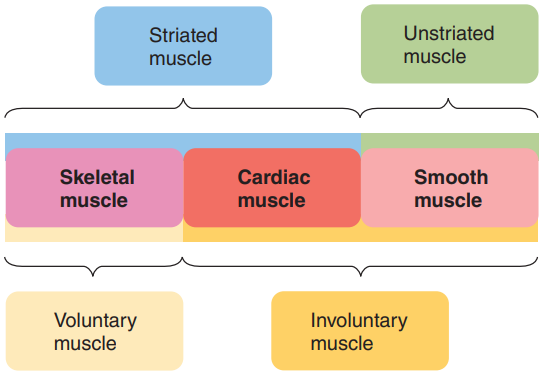
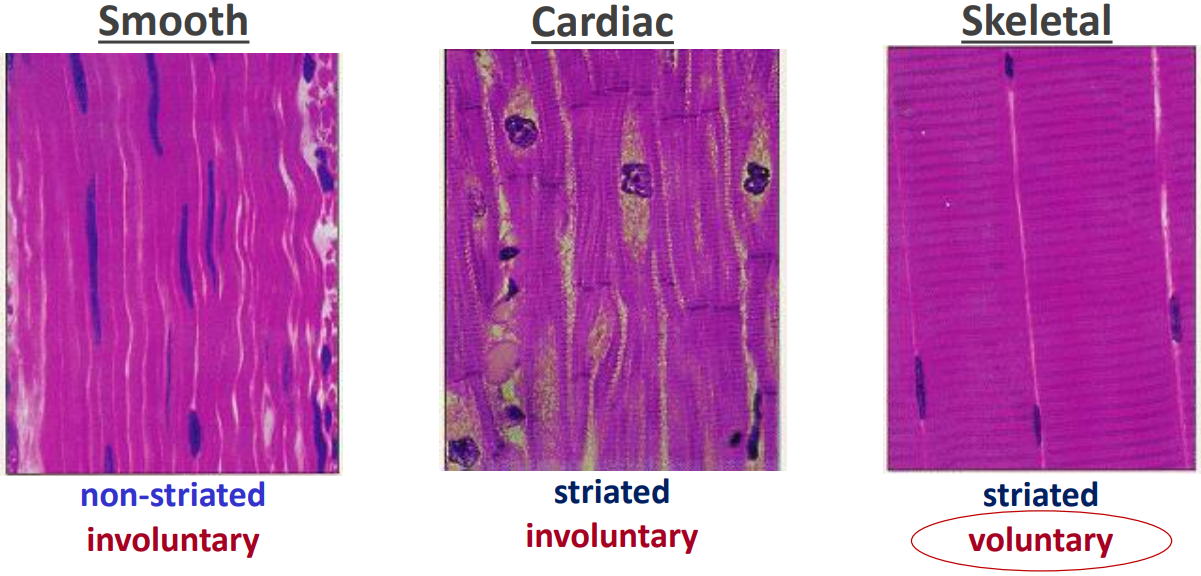
**Muscles**

