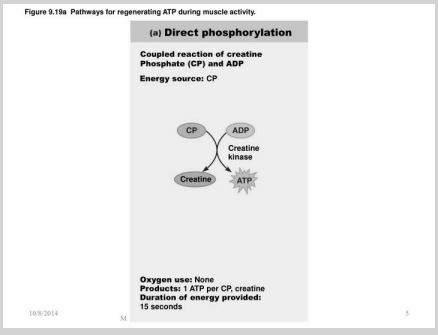
Muscle Metabolism

•Skeletal muscle
–Able to switch between low and high activity levels
•Low activity
–Relaxed and using a moderate amount of ATP
•High activity
–Contracting and using ATP at a rapid pace

Muscle Metabolism: Creatine Phosphate

•Creatine is a small, amino acid derived molecule that is synthesized in the liver, kidneys, and pancreas
–It is then transported to muscle fibers
–Can also be obtained through milk, red meat, and some fish
•When relaxed, muscle fibers produce more ATP than is needed for resting metabolism
–The excess ATP is used to make creatine phosphate(CP)
–Creatine kinase (CK), an enzyme,catalyzes the transfer of one of the high energy phosphates from ATP to creatine forming CP and ADP
•It does the reverse, too – CP and ADP to Creatine and ATP

Sources of Muscle Energy



Anaerobic Pathway

•Lactic acid
–Diffuses through muscle transport proteins into the interstitial fluid and then bloodstream
–Can be used as fuel by liver, kidneys, and heart

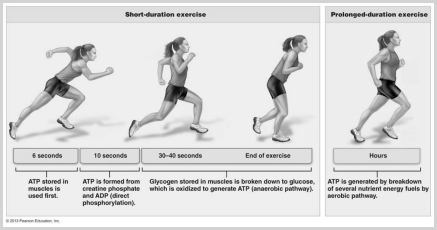
Anaerobic Pathway (cont)

–Can also be converted back into pyruvic acid or glucose by liver
•Anaerobic respiration yields only 5% as much ATP as aerobic respiration, but produces ATP 2½ times faster
–Rapidly provides fuel for ~30 – 40 seconds of strenuous exercise
–Drawback - uses huge amounts of glucose for relatively small amounts of ATP produced and creates lactic acid as byproduct

Aerobic Pathway

•Produces ~95% of ATP during rest and light to moderate exercise
–Slower process than anaerobic
•Series of chemical reactions that require oxygen
•Glycolysis is first step
–When oxygen is present in proper amounts, pyruvic acid is modified and sent to the mitochondria
•Occurs in the mitochondria in two steps (citric acid cycle and oxidative phosphorylation)
–Breaks pyruvate down producing CO2 ,H2O, and a large amount of ATP
•Glycolysis breaks down the glucose into pyruvate (pyruvic acid)
•With enough oxygen present in the cytosol, pyruvate is modified and enters the mitochondria where the breakdown of the modified pyruvate during the citric acid cycle produces molecules that are used in oxidative phosphorylation to produce a lot of ATP
•Beta oxidation of fatty acids (lipids) and oxidative deamination, followed by transamination, of amino acids provide substrates for aerobic respiration to produce ATP as well
•Fuels - stored glycogen, blood borne glucose, pyruvic acid from glycolysis, amino acids, and free fatty acids

Energy Systems Used During Sports



Skeletal Muscle Metabolism

•Oxygen Debt, or "Excess Post-Exercise Oxygen Consumption" (EPOC) is the amount of O2 repayment required after exercise in skeletal muscle to:
–Replenish ATP stores
–Replenish creatine phosphate and myoglobin stores
–Convert lactic acid back into pyruvate so it can be used in the mitochondria to help replenish ATP
–Balance hormones
•Some studies have shown that high-intensity exercise periods, such as interval training, may increase EPOC and thus allow you to increase post exercise metabolism
–EPOC is commonly referred to as the “after burn”
•The greater the EPOC, the more fat stores you may potentially use throughout the day to return muscle back to original state

Imbalances of Homeostasis

•Spasm
–A sudden involuntary activation of a motor unit within whole muscle
– usually painless
•Cramp
–Involuntary and often painful tetanic muscle contractions
–Caused by:•inadequate blood flow to muscles (such as in dehydration or blood clot)
•nerve compression
•overuse
•Injury
•abnormal blood electrolyte levels

