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. Major

    a. Movements

        -- Most body movements

        -- Exceptions

            -- cilia -- e.g. tracheal lining epithelium

            -- flagella -- sperm

            -- amoeboid -- e.g. phagocytes

    b. Prevention or limiting of movements

        --Prevention -- e.g. posture maintenance

        --Stabilization -- e.g. limiting joint movements

        --Blocking an opening -- e.g. sphincters

2. Minor

    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. Fasciculi

-- 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 O_2 -- 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. zygomaticus

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. pronator teres

7. Multiple (Divided)

--e.g. Serratus Anterior

Naming

1. Location

-- Intercostals -- between ribs

-- Pectorals -- in that region

2. Shape

Deltoid -- delta (triangle)

3. Size

Gluteus maximus & gluteus minumus

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

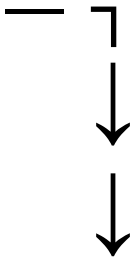
8. Combination

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*]

c. Role of bones -- act as levers

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

e. 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

f. 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 A

-- 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

-- Mittlescheibe = "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 A

-- 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 µm x 1 cm with 1 µm 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

[Example of homeostasis, as in bone]

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 – splitting (like DNA replication)

b. Length

-- Change in number of sarcomeres

-- Possible to occur at rate of several/minute

--Stimulated by stretching

c. Fiber type -- can be modified to a slight extent [explained later]

d. Enzyme systems

-- will affect ATP production capability

--e.g. glycolytic

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 A 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 <u>whole muscle</u>

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 -- <u>arrangement</u> 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 + PO_4 [*details later*]

2. Arrangement

a. Location

-- Compose thick filaments

-- About 200 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

-- only 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 Process

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