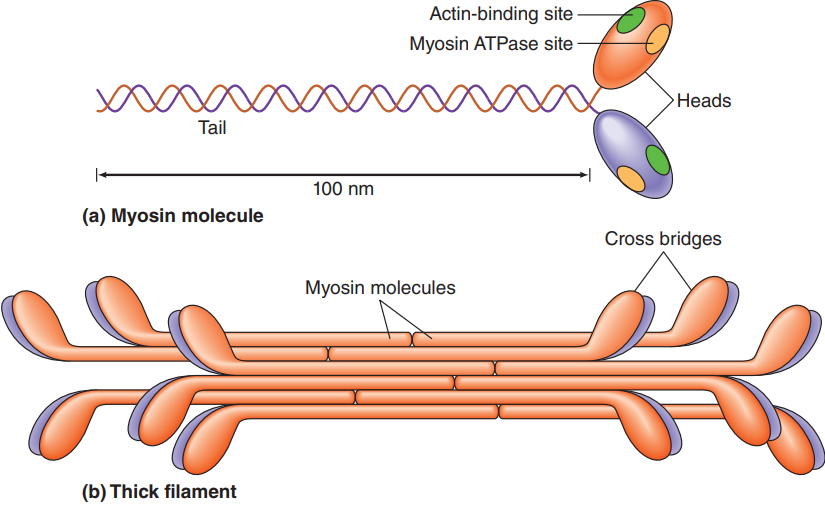
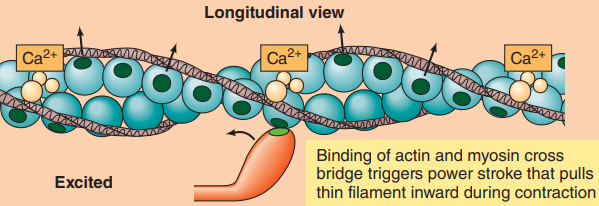
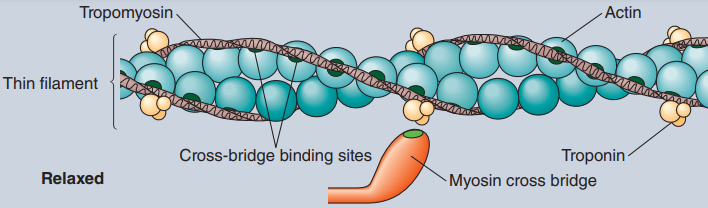
* **Muscle cells**: abundance of mitochondria, excitable, contractile, extensible, elastic
* **Striated**: whether alternating dark and light bands can be seen under microscope
* **Voluntary** (somatic nervous system) vs. **involuntary** (automatic)
* Skeletal muscle ~ 40%, smooth (STOVE) and cardiac 2 ~ 10%

**Structure of Skeletal Muscle**

* Connective tissues: epimysium (whole muscle) => perimysium => endomysium (per cell)
* **Sarcolemma**: cell membrane of muscle cells
* Satellite cells: attached to muscle cells, muscle stem cells used for repair
* **Myofibril structure**: **Thick** and **thin** filaments, **myosin** and **actin** (contractile proteins)
  + **A band** (dark, anisotropic/scatters light): thick + thin filaments
  + **I band** (light, isotropic/light passes through): thin filaments only
  + **H zone**: thick filaments only; **M line**: proteins holding thick middle of H zone
  + **Z line**: proteins holding thin filaments middle of I band
  + **Titin**: spring like protein form M to Z line both directions, helps restoration
  + **Sarcomere** (functional unit): Z line to Z line, smallest contractable unit
    - Muscle growth: adding sarcomeres to ends of myofibril
  + Thick filaments have **cross bridges** (myosin heads), extending **hexagonally** corresponding to thin filament arrangement, as a result thick arrange **triangularly**
* **Diagram, schematic

