _ Actually, one muscle attaching to another
- _ e.g. buccinator (to orbicularis oris)

2. Tendons

[Their shape reflects muscle belly]

- _ Cord
 - _ Round or oval in cross section
 - _ e.g. Achilles tendon of gastrocnemius

- _ Flat ribbon -- e.g. rectus abdominis
- _ Aponeurosis
 - _ Very broad & flat, sheet-like
 - _ e.g. latissimus dorsi

- _ Divided
 - _ Multiple parts, split
 - _ e.g. extensor digitorum

3. Non-tendon types

- _ Some muscles lack tendons technically
- _ Attach more or less directly
- _ Utilize collagenous fibers of epi-, peri- & endomysia
- _ e.g. intercostals

Shapes

1. Parallel

- _ Muscle fibers parallel throughout length
- _ Usually ribbon-like
- _ e.g. sternohyoid

2. Fusiform

- _ Fibers essentially parallel in middle of muscle
- _ Come together at one or both ends
- _ e.g. biceps brachii

3. Convergent

- _ Fibers at one end quite spread apart
- _ Converge sharply at other end
- _ Power converges as well
- _ Muscle triangular
- _ e.g. trapezius

4. Pennate

a. General

- _ Fibers at oblique angle to muscle's long axis

- _ Also at oblique angle to attachment structure
- _ Resembles a feather(s) or a part
- _ Develops much power with little shortening

b. Unipennate

- _ Resembles half of a feather
- _ e.g. extensor digitorum

c. Bipennate

- _ Resembles an entire feather
- _ e.g. rectus femoris

d. Multipennate

- _ Resembles two or more feathers, parallel
- _ Each portion has slightly different function
- _ e.g. deltoid

5. Circular

- _ Also termed sphincter
- _ Fibers encircle a central opening
- _ Controls size of opening
- _ e.g. orbicularis oris

6. Spiral

- _ Muscle spirally wrapped around body part
- _ Twists part around
- _ e.g. supinator

Naming

1. Location

- _ Intercostals -- between ribs

_ Pectorals -- in that region

2. Shape

Deltoid -- delta (triangle)

3. Size

Gluteus maximus & gluteus minimus

4. Fiber direction

_ Rectus muscles run straight down body's long axis

_ Oblique -- 45° to an axis

5. Number of parts

Triceps brachii -- three heads

6. Attachments

Sternocleidomastoid -- sternum to clavicle to mastoid process

7. Action

_ Adductor -- causes body part to move in

_ Levator -- lifts body part

8. Combination

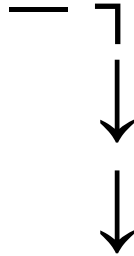
Levator scapulae ventralis

GENERAL FUNCTIONAL FEATURES

Underlying Principle

In order to accomplish any of its particular functions, a muscle

can only



PULL

. . . therefore, for complicated movements:

- _ More than one muscle required
- _ Each muscle has separate pulling role -- e.g. angle
- _ Different group combinations cycle for various needs
- _ Puppet analogy

[Note: *basic concepts now -- details later -- Mechanics*]

Parts -- Functional

1. Origin

- _ One of 2 functional ends of muscle
- _ More stable end of attachment -- more fixed

- _ Relatively less moveable during contraction

2. Insertion

- _ Opposite functional end from origin
- _ Less stable end of attachment -- less fixed
- _ Relatively more moveable during contraction
- _ If movement function occurring, happens here

3. Reasons

a. Origin

- 1) Attached to more stable bone (or other structure)
- 2) Joint design or relative location
- 3) Typically more proximally oriented
- 4) More pull from other muscles at this point

b. Insertion

- 1) Attached to more moveable bone
- 2) Joint design or relative location
- 3) Typically more distally oriented
- 4) Less pull from other muscles

4. Interchangeable roles [*many, but not all muscles*]

a. Concept

- _ At different times, reversal of stability of 2 ends
- _ Origin becomes less stable -- now called insertion
- _ Insertion becomes more stable -- now called origin

b. Causes

- _ Basically, different conditions exist
- _ Typically, other muscles accomplish changes

