

Motor Unit: The Nerve-Muscle Functional Unit

- Neuron
 - Functional unit of the nervous systems
- Cell that communicates to others (neurons or targets) via the release of neurotransmitters
- Nerve
 - Bundles of axons (electrical signal relaying portions of neurons)
- Ex: Sciatic nerve

Motor Unit

- Muscle fibers that are part of a motor unit are found spread throughout a muscle
 - A single motor unit activation typically causes weak contraction of that muscle
- However, when activated, only the muscle fibers of that motor unit in that muscle are contracting
- Motor units in a muscle usually contract asynchronously (not at the same time)
 - helps prevent, or decrease, overall muscle fatigue

Graded Muscle Responses

- Muscle contractions exhibit graded responses
 - Varying strength of contraction for different demands
- Required for proper control of skeletal movement
- Responses graded by
 - 1.Changing frequency of stimulation
 - 2.Changing strength of stimulation
- More so, applies to activation of additional motor units activating more muscle fibers in a muscle
- APs in motor neurons and muscle fibers do not increase in strength

Response to Change in Stimulus Frequency

- Wave (temporal) summation
 - Increased stimulus frequency (muscle does not completely relax between AP stimuli) second contraction of greater force
- Additional Ca²⁺ release from SR with second stimulus stimulates re-unblocking of myosin binding sites and more shortening before full relaxation length is obtained
- Continued temporal stimulus frequency unfused (incomplete) tetanus
 - Produces sustained, but quivering, contraction that increases in successive twitch maximum tension
- Once again, to a point

Tension Increase due to Frequency Increase

- Why continued:
 - During tetanic contraction, the successive APs each release Ca from the SR before much of the Ca from the previous AP can be pumped back into the SR.
 - This results in persistent elevation of sarcoplasmic Ca concentration
 - »This prevents a decline in the number of available binding sites on the thin filaments by keeping them unblocked
 - Results in many more cross-bridges formed and power strokes which equals more tension
 - Another cause
 - Lower tension in single twitches are also a result of the elasticity of muscle tendons and the protein Titan
 - These must stretch/compress before tension produced from the contractile units is transferred
 - »Like a bungee cord or spring

Tension Increase due to Frequency Increase (cont)

- Because a single twitch is so brief, the cross-bridge activity is already declining before force has been fully transferred through the elastic structures
 - This is less of a factor during tetanic stimulation because of the long duration of cross-bridge activity and force generation

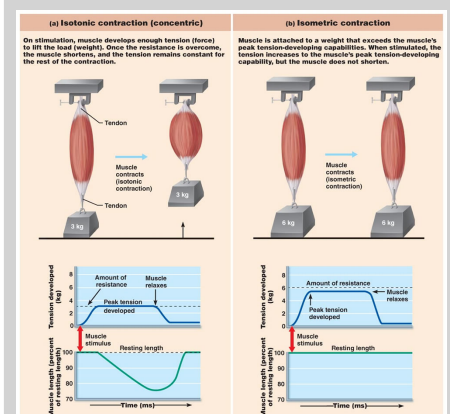
Response to Change in Stimulus Strength

- Recruitment works on size principle
 - Motor units with smallest muscle fibers recruited first
 - Motor units with more, and larger, fibers recruited if more force is required
 - Largest motor units activated only for most powerful contractions where maximal force is needed

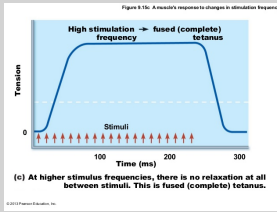
Isotonic Contractions

- Muscle changes in length and moves load
 - Thin filaments slide
- Isotonic contractions either concentric or eccentric:
 - Concentric contractions
 - muscle shortens and does work
 - Eccentric contractions
 - muscle generates force as it lengthens
- The negative rep

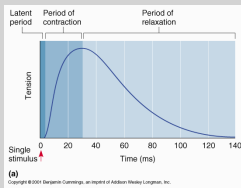
Isotonic (concentric) and isometric contractions



Response to Change in Stimulus Frequency

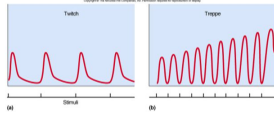


Muscle Twitch



Twitch and Treppe Contractions

Twitch and Treppe Contractions



- **Muscle stimulation at variable frequencies**
 - low frequency (up to 10 stimuli/sec)
 - each stimulus produces an identical twitch response
 - moderate frequency (between 10-20 stimuli/sec)
 - each twitch has time to recover but develops more tension than the one before (treppe phenomenon)
 - calcium was not completely put back into SR
 - heat of tissue increases myosin ATPase efficiency