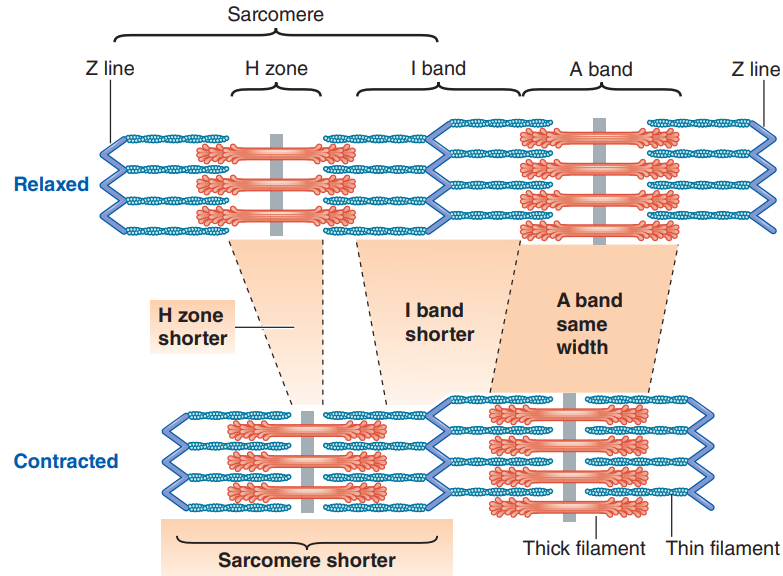
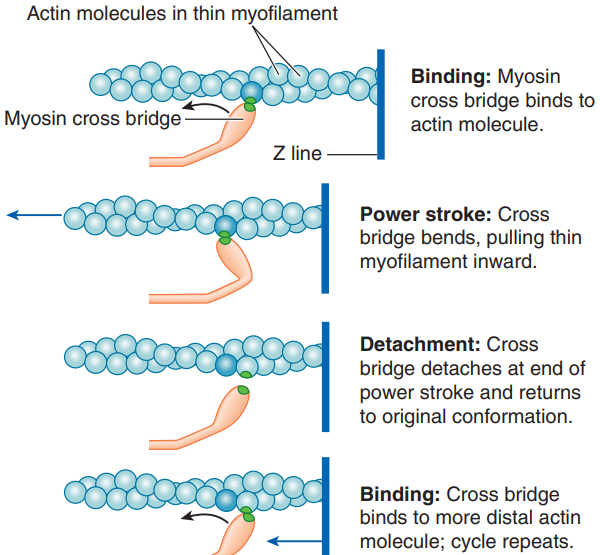
  Description automatically generatedSarcoplasm**: cytoplasm in muscle cell
* **Sarcoplasmic reticulum**: specialized ER for Ca2+ storage
* Fusion of **myoblasts** results in **multinucleated** muscle fibres

**Contractile Proteins**

* **Myosin**: protein packed into thick filaments with tail in center and head outside
  + Each head (cross bridge) has two important sites for contraction:
    - **Actin-binding** site: binds to actin for contraction (power stroke)
    - **Myosin ATPase** (ATP-splitting) site: ATP => ADP + P
    - Rate of ATPase activity on head => muscle fibre typing
* Actin, tropomyosin, and troponin: made thin filaments, actin is primary structure
  + **Actin**: spherical, backbone of a thin filament => two strands twisted together
    - had binding site myosin cross bridge => result in contraction
  + Regulatory proteins:
    - **Tropomyosin**: wraps around actin backbone
    - **Troponin:** each polypeptide unit binds to actin, tropomyosin, and Ca
    - Calcium triggers troponin to move away from blocking position, each troponin affects seven actin sites

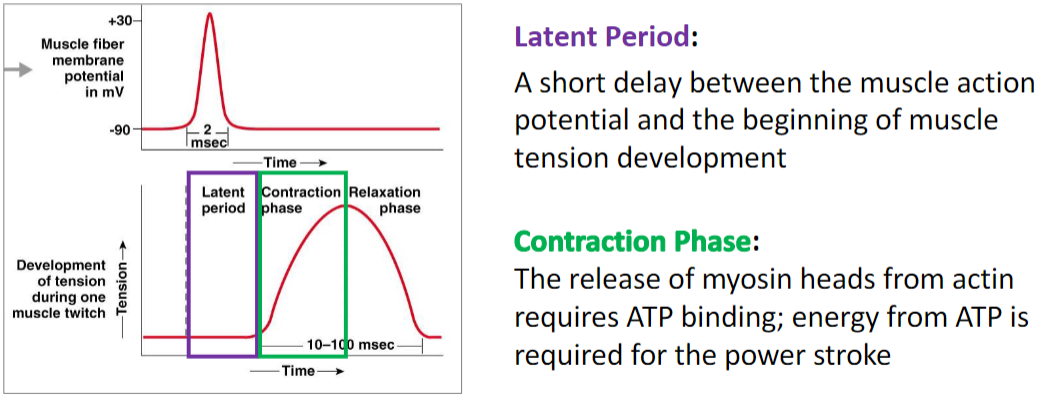
**Molecular Basis of Skeletal Muscle Contraction**

* **Sliding filament mechanism** through **power strokes**
  + myosin heads repeatedly attach to actins and pull inwards (power strokes), so thin filaments slide inwards towards M line (concentric contraction / sliding filament)
    - 6 heads stroke **asynchronously** (prevent bouncing back between strokes)