Imbalances of Homeostasis (cont)

–calcium and magnesium levels important
•Intra vs extracellular Na and K also important

Roids... Juice

•Length of use and doses required to produce desired results can be dangerous
–Cause many cells in the body to grow, including cancerous cells
•Liver damage and various types of cancer is common with oral and injected steroids
–Kidney damage
–Stunted growth for those still growing
–Mood swings in long-term users from affected neurotransmitter release in the brain
•Increased irritability and aggression... Roid Rage!
•Depression
–Increased blood pressure and risk of heart disease
–Increased LDL levels... these are the bad kind
–Increased sebaceous gland secretion
•Pimple Party!!!
•...Backne and trapne
–Users often combine different types of steroid and non-steroid drugs when undergoing a cycle – stacking

Exercise Supplements

•Claimed benefits of most supplements not well supported by quality scientific evidence
–ACSM Discussion of vitamins and supplements
–Wikipedia article on BB supplements
•Some info may be incomplete or incorrect, usual Wikipedia risk
–NIH resource on supplements
–Consumer medical watchdog group (science-based medicine)
•Some products may contain unlisted ingredients that may be harmful or banned by athletic organizations

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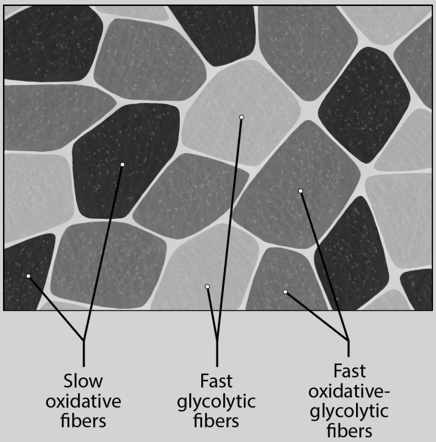
Skeletal Muscle Fiber Types

•By Function
–Slow oxidative fibers (SO)(Type I)
•Small, appear dark red, are the least powerful type.
•Myosin heads hydrolyze ATP slowly leading to a lower rate of contraction... hence slow
•They are very fatigue resistant
•Low amount of glycogen stores compared to FOG and FG
•Highly vascularized
•Have a lot of mitochondria

Skeletal Muscle Fiber Types (cont)

–Generate ATP mainly through aerobic respiration, hence oxidative
•High myoglobin
•Used for endurance activities where big, powerful contractions are not needed
–Ex: postural maintenance, long distance activities in running, swimming, and cycling

Skeletal Muscle Fiber Types



Skeletal Muscle Fiber Types

•Within a particular motor unit, all the skeletal muscle fibers are of the same type
–The different motor units in a muscle are recruited in a specific order depending on the task being performed
•Weak contractions usually require SO motor units only•If more force is required, FOG motor units are recruited
•If maximal force is required, the big FG fibers are recruited!

Exercise-induced Muscle Damage

•Strenuous exercise produces stress and damage to muscle fibers
–Torn sarcolemmas in some muscle fibers
–Damaged myofibrils
–Disrupted Z-discs
•Blood analysis post exercise shows the presence of proteins that are normally confined to muscle cells

Exercise-induced Muscle Damage (cont)

–Myoglobin
–Creatine Kinase

Muscle Response to Exercise

•Muscle cells undergo atrophy in response to lack of use
–Decrease in size/diameter due to decrease in the things listed under hypertrophy slide
•Muscle strength can decline around ~5% per day
–Atrophy can occur from simply not using them (disuse atrophy) or damage to the nerves that cause them to contract (denervation atrophy)
–If atrophy persists for extended periods, 6 months to over 2 years, muscle fibers can be irreversibly replaced by fibrous connective tissue