- less pull against previous origin
- more pull against previous insertion
- _ Other cause -- different body position

c. Example -- rectus abdominis

- _ Hips & legs held tight -- head & upper torso move
- _ Head & upper torso held tight -- hips & legs move

Action

1. Basics

a. Concept

- _ Muscle contraction exerts pulling force -- tension
- _ Influence on origin
 - tension more absorbed & resisted
 - little or no pulling force
- _ Influence on insertion
 - tension much less resisted
 - maximum pulling force

b. Possible results

- _ Isotonic
 - resistance at insertion overcome
 - insertion pulled towards origin
 - movement occurs
- _ Isometric
 - resistance at insertion too great
 - insertion held tightly

-- no movement [*explanation later*]

d. Role of bones -- act as levers

e. Role of joints -- act as fulcrums (pivot points)

f. Muscle positions

- _ Relative positioning will be logical
- _ No movement possible if directly over body part
- _ Therefore, only insertion would cross joint(s)
- _ Origin & belly -- in front of, behind, above or below

g. Cycling in groups

- _ Contracted muscle
 - pulls on its insertion
 - action performed
- _ Relaxed muscle
 - has no tension
 - cannot push part at insertion
- _ For opposite & complex movements
 - cycles of contraction & relaxation
 - different muscles involved
 - each pulls part in different direction
 - minimum group size is 2

2. Individual muscle actions

a. Agonist (prime mover)

- _ Applied to muscle producing particular action

- _ e.g. biceps brachii flexing forearm
 - origin - scapula (2 heads/tendons)
 - insertion - radial tuberosity

b. Antagonist

- _ Muscle with *potential* to produce opposite action
- _ Must be relaxed for agonist to produce action
- _ e.g. triceps brachii can extend forearm
 - origin - scapula & humerus (3 heads/tendons)
 - insertion - olecranon process

c. Interchangeable roles

- _ Triceps brachii now contracts
 - it becomes agonist
 - extension of forearm

- _ Biceps brachii
 - it now becomes antagonist
 - must be relaxed
 - gradual relaxation usually

3. Actions of more than one muscle

a. Action with no agonist(s) or antagonist(s)

[*this will explain isometric contraction*]

- _ Concept
 - simultaneous contraction 2 or more muscles
 - former agonist(s) & antagonist(s)
 - neither relaxes

- _ Result

- insertion will not move
- held tightly in fixed position
- being pulled in opposite directions

- _ Example

- holding weight out in hand
- biceps brachii contracted
- triceps brachii contracted

b. Direct synergists

- _ Cooperative agonists

- _ One action being performed by 2 or more muscles

- _ e.g. forearm flexion

- biceps brachii contracts
- brachialis contracts simultaneously

c. Indirect synergists

- _ Muscles which assist agonist(s)

- _ Do not perform same action as agonist(s)

- _ Not an antagonist

- _ Perform different action

- at another insertion point
- typically control intermediate joint
- isotonic or isometric
- necessary for effective action

- _ e.g. making a tight fist
 - flexor digitorum group co-agonists
 - extensor digitorum relaxes - antagonist
 - wrist must be held tightly - isometric
 - flexor carpi ulnaris contracts
 - flexor carpi radialis contracts
 - extensor carpi ulnaris contracts
 - extensor carpi radialis contracts
 - wrist holding not directly related to fingers

FUNCTIONAL MICROANATOMY

Fiber (Cell)

1. General

a. Shape

- _ Elongated cylinder
- _ Round in cross section
- _ Ends taper slightly

b. Size

- _ Diameter
 - 10 - 100 μm
 - some authorities dispute 100 μm , say 40 μm
- _ Length
 - 1 mm - 30⁺ cm
 - authorities disagree greatly
 - runs length of muscle's belly

c. Multinucleated

- _ Approximately 35 nuclei / mm of length
- _ Thousands of nuclei in longer cells

d. Cellular status

- _ Some authorities dispute fiber being true cell
- _ Considered as syncytium
 - multicellular mass
 - formed by fusion of embryonic cells
 - separate cell membranes lost