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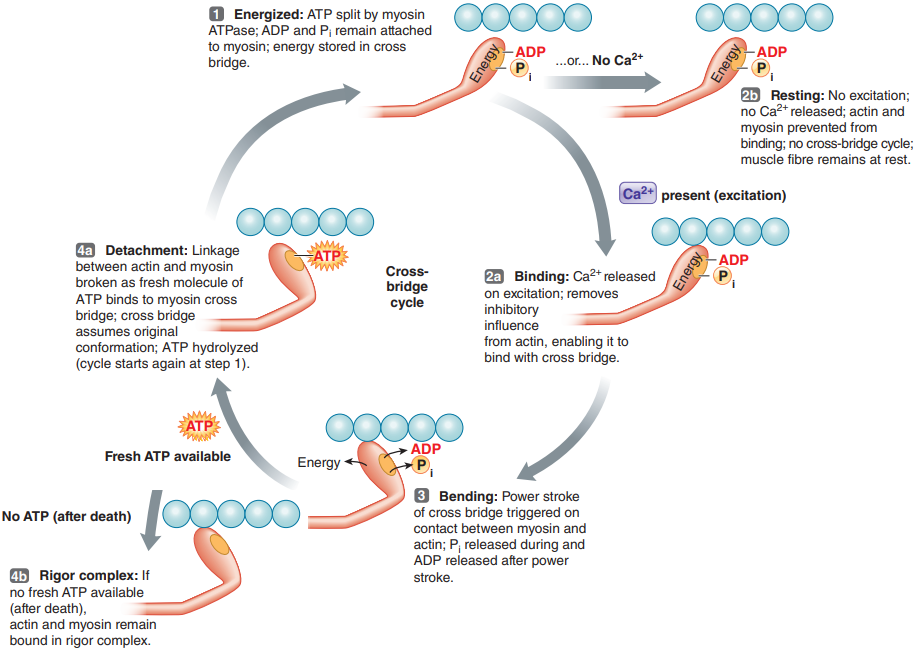
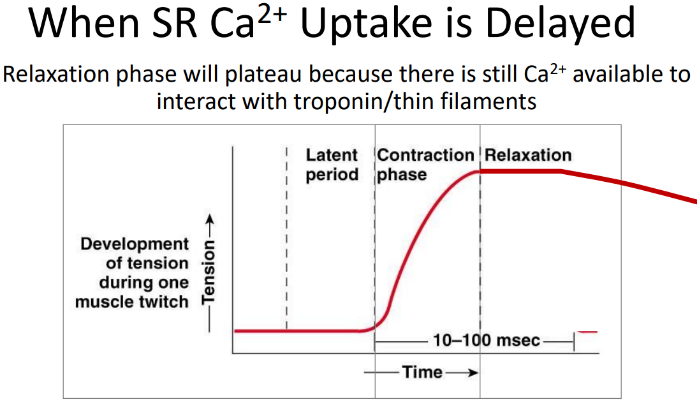
**Neuromuscular Junction**

* CNS => Somatic PNS => motor neurons => NMJ => skeletal muscle fibres
* Motor neuron axon **loses myelin**, divides into many **branches**, and forms neuromuscular junction with one of the many muscle cells / fibres in the whole muscle
  + **Terminal button**: knoblike structure of the axon terminal
  + **Motor end plate**: muscle cell membrane immediately under terminal button
    - **End-plate potential** (EPP): excitatory graded potential, much larger
      * More neurotransmitter released
      * Larger surface area and higher density of receptors
      * More channels open in respond to acetylcholine binding
    - magnitude of 1 EPP triggers AP (one-to-one from neuron to muscle)
  + EEP brings action potential in rest of muscle fibre, NMJ usually in middle
    - Action spreads from middle outwards => contraction!
* **Acetylcholine**: NT in NMJ, destroyed by acetylcholinesterase
* **Acetylcholinesterase** (AChE):
  + Constant relaxation, ACh only binds briefly
  + As soon as ACh (neuron AP) stops, muscle relaxes
* **ONLY excitatory**, inhibition must be in CNS