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Motor Unit: The Nerve-Muscle Functional Unit

- Each muscle connected to at least one motor nerve
 - Motor nerve contains axons of a few to hundreds of motor neurons
 - Individual axon of a motor neuron can branch many times before ending at nerve terminals, each nerve terminal making a NMJ with a single muscle fiber
- Motor unit = motor neuron and all (four to several hundred) muscle fibers it innervates (controls)

Muscle Twitch

- Motor unit's response to single action potential of its motor neuron
 - Results in an AP in the muscle fibers connected through NMJs with that neuron
 - Produces short period of motor unit's muscle fiber contraction that generates tension
- Different strength and duration of twitches in whole muscle can be observed
 - Due to variations in metabolic properties and enzymes between muscle fiber types
 - Different whole muscles have differing ratios of muscle fiber types • Simplest contraction (twitch) observable in lab
 - The tension (force) generated can be recorded by a sensor and graphed as a myogram

Contraction Strength of Twitches

- Threshold stimuli produces twitch
 - "Muscle fiber obeys an all-or-none law" contracting to its maximum or not at all
 - not a necessarily a true statement since twitches can vary in strength
 - depends upon Ca^{2+} concentration, previous stretch of the muscle, temperature, pH, and hydration
 - AP (action potential) in muscle cell occurs much faster than actual contraction
 - 2 milliseconds vs. up to 100 milliseconds respectively
 - Thus a second AP may be initiated during the period of mechanical activity of the muscle fiber

Response to Change in Stimulus Frequency

- If successive stimuli are given quickly enough, muscle reaches maximal tension
 - fused (complete) tetanus results
 - Smooth, sustained contraction
 - No muscle relaxation due to consistently high sarcoplasmic Ca^{2+} from continued release from SR
 - Muscle fiber reaches sustained maximum tension
 - Will eventually lead to muscle fatigue as metabolites accumulate and ionic imbalances form
 - During fatigue, muscle cannot contract and tension returns toward zero

Response to Change in Stimulus Strength

- Recruitment (multiple motor unit summation) controls force of contraction of a whole muscle
 - Subthreshold stimuli
 - a stimulus that is too weak to illicit activation of any motor units in a muscle
 - no observable contractions or tension
 - Threshold stimulus: the stimulus strength that causes first observable muscle contraction (activation of a motor unit) and generation of tension
 - Maximal stimulus
 - strongest stimulus that increases contractile force of whole muscle to its maximum

Principles of Muscle Mechanics

- Same principles apply to contraction of a single fiber as well as the whole muscle
 - Contraction produces muscle tension
 - Force exerted on load or object to be moved
 - Force and duration of contraction vary in response to stimuli of different frequencies and intensities
 - Contraction may, or may not, shorten muscle

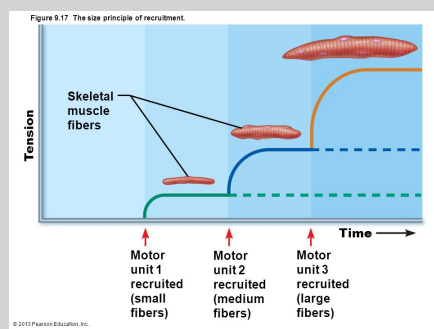
Principles of Muscle Mechanics (cont)

- Isometric contraction
- Isotonic contraction

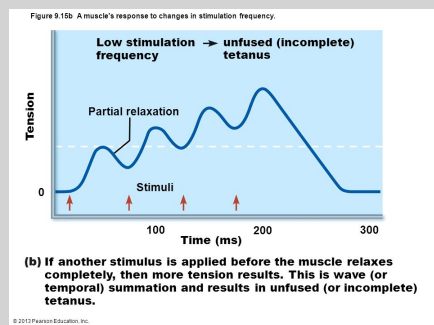
Isometric Contractions

- Load greater than tension muscle can develop
- Tension increases to muscle's capacity, but muscle neither shortens nor lengthens
- Cross bridges generate force but do not move actin filaments

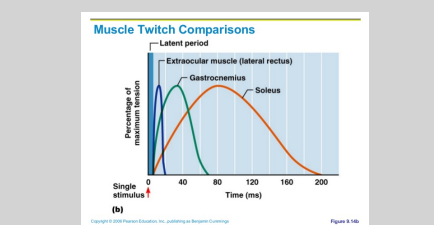
The size principle of recruitment



Response to Change in Stimulus Frequency



Muscle Twitch



Motor Units

- Fine control
- Produce small, finely controlled movements
- small motor units can contain as few as 10-20 muscle fibers
- eye muscles
- Larynx muscles
- Strength control
- Produce large, strong movements
- gastrocnemius muscle can have as many as 2000 muscle fibers in a motor unit