2. Terminology

a. General

- _ Special terms for cell structures/organelles
- _ Jargon from intense study -- not different

b. Sarcolemma = cell (plasma) membrane

c. Sarcoplasm = cytoplasm

d. Sarcosomes = mitochondria

e. Sarcoplasmic reticulum = endoplasmic reticulum

- _ Extremely elaborate
- _ Highly organized

3. Striations

a. Appearance / effect

- _ Alternate dark & light stripes
- _ Subdivide cell -- apparent partitions

b. Cause

_ Fibrils

- intracellular linear structures
- composed of smaller rod-like filaments

_ Creation of striations

- highly orderly filament arrangement
- repeats throughout cell's thickness

Fibrils (Myofibrils)

1. General

a. Volume

- _ Compose 80% of cell
- _ Remaining 20% in intervening spaces
 - sarcoplasm
 - nuclei
 - all other organelles

b. Appearance

- _ Resemble miniature of entire cell
- _ Have same pattern of striations
- _ Run length of cell

c. Alignment

- _ Perfectly parallel to each other
- _ Striations precisely aligned for all fibrils
- _ Produces illusion that entire cell striated

d. Numbers

- _ Hundreds to thousands per cell
- _ Varies with cell's diameter

e. Size

- _ Diameter -- 1 - 2 μm
- _ Length -- just as long as cell

f. Composition

- _ Primarily of rod-like filaments
- _ 2 types
 - thick
 - thin
- _ Other secondary components [*details later*]

2. Thick filaments

a. Shape & size

- _ Rods
- _ Diameter -- 150 \AA
- _ Length -- 1.5 μm

b. A-band

- _ Anisotropic -- not clear; blocks light; dark
- _ Cause
 - perfect alignment of thick filament groups
 - repeat along fibril length
 - in 1 μm thick fibril, 450 filaments / group

c. M-line

- _ Mittelscheibe = "middle of the disks"
- _ Appears as very thin dark line middle of A-band

- _ Cause
 - attachment point for thick filament groups
 - holds them in position

3. Thin filaments

a. Shape & size

- _ Thinner, smaller rods
- _ Diameter -- 60 Å
- _ Length -- 1 µm

b. I-band

- _ Isotropic -- clear; permits light to pass through
- _ Cause
 - perfect alignment of thin filament groups
 - repeat at identical intervals along fibril
 - in 1 µm thick fibril, 450 filaments / group
 - alternate with thick filament groups
 - partly overlap with thick filaments

c. Z-line

- _ Zwichenscheibe -- "between the disks"
- _ Cause
 - attachment point for thin filament groups
 - one group on either side

-- holds them in position

_ Marks boundary for sarcomere [*details later*]

4. Filament overlap

Produces H-zone

_ Hell or heller -- "bright"

_ Appears as lighter central streak in middle of A-band

_ Cause

-- where thin filaments do not overlap thick

-- contains only thick filaments

-- group of thins overlap on either side

5. Filament distribution

_ Evenly distributed

_ Precise pattern (arrangement) of thicks & thins

_ Reflects important functional relationship

_ Evident in fibril cross section, where overlap occurs

_ Any 1 thick as reference point

-- surrounded by 6 thins

-- form equal sided hexagon

-- thick in exact center

_ Any 1 thin as reference point

-- surrounded by 3 thicks

-- form equilateral triangle

-- thin in exact center

_ Thick filament centers exactly 450 A apart

_ Thin filament centers exactly 260 A apart

6. Filament numbers

Based on cell $100\ \mu\text{m} \times 1\ \text{cm}$ with $1\ \mu\text{m}$ thick fibrils

a. Thick filaments = 16.2 billion in entire cell

_ 450 thicks / group

_ 4500 groups / fibril

_ 8,000 fibrils in entire cell

b. Thin filaments = 32.4 billion in entire cell

[recall -- a thin group is on either side of thick]

Sarcomere

1. Concept

_ Portion of fibril length from any one Z-line to next Z-line

_ Included components

a. One group of thick filaments

-- A-band

-- H-zone

-- M-line

b. Two groups of thin filaments -- 2 half I-bands

_ Fibril = series of sarcomeres attached end to end

2. Importance

_ Basic functional unit of a muscle **cell**

[*contrast with motor unit below*]

