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

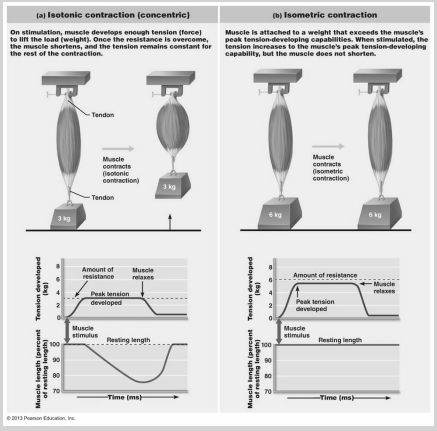
Response to Change in Stimulus Strength

•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

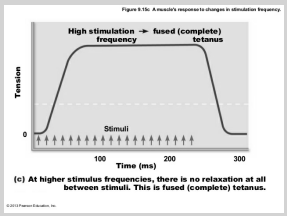
Isotonic Contractions

•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

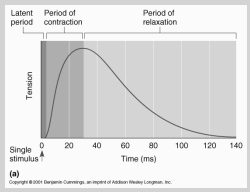
Isotonic (concentric) and isometric contractions



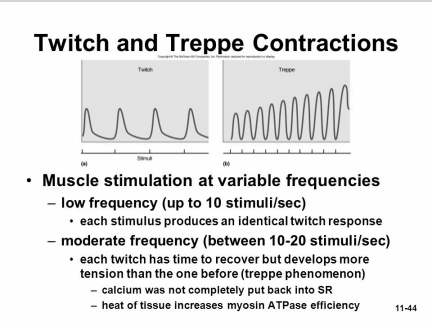
Response to Change in Stimulus Frequency



Muscle Twitch



Twitch and Treppe Contractions



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 Ca2+ 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) tetany results

–Smooth, sustained contraction

–No muscle relaxation due to consistently high sarcoplasmic Ca 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

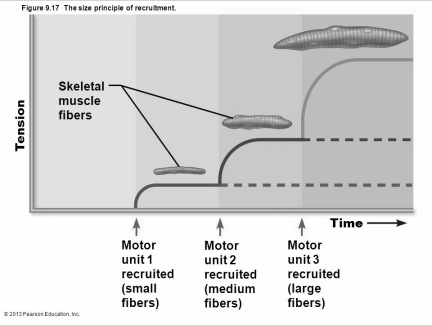
Principles of Muscle Mechanics (cont)

–Isometric contraction
–Isotonic contraction

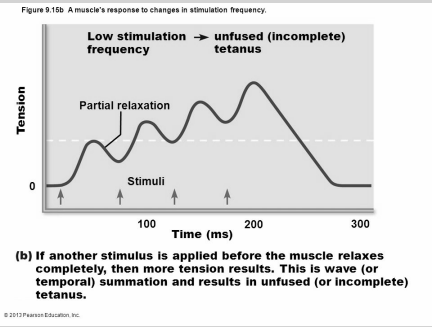
Isometric Contractions

•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

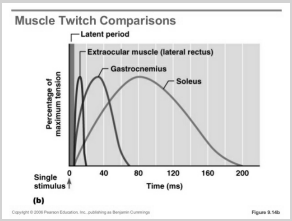
The size principle of recruitment



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

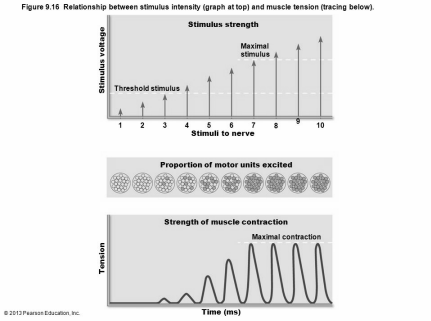
Muscle Tone

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

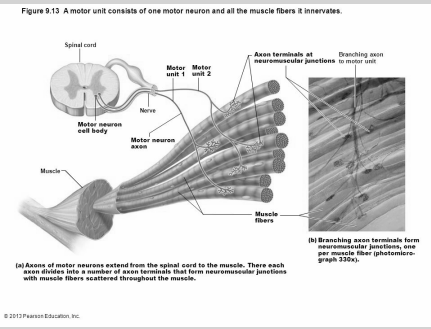
Muscle Tone (cont)

–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