**Excitation–contraction coupling:**

* Diagram

  Description automatically generatedA picture containing text

  Description automatically generatedlinks muscle excitation (AP) to muscle contraction
* **Transverse tubules**: transport AP down to myofibrils, trigger SR
  + **Dihydropyridine receptors**: voltage-gated, binds to foot proteins on SR, triggers lateral sacs to release Ca2+
* **Sarcoplasmic reticulum** (SR): modified ER, release Ca2+ after transverse tubules trigger
  + SR has Ca–ATPase pump, which transports Ca2+ from cytosol back to lateral sacs
  + Ca2+ allows binding, removal of Ca2+ allows relaxation
* **Cross-bridge cycling**: key factor is myosin ATPase & ATP
  1. Breakdown of ATP (energy) occur before biding to actin, “energetic/ready to fire”
  2. Energy released causes myosin head to swing on to actin ahead
  3. Phosphate released during power stroke, ADP after, myosin stroke and pull actin
  4. When P and ADP are released, ATPase ready for another ATP, still attached
  5. ATP binding triggers detachment, go back to 1 (split ATP & bind to actin again)
* **Relaxation**: SR actively takes up Ca & AChE takes up ACh (no contraction is relaxation)
  + Will not occur if calcium is pumped back to SR
* **Rigor Mortis**: stiffness due to lack of ATP to break crossbridges
  + When dead SR breakdown and release calcium
  + After ~36-60 hrs subsides because myosin heads break down by enzymes

**Whole Muscle Mechanics**

* **Whole muscle**: contains many (hundreds of thousands) muscle fibres, layers of connective tissues extend to form **tendons** which attach to bones
  + **Twitch**: contraction from single AP => single contraction-relaxation cycle
* Contraction of whols muscle depends on mainly **number** of fibres and **frequency**
  + \*Number of fibres contracting - **motor unit recruitment**
    - **motor unit**: motor neuron + all fibres it connects to
      * single fibre type, motor neuron secretes differentiation growth factor during embryonic development
    - **size principle**: larger motor unit, harder to activate, stronger tension
    - **asynchronous recruitment of motor** units prevents **fatigue**
      * slow-twitch more resistant to fatigue
  + \*Frequency of stimulation
    - **Twitch summation**:similar to temporal summation of EPSPs
      * possible since duration of AP << duration of twitch
      * twitch summation for a submaximal force => ~8-12 Hz
      * **Tetanus**: ~60 Hz, no time to relax – sustained maximal contraction, soon fatigues
        + **Fused** (continuous max) vs **unfused** (with some relaxation)
      * Maximal contraction = enough Ca to keep all actin sites open
  + \*Length of the fibre (at the onset of contraction)
    - **Optimal length** (): when thin filaments overlap all myosin heads, maximal force on next tetanic contraction (~quadratic graph)
      * In the body, relaxed length ~ optimal length
      * > : some heads can’t reach actin
      * < : actin overlaps, no room for pulling, less Ca release & bind
    - **Passive tension:** exponential increase when stretched too far (unrealistic)
* **Series-elastic components**: noncontractile tissues, spring between tension-generating elements (fibres) and bone
* Muscle connects by tendons to at least 2 different bones across a joint
  + **Origin**: stationary end of muscle
  + **Insertion**: moving end of muscle
  + Muscles, bones, and joints functions as lever
* Antagonistic muscle pair consists of a **flexor** and an **extensor**
  + Ex: hamstring & quadricep, bicep & tricep
* Types of contractions:
  + Single fibre: **isotonic** (constant tension) vs **isometric** (constant length) vs other
  + Whole muscle: **static** (constant length, isometric) vs **dynamic** (moving)
    - **Concentric**: tension during shortening motion (lifting), slower with load
    - **Eccentric**: tension during lengthening (putting down), faster with load
* Velocity of shortening
  + Concentric: slower with load
  + Eccentric: faster with load
    - **Delayed onset muscle soreness**: caused by muscle damage from breaking cross bridges of actin & myosin molecules during eccentric with load
* Dynamic contractions create heat => warms the body