- _ Contractile phenomena occur in sarcomeres
 - _ Thus, each sarcomere shortens simultaneously
 - _ Causes fibrils (so entire cell) to contract & pull

Muscle Remodeling

1. Concept

- _ Atrophy or hypertrophy
 - _ Atrophy = muscle wasting
 - _ Hypertrophy = muscle increase
- _ Strength will decrease or increase
- _ Long or short term
- _ Time -- maximum hypertrophy may take 6-10 weeks

2. Causes

- _ Decreased use
 - _ Inactivity
 - _ Immobility
- _ Increased use

3. Muscle cell changes

[*all can be either decreased or increased*]

a. Diameter -- change in number of fibrils

b. Length

- _ Change in number of sarcomeres
- _ Possible to occur at rate of several/minute

c. Fiber type -- can be modified to a slight extent

d. Enzyme systems -- will affect ATP production capability

4. Whole muscle changes

[*all can be either decreased or increased*]

a. Connective tissues

- _ Endo-, peri- & epimysia
- _ High correlation between this & muscle strength

b. Vascularity -- correlated with nutritional/gas needs

c. Diameter -- due to 3 factors:

- _ Collective cell diameter changes
- _ Connective tissue changes
- _ Vascularity changes

d. Length -- due to cellular length changes

Channel Systems

1. T-system

a. Concept

- _ This stands for *transverse*
- _ Series of intercellular hollow tubules -- sarcotubules

b. Arrangement

- _ Positioned at regular intervals along cell's length
- _ Run perpendicular (transverse) to long axis
- _ Continuous with sarcolemma
- _ All T-tubules in cell interconnected

c. Relationship with fibrils

- _ Extend into cell interior
- _ Wrap around fibrils
- _ One T-tubule forms loop around each fibril

d. Relationship with sarcomere

- _ Two loops per sarcomere
- _ Located at either outer edge of A-band

2. Sarcoplasmic reticulum

a. Concept

- _ System of hollow, interconnected channels
- _ Similar to, but separate from, T-system

b. Longitudinal division

- _ Highly interconnected, net-like tubes
- _ Run in cell's long axis
- _ Between & wrapped around fibrils
- _ Repeating pattern -- corresponds with sarcomeres

c. Terminal cisternae

- _ Continuous with longitudinal
- _ Wrapped around fibrils in pairs
 - one on either side of each T-tubule
 - thicker than T-tubules
 - no direct interconnection

d. Triad

- _ Denotes relationship between T-tubule & cisternae
- _ Important functional site [*details later*]

Nerve Supply

1. Myoneural (neuromuscular) junction

a. Motor nerve

- _ Peripheral part of nervous system
- _ Carries controlling impulses

- _ Motor implies movement

b. Nerve fiber (axon)

- _ One portion (strand) from motor nerve

- _ Extension from body of one nerve cell (neuron)

c. Axon endings

- _ String-like extensions

- _ Several to many per axon

- _ Each goes to one muscle fiber (cell)

d. Motor end plate

- _ Modified portion of sarcolemma

- _ No physical contact with ending -- 100 Å gap

- _ Membrane receptor proteins

- _ Receives chemical signal from axon ending

2. Motor unit

a. Components

- _ One axon & all of its endings

- _ All muscle cells controlled (via motor end plates)

b. Size variations

- _ Number of endings/motor end plates

- _ From 1 - 2,000

c. Arrangement

- _ Probably only one ending per muscle fiber

- _ Fibers of one unit usually not in same fasciculus

- scattered throughout muscle

- important for producing widespread effect

d. Importance

Basic functional unit of whole muscle

Smooth Muscle Differences

_ SKIP THIS _

Cardiac Muscle Differences

_ SKIP THIS _

MUSCLE PROTEINS

General

1. Extent

Muscle cells are 80% protein by volume

2. Myofibrillar

- _ Group of 4 main proteins
- _ Compose thick & thin filaments
- _ Not unique to muscle tissue -- arrangement is unique
- _ Comprise 60% of total cellular proteins
- _ Other 40% -- Misc. membrane proteins & enzymes
 - _ Misc. membrane proteins & enzymes
 - _ Same arrangement & functions as other tissues