Muscle Response to Exercise

•Endurance (aerobic) training
–Leads to increased
•Muscle capillaries (blood flow)
•Number of mitochondria (ATP production when oxygen present)
•Myoglobin synthesis (more oxygen storage)
–Results in greater endurance, strength, and resistance to fatigue
•Greatest effect seen in SO fibers
–May cause the gradual transformation of some FG fibers to FOG fibers
•The transformed fibers show a slight decrease in size, but an increase in number of mitochondria (aerobic ATP capacity) and blood supply
–Endurance training also results in cardiovascular and respiratory adaptations that increase the nutrient transport and waste removal for skeletal muscle cells
•VO2 max and lactate threshold come into play here

Muscle Metabolism: Energy for Contraction

•ATP is the only source used directly for contractile activities
–Move and detach cross bridges, power calcium pumps in SR and sarcolemma, and power the return of Na+ & K+to normal levels after excitation
–Available muscle stores of ATP depleted in 3–6 seconds from the onset of contraction
•In order to maintain activity, the muscles must make more ATP

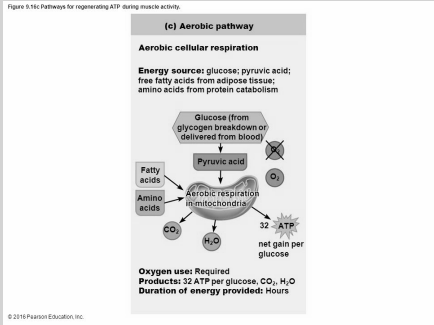
Muscle Metabolism: Creatine Phosphate

–CP is 3-6 times more plentiful than ATP in the sarcoplasm of a relaxed muscle fiber
•When contraction begins, muscles quickly use ATP stores
–Leads to increase in ADP in sarcoplasm
–CK takes a phosphate back from CP and adds it to ADP forming ATP
•CP catalyzed regeneration of ATP allow muscles to contract for roughly 15 seconds

Muscle Metabolism: Creatine Phosphate

•The metabolite (break down product) of creatine is creatinine
–Creatinine is filtered by the kidneys into the urine
–Adults require about 2 grams of creatine a day through synthesis or dietary means to replace the urinary loss.
•Some studies have shown that creatine supplementation can increase explosive movements such as sprinting or resistance training
•Others have shown no performance enhancement
•Some murine (mouse) studies have shown that ingesting excess creatine can cause the body to produce less endogenous (self produced) creatine
–The mechanisms of how this works are still not entirely understood
–The long term effects of creatine supplementation have yet to be determined

Aerobic Pathway



Heat Production During Muscle Activity

•~40% of energy released in muscle activity used for work
•Remaining energy (60%) is converted to heat
–Heat is a byproduct of many chemical reactions in the body
•Dangerous build up of heat levels prevented by radiation of heat from skin
–Sweating increases rate of heat removal from skin surface
•Shivering - result of involuntary skeletal muscle contractions to increase muscle metabolism
–Increases skeletal muscle heat production to offset a dangerous decrease in core body temperature

Skeletal Muscle Fiber Types

•Skeletal muscle fibers are not all alike in appearance and function. By appearance:
–Red muscle fibers (the dark meat) have a high myoglobin content, many mitochondria, and rich vascularization (blood supply)
–White muscle fibers (the white meat) have high amounts of glycolytic enzymes, low myoglobin content, fewer mitochondria, and less vascularization vs. red fibers

Imbalances of Homeostasis

•Aging
–By age 30, loss of muscle mass (sarcopenia) begins
•In part,due to decreased levels of physical activity

Imbalances of Homeostasis (cont)

•With aging,humans undergo a slow, progressive loss of skeletal muscle mass that is replaced largely by fibrous connective tissue and adipose tissue
–Muscle strength at 85 is roughly 40%of what it was at age 25
–Regular exercise can slow the rate of loss
–Exercise in the elderly can still produce significant adaptation
•Aerobic training is of particular importance due to it's cardiovascular effects
•Strength training, even a modest amount, can partially prevent the loss of muscle tissue that occurs with aging
–Also helps reduce bone density loss and loss of ROM in joints

Roids... Gym Candy

•Male side effects
–Decreased endogenous testosterone production
–Conversion of excess testosterone to estradiol
•Causes gynecomastia – female-like breast tissue in males
–Testicular atrophy from decreased sperm production
–Sterility
–Baldness
– increased development of androgenic alopecia for those with the affected
•Female side effects
–Atrophy of breasts and uterus
–Menstrual irregularities
–Sterility
–Increased male-pattern growth of body and facial hair (hirsutism)
–Permanent deepening of voice
–Clitoral enlargement
•Adolescent side effects
–stunted growth due to premature skeletal maturation and accelerated puberty changes

Roids... Gym Candy (cont)

–risk of not reaching expected height if steroid use precedes the typical adolescent growth spurt

Skeletal Muscle Fiber Types

•By function cont.
–Fast oxidative-glycolytic fibers (FOG) (Type IIa)
•Intermediate in size, appear red to pink
•More myofilaments than SO
•As much to slightly less vascularized vs. SO
•Moderately resistant to fatigue
•Myosin heads hydrolyze ATP 3-5x faster than SO which make them contract faster
–Twitches reach peak tension faster than SO and are briefer in duration
– less than 100 msec
•Have the most mitochondria of the different types
–Generate considerable ATP through aerobic (oxidative) respiration to power the greater number of myofilaments vs. SO
•High myoglobin
•Have a moderate amount of intracellular glycogen and can use anaerobic pathway (fermentation) efficiently when oxygen drops
•Contribute to exercises such as walking and sprinting

Skeletal Muscle Fiber Types

	SLOW OXIDATIVE FIBERS	FAST OXIDATIVE FIBERS	FAST GLYCOLYTIC FIBERS
Metabolic Characteristics			
Speed of contraction	Slow	Fast	Fast
Myosin ATPase activity	Slow	Fast	Fast
Primary pathway for ATP synthesis	Aerobic	Aerobic (some anaerobic glycolysis)	Anaerobic glycolysis
Myoglobin content	High	High	Low
Glycogen stores	Low	Intermediate	High
Recruitment order	First	Second	Third
Rate of fatigue	Slow (fatigue-resistant)	Intermediate (moderately fatigue-resistant)	Fast (fatigable)
Activities Best Suited For			
	Endurance-type activities—e.g., running a marathon; maintaining posture (antigravity muscles)	Sprinting, walking	Short-term intense or powerful movements, e.g., hitting a baseball
Structural Characteristics			
Fiber diameter	Small	Large*	Intermediate
Mitochondria	Many	Many	Few
Capillaries	Many	Many	Few
Color	Red	Red to pink	White (pale)

*In animal studies, fast glycolytic fibers were found to be the largest, but not in humans.

Skeletal Muscle Fiber Types

Exercise-induced Muscle Damage

•Delayed Onset Muscle Soreness (DOMS)
–Muscles become sore 12-48 hours post exercise
•Due to inflammation from damage to muscle
•Accompanied by stiffness, tenderness, and swelling
•Greatest effects felt 24-72 hours post activity
–Causes of DOMS not completely understood. but studies reveal that microscopic muscle damage (microtrauma) may be a major contributing factor
•Damage to sarcomeres (z-discs, thin, and thick filaments can tear or become dislodged), calcium homeostasis in muscle cell disrupted, ATP production may slow, possible increase in sarcomere protein breakdown by the proteases
–Interestingly, muscle become more damaged, and sore, from eccentric contractions (the negative rep) than from concentric or isometric contractions
•Mechanisms not entirely understood
–Not caused by lactic acid build-up
•Concentric contractions produce lactic acid and do not cause DOMS
•Studies show lactic acid levels in blood return to normal within 1 hour after exercise

Muscle Response to Exercise

•Ratio of FG to SO fibers in each muscle is most likely genetically determined
–This provides a partial explanation for why some people may be better at particular activities than others
•People with higher proportions of FG fibers may excel in activities involving short, powerful, intense activities
–Weight lifting and sprinting
•People with a higher percentage of SO fibers may excel in endurance activities
–Long distance cycling, running, swimming

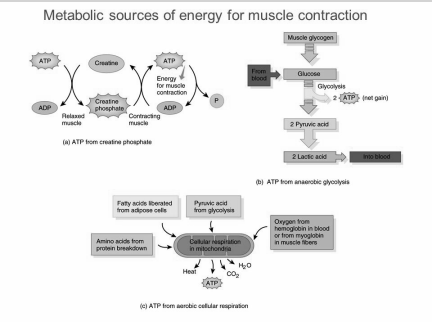
Muscle Response to Exercise

•Strength training (anaerobic activity) increases the size and tension production of FG fibers
–Increase in size and strength due to increase in number of myofilaments in muscle fiber.
•Overall result is hypertrophy
–Bulging muscles
–Increased number of mitochondria
•Quicker ATP replenishment during rest when blood flow is restored
–Increased glycogen stores•Increased glucose availability for glycolysis during contraction
–Increase in number of glycolytic enzymes
•results in greater ATP production capacity during contraction
–May cause the gradual transformation of some FOG fibers to FG fibers

Muscle Metabolism: Energy for Contraction

•Muscle fibers regenerate ATP by:
–Direct Phosphorylation (adding a phosphate) of ADP using creatine phosphate (CP)
•Especially important in muscle fibers
–95% of the body's creatine is found in skeletal muscle
–Anaerobic pathway (glycolysis lactic acid)
•No O2 required•If Anaerobic, glycolysis is followed by fermentation
–Aerobic respiration
•glycolysis O2 and modified glycolysis products into mitochondria

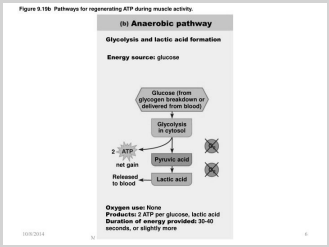
Sources of Muscle Energy



Anaerobic Pathway

•Glycolysis
– does not require oxygen
–1st step in both aerobic and anaerobic pathway
–In the cytosol, glucose is degraded to 2 pyruvic acid molecules via enzyme catalyzed reactions
–Produces 2 ATP per glucose molecule
•At 70% of maximum contractile activity
–Bulging muscles compress blood vessels
–oxygen delivery impaired
–W/o oxygen, pyruvic acid converted to lactic acid in order to regenerate specific molecules needed for glycolysis to continue making ATP•Fermentation

Anaerobic Pathway



Energy Systems Used During Sports

Aerobic endurance
–Length of time muscle is capable of contraction using ATP primarily produced from aerobic pathway
•Anaerobic threshold
–Point at which muscle metabolism converts to primarily anaerobic ATP production

Muscle Fatigue

•Physiological inability to contract despite continued stimulation
•Occurs when
–Ionic imbalances (K+, Ca2+, Pi) interfere with E-C coupling
–Prolonged exercise may damage SR and interfere with Ca2+regulation and release
–Inhibition of Cross-bridge cycling
•Build up of ADP and Pi in muscle fibers during activity may directly inhibit cross-bridge cycling

Muscle Fatigue (cont)

•Lactic acid build-up not necessarily a cause
–Elevated H+ ion concentration (acidification) in sarcoplasm may affect muscle fiber function
•Thought to be caused by release of H+ during ATP hydrolysis by contractile proteins, not lactic acid production
–Recent studies show that increasing acidity in muscle fibers does not directly hinder contractile proteins.
•It does directly create dysfunction in Ca regulation and release which affects contractility and relaxation
•Total lack of ATP rarely occurs during states of continuous contraction, and would cause contractures (continuous contractions)

Skeletal Muscle Fiber Types

•Classified functionally according to two characteristics
–Speed of contraction:
•slow or fast fibers according to
–Speed at which myosin ATPases split ATP
–Pattern of electrical activity of motor neurons
–Primary Metabolic pathways used for ATP synthesis while contracting
•Oxidative fibers—use aerobic pathways
•Glycolytic fibers—use anaerobic glycolysis

Muscle Response to Exercise

•Training programs should reflect the type of activity an athlete wishes to perform
–High weight/low rep resistance training will have little effect on a marathoner's ability to run long distance
–Endurance type activities, like half marathons and three mile swims, will not lead to the strength and size gains desired by weight lifters
–However, most successful long-term fitness regimens include both endurance and resistance training

Muscle Response to Exercise (cont)

•Changes in muscle in response to repeated periods of exercise occur over a period of weeks to months
–Speed of recovery, growth, and adaptation of muscle to exercise depends on many factors•Genetics, age, hormones, nutrition, Satellite cells
•If regular exercise ceases, the muscle revert to their unexercised state