**ATP Supply**

* Amount of ATP in a cell is only enough for 8 twitches
* **Substrate-level** (direct transfer of phosphate) vs **oxidative** (ETC) phosphorylation
* Contraction compresses blood vessels and decrease oxygen supply
* When aerobic metabolism pathway (main source is ETC) is not enough, relies on:
  + **Creatine Phosphate**: first energy store, transfer high energy phosphate to ADP
    - Obtained from liver, kidney, and eating meat
    - Creatine and creatinine (formed from the metabolism of creatine) waste is removed through kidneys and urinary system
  + **Fermentation** (aerobic glycolysis): produces **lactic acid**
    - **Lactic acid**: high acidity, metabolic disruptions, burning sensations
    - **Cori Cycle**: lactic acid is removed by
      * Diffusing into blood stream
      * Can be used by liver, kidney, and **heart**
      * Converted back to pyruvic acid by **liver**
* Fatigue
  + **Muscle fatigue** (peripheral fatigue): muscles no longer respond to stimulation with same degree of contraction
    - Defence mechanism, protects from inability to produce ATP (rigor mortis)
  + **Central fatigue**: CNS no longer adequately activates motor neurons while muscles can still perform, often physiologically based
* Muscle fibre types within a single motor unit
  + **Slow-twitch (type I) vs fast-twitch (type II)**: depends on motor input & ATPase
    - Type I – motor neurons, smaller => lower threshold & transmission; slow form ATPase (isoforms has same protein but alternative splicing)
    - Type II – motor neurons, larger => higher threshold & transmission; fast form ATPase
  + **Glycolytic** (anaerobic) vs **oxidative** (aerobic): continuum
    - **Type I –** slow oxidative
    - **Type II -** fast oxidative glycolytic or fast glycolytic
    - **Red fibre** / oxidative fibres: both slow and fast, abundance of mitochondria and myoglobin (iron-oxygen & red like haemoglobin)
    - **White fibre** / fast glycolytic: specialized for glycolysis, few mitochondria but many glycolytic enzymes and glycogen (branched strand of glucose)

Table

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**Fibre Adaptation**

* **Plasticity**:adapt over time given the type of exercise they endure, through
  + **ATP synthesis capacity** (aerobic exercise)
    - Increased number of mitochondria (i.e., ATP)
    - Increase in the capillary supply (i.e., improved O2 delivery)
  + Changes in **fibre diameter** (resistance training)
    - **hypertrophy** (thicker fiber) not hyperplasia (split, more fibres)
    - **Satellite cells**: oversee myocyte maintenance, donate DNA for repair
    - Inflammation: contain, repair, and clean-up damage
    - Hormone: growth hormone (GH) increases muscle mass via sarcomere hyperplasia, also stimulates liver to promote satellite cell activation; • stimulate insulin metabolism and protein synthesis
    - Myofibrils versus sarcoplasm hypertrophy: want to increase myofibrils, start with increasing cytoplasm
  + **Atrophy** (loss, often due to disuse) vs **dystrophy** (muscle-destroying diseases)
  + **Regeneration**:
    - Skeletal limited & cardiac bad due to scars forming
    - Smooth muscle and tendons replenish themselves more efficiently

**Neural Control**

* Input at 3 levels:
  + Spinal cord (afferent neurons; spinal reflexes)
  + Primary motor cortex (discrete, intricate movements of the hands)
  + Multi-neuronal motor system (originates in brain stem but influenced by cerebellum, basal nuclei and cerebral cortex)
* Adjust upon continuous afferent input (sensory receptors):
  + **Proprioceptors** –sensitive to pressure and tension in joints, muscles, and tendons, which communicate with the nervous system to perform coordinated movements
  + **Muscle spindles** – proprioceptors that run parallel to muscle fibers, and provide information on muscle length or change in length. load => longer => contract
  + **Golgi Tendon Organs** – proprioceptors in tendons that inhibit a motor neuron if a tendon is overstretched, causing the muscle to relax
* **Spasm** (single muscle suddenly and involuntarily contracts) vs **cramp** (when it hurts)