3. Structural review [*Drawings only*]

Myosin

1. Molecular structure

- a. Size -- molecular weight 500,000 (quite large)
- b. Shape
 - _ Two identical polypeptide subunits
 - _ Tails (2) -- intertwined, more linear
 - _ Heads (2) -- globular, elongated, right angle to tails
- c. Actin binding site
 - _ Special chemically active site on each head
 - _ Will bond with actin molecules [*details later*]
- d. ATPase
 - _ Another separate active site on each head
 - _ Enzymatic -- splits ATP to ADP + PO₄ [*details later*]

2. Arrangement

- a. Location
 - _ Compose thick filaments
 - _ About 200 hundred myosin molecules per filament
- b. Appearance
 - _ Tails -- parallel, bind molecules
 - _ Heads -- project outwards
 - _ Two equal size groups
 - tails towards each other
 - heads project from opposite ends
 - no tails in mid-filament

Actin

1. Molecular structure

- a. Size -- 60,000
- b. Shape -- globular, spherical

2. Arrangement

- a. Location -- framework of thin filaments
 - _ Framework of thin filaments
 - _ 300-400 actin molecules per filament
- b. Appearance
 - _ Two strings (filaments) of actin molecules
 - _ Twisted together
 - _ Very precise -- 7 double actins per twist

Tropomyosin

1. Molecular structure

- a. Size -- 70,000
- b. Shape
 - _ Basically linear, but asymmetrical
 - _ Two helically intertwined polypeptide subunits

2. Arrangement

- a. Location -- part of thin filaments
- b. Appearance
 - _ One tropomyosin bonds with 7 actins
 - _ Corresponds to one twist of one actin filament
 - _ Conforms to shape of twist
 - _ Repeated along both actin filaments

Troponin

1. Molecular structure

a. Size -- 80,000

b. Shape

_ Globular

_ 3 non-identical spherical subunits

2. Arrangement

a. Location -- part of thin filaments

b. Appearance

_ One troponin bonds at end of each tropomyosin

_ Subunit relations [*details later*]

-- largest binds entire molecule to tropomyosin

-- middle freely binds with Ca

-- third alters troponin/tropomyosin bond

Others

1. Alpha-actinin

_ Located in Z-line

_ Probably aligns & holds thin filaments in place

_ May help transmit contractile force between sarcomeres

b. M-protein

_ Located in M-line

_ Probably aligns & holds thick filaments in place

Functional Correlations

1. Actomyosin

a. Formation

- _ Actin & myosin naturally bond
- _ Form viscous substance -- long, fiber-like strands
- _ Can even occur in non-living situation

b. ATP, Ca & Mg

- _ Energy source
- _ Catalysts

c. Shrinkage

- _ Actomyosin strands contract
- _ Become shorter & thicker

d. Tension development

- _ If strands arranged linearly & ends attached
- _ Power (tension) could cause pull

e. Significance

- _ 2 main proteins have inherent contractile ability
- _ Not dependent on being part of muscle cells
- _ Good example of body's design logic

2. Cross-bridge (head) linkage

- _ Each myosin head binds with one actin
 - _ At various times different actins bind with any one head
- [*explained later -- sliding filament cycling*]

3. Tropomyosin & troponin

- _ Roles involve modification of actin/myosin relationship
 - _ Primarily determine when contraction can occur
- [*explained later -- sliding filament initiation*]

CONTRACTION -- MOLECULAR AND CELLULAR

Sliding Filament Theory

1. Concept

- _ Thin filaments of each sarcomere slide during contraction
- _ Increases overlap with thick filaments
- _ Each of 2 sets of thins sliding towards each other
- _ Caused by pull of thick filaments

2. Force

a. Cross-bridges (myosin heads)

- _ Develop energy for pulling thin filaments
- _ Recall binding to actins

b. Swiveling

- _ Heads undergo movement
- _ Change in position

c. Pulling

- _ Swiveling produces pulling action
- _ Slides thin filaments towards middle of sarcomere