Muscle Twitch

- Three phases of muscle twitch
- Latent period: events of excitation-contraction coupling
- Action potential must cause all of the events we discussed in the previous lectures for muscle fibers to shorten
- no "visible" shortening or tension of the muscle
- Period of contraction: sarcomere shortening from cross bridge formation and power stroke produce visible tension (External tension)
- Visible shortening and tension of muscle
- Period of relaxation: Ca²⁺ reentry into SR; tension declines to zero
- Muscle contracts faster than it relaxes

Twitch and Treppe Contractions

- Muscle stimulation at variable frequencies of APs-low frequency (up to 10 stimuli(AP)/sec)
- each stimulus produces an identical twitch response
- Max tension produced from each twitch remains equal

Twitch and Treppe Contractions (cont)

- moderate frequency (between 10-20 stimuli/sec)
- each twitch has time to recover but develops more tension than the one before (treppe phenomenon)
- Not enough time between stimuli for sarcoplasmic calcium to return to full resting levels
- »thus calcium not completely put back into SR
- Increase in sarcoplasmic Ca²⁺ concentration with each successive AP stimulation = longer unblocking = more cross bridge formation and power strokes= increase in tension produced
- »...To a certain point

Tension Increase due to Frequency Increase

- Why is tetanic tension so much greater than single twitch tension?
- Isometric tension produced by muscle fiber at any moment depends mainly on the total number of cross bridges undergoing power stroke.
- A single AP in a skeletal muscle fiber briefly releases enough calcium to saturate troponin C making all of the myosin sites on the thin filament initially available.
- However, the binding of the energized myosin head to the myosin binding site takes time
- During this time, the Ca that was released by the SR is being pumped back into it by the SR calcium ATPases (SERCA pumps)
- Thus, after a single AP and Ca release, the sarcoplasmic Ca concentration begins to decrease and the troponin/tropomyosin complex starts to re-block a lot of the binding sites before many of the actin/myosin cross-bridges can be formed

Response to Change in Stimulus Strength

- During recruitment, muscle contracts more vigorously as stimulus strength increases above threshold
- This applies to stimulation of the motor nerve with an electrode that applies voltage
- Shocking the motor nerve
- Contraction force of whole muscle precisely controlled by recruitment
- Recruitment (multiple motor unit summation)
- Used to increase the force of a muscle contraction by activating additional motor units of that muscle
- Each muscle fiber capable of generating a certain amount of force
- More active motor units = more muscle fibers shortening and pulling = more force generation
- Beyond maximal stimulus no increase in force of contraction
- Why?

Principles of Muscle Mechanics

- Contraction may/may not shorten muscle
- Isometric contraction: no shortening; muscle tension increases but does not exceed load
- Same length
- Isotonic contraction: muscle shortens because muscle tension exceeds load
- Same tension, or tone, once load exceeded

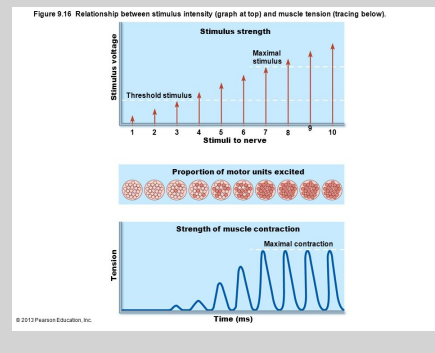
Muscle Tone

- Constant, slightly contracted state of all muscles
- Due to spinal reflexes

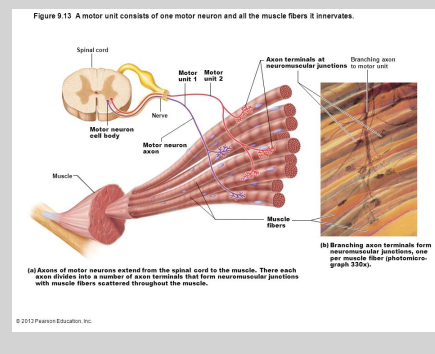
Muscle Tone (cont)

- Groups of motor units are alternately activated in response to input from stretch receptors in muscles
- Keeps muscles firm, healthy, and ready to respond

stimulus intensity and muscle contraction



Response to change in Stimulus



Contraction Strength of Twitches