Anabolic Steroids... Roids

•Anabolic-Androgenic Steroids
–Mimics the effects of testosterone and DHT in the body
–Cause an increase in muscle size and thus strength
–Cause increase in lean muscle mass
•With proper diet
–Cause increased bone growth and remodeling
–Stimulates red bone marrow•Increase in RBCs

Exercise Supplements

•Vitamins
–Most Americans do not require vitamin supplements
–Much of the vitamins needed are obtained from a healthy diet
–Vitamin supplements can be useful in those with nutritional deficiencies and professional athletes
•Protein supplements
–Daily protein requirement for an adult human is about 0.8 grams per 2.2 lbs of body weight
•Can be higher in growing children, pregnant women, postsurgical patients, and athletes.
–Excess protein intake (over 200 g/day) may lead to kidney damage over time
–High protein diets can lead to fat gain if total caloric intake greater than expenditure
•Pre-, during, and post workout supplements
–Many contain high amounts of various stimulants

Exercise Supplements (cont)

•May cause increases in blood pressure
•May cause concentration issues
•May increase rate of dehydration during activity
–Typically contain low amounts of advertised ingredients
•below amounts needed for physiologically relevant levels as based on scientific studies quoted by the supplement company

Skeletal Muscle Fiber Types

•By function cont... cont
–Fast Glycolytic fibers (FG)
–Type IIx (or IId) in humans, or Type IIb in small mammals
•largest, white in color, and powerful
–Many myofibrils, very low myoglobin content
•Low amount of mitochondria compared to types I (SO) and IIa (FOG)
•Have a lot of glycolytic enzymes in the sarcoplasm for glycolysis
–Primarily use anaerobic pathway in generating ATP during contraction
–Suited to intense, powerful activity of short duration
•Contain large amounts of glycogen
–Blood glucose and oxygen delivery severely decreased when contracting
–Glycolysis and fermentation use a lot of glucose to make small amounts of ATP compared to aerobic
•Myosin heads hydrolyze ATP very quickly
–Fast and powerful contractions•Used in short, powerful activities
–resistance training programs
– lifting weights

Skeletal Muscle Fiber Types

•Most whole skeletal muscles are a mixture of all three types of skeletal muscle fibers
–About half the fibers in a "typical"skeletal muscle are slow oxidative (SO) fibers
–Ratio of the three types in a whole muscle can vary depending on:
•The action of the muscle
•Training program
•Genetic factors
–Neck and back muscles often contain a higher proportion of SO fibers
•Primarily used for postural support
–Shoulder and arm muscles contain higher proportion of FG fibers
•Not used all the time
•Used briefly to produce large amounts of tension for activities like lifting or throwing
–Leg and thigh muscles contain large numbers of both SO and FOG fibers
•Used for support, walking, and running

Muscle Response to Exercise

•The regularity of muscle use, as well as the duration and intensity of activity, affect the properties of muscle
•Exercise can produce an increase in size as well as changes in a muscle cell's capacity for ATP production
•Muscle cells undergo hypertrophy in response to stress
–Increase in size/diameter, not in number
•Enlargement of existing fibers due to increase in the number of:
–Myofibrils
»More contractile organelles = more tension generated
–Mitochondria
»Bigger muscle cells with more contractile organelles need more ATP to power them
–Sarcoplasmic reticula

Muscle Response to Exercise (cont)

»Need more Ca storage and release for new myofibrils
–Other organelles and proteins necessary for increased metabolic capacity

Exercise-induced Muscle Damage

•Muscle fibers undergo repair and adaptation in response to damage
–Muscles become more resilient to type of activity that induced damage thus decreasing damage and soreness from future activities of similar type
•New regions of sarcolemma are formed to replace damaged areas
•More muscle proteins, such as myofibrils, and organelles are formed
–Allow for greater contractile strength and support
•Better able to resist, or buffer, the effects of the build up of metabolites such as acid

Muscle Response to Exercise

•Total number of muscle fibers typically does not increase
–Most people have roughly the same amount of muscle cells regardless of difference in body size
•Although, the characteristics of the fibers can change
–Different types of activity induce changes in muscle fibers
•Endurance vs. Strength