3. Cycling of cross-bridges

a. General

- _ Each head undergoes repeating cycle
- _ About 180,000 heads per sarcomere

- _ Recall

-- each thick contacts 6 thins

-- each thin contacted by 3 thicks

b. Attachment

- _ Head binds with one actin molecule
- _ Goes into active configuration [*details later*]

c. Swiveling

- _ Head undergoes movement
- _ Sort of power stroke
- _ Exerts its share of pull on thin

d. Detachment -- head breaks loose from this actin

e. Reattachment

- _ Head binds to different actin
- _ Farther down thin filament -- towards Z-line

f. Asynchronous

- _ All heads of sarcomere **not** synchronized
- _ At any moment -- different heads in all cycle stages
- _ Produces smooth & constant pulling of thins
- _ Rope climbing analogy

4. Results

a. Filament overlap increases

b. Sarcomere shortening

- _ Decreased to 60% (max.) of relaxed length
- _ In each of several thousand per fibril
- _ In each of hundreds - thousands fibrils per cell
- _ Sarcomere attachment causes total shortening

- _ Actual contraction of cell -- source of tension

c. Changes in sarcomere banding

- _ Z-lines closer together
- _ A-bands same length
- _ H-zone less wide
- _ I-bands more narrow -- could disappear

d. Limiting factors

- _ Thin filaments never touch M-line
- _ Z-lines contact thick filament ends
- _ Prevents more filament sliding

5. Energy coupling

a. General -- source & means of cycling steps

b. ATP-binding -- ATP molecule bonds to myosin head

c. ATPase

- _ Recall this myosin head active site
- _ Catalyzes splitting ATP to ADP + PO_4

d. Energized head -- used for swiveling & pulling

e. Detachment

- _ Requires another ATP molecule
- _ Split by ATPase
- _ Energy forces head to break away from actin

f. Recycling

- _ Above (b - d) continues
- _ Limiting factors will stop recycling
 - Z-lines hitting thick filament ends
 - ATP running out

g. Calcium dependency

- _ Cycling only occurs if Ca level sufficient
- _ [*details below*]

Initiation

1. Excitation

a. Nerve fiber stimulation

- 1) Nervous impulse conducted down axon endings
- 2) Transmitter release
 - chemical substance from ending tip
 - diffuses across gap to motor end plate
- 3) Motor end plate
 - receptors affected by transmitter
 - depolarization of membrane

b. Conduction of depolarization

- 1) Over sarcolemma
 - from motor end plate depolarization
 - depolarization wave spreads out
- 2) Along T-tubules
 - conducted wave from sarcolemma
 - continues into cell interior
- 3) Terminal cisternae
 - wave reaches triads
 - stimulation of cisternae

2. Excitation-contraction coupling

- a. Calcium released from cisternae
 - _ Stimulation made membrane more permeable
 - _ Diffuses out from more concentrated interior
- b. Troponin binding
 - _ Ca level now elevated around filaments
 - _ Troponin subunit attracts Ca
- c. Troponin altered -- shape change from Ca addition
- d. Tropomyosin alteration
 - _ Troponin causes cooperative shape change
 - _ Tropomyosin slides over its 7 actins
- e. Effect on myosin heads
 - _ Special area on actins now exposed
 - _ Myosin heads move over into this site
 - _ Heads can only swivel & pull here

3. Filament sliding

- _ Only now can this occur
- [*cycling & sliding covered previously*]

Relaxation

1. Calcium influence

- a. Pumped back into cisternae
 - _ Ca forced away from troponin
 - _ Actively transported into longitudinal reticulum
 - _ Returned to interconnected terminal cisternae
- b. Myosin head inhibition
 - _ Troponin returns to original shape
 - _ Reciprocal change in attached tropomyosin

- _ Active sites on actins again blocked

2. Muscle relaxation

a. Filament sliding stopped

- _ Heads can no longer attach at active sites
- _ Halts cycling & pulling

b. Lengthening

- _ Contractile power (tension) removed
- _ Filaments can be pulled back out
- _ Lengthens sarcomeres/fibrils/fibers

c. Elastic elements

- _ Filaments can only actively slide together
- _ Lengthening (relaxation) caused by other parts
- _ These are elastic elements [*details later*]
- _ Were compressed during contraction by tension
- _ This stored energy used to pull filaments out
- _ By association entire muscle back to resting length