Chapter 12: Nutrition for Exercise

12.1 Nutrient Needs for Exercise

Section Objectives

- Discuss the metabolic demands of aerobic and resistance exercise types
- Translate theoretical sports nutrition concepts to simple daily intake guidelines
- Introduce nutritional and pharmacologic ergogenic aids

Learning Outcomes

- Identify the types of muscle fibers that contract during activities of various intensities
- Recall fluid intake guidelines for before during and after exercise
- Recall pre and post exercise carbohydrate intake guidelines
- Calculate the additional protein requirements to support recovery
- Recognize nutritional and pharmacologic ergogenic aids

Exercise is bodily activity that enhances or maintains one's capacity to perform physical activities. While humans voluntarily engage in physical exercise for a variety of reasons including leisure, employment, self-care and competitive sports, physical exercise by definition involves voluntary muscle contractions that elicit a substantial increase in expended energy.

Nutrients from the diet fuel the working muscles that perform exercise. Chemical energy is released from cellular nutrients and transformed into mechanical energy that propels coordinated muscle movements such as jumping, running, pushing and lifting. There are two major pathways that transform nutrient energy within muscle cells, each specialized for a particular physical exercise type.

Intensity	% Capacity (HR\02)	Daily Duration (minutes)	Primary Energy System	PrimaryFuel
Light	40	60-90	Aerobic	Fat
Moderate	40-60	30-60	Aerobic	Carb & fat
Vigorous	60	20	Anaerobic Aerobic	Carb

Figure 12.1 Aerobic Exercise Intensities

Aerobic exercise recruits large muscle groups and a large proportion of **slow twitch, type I** muscle fibers. Type I fibers are specialized for performing repeated contractions for long periods of time using the "oxidative," or oxygen-requiring, energy transformation pathway. Aerobic activities are performed at intensities that can require **light, moderate or vigorous** amounts of metabolic effort, which are delineated in most fitness settings by heart rate response and oxygen consumption. To confer the health benefits associated with aerobic exercise, the intensity must be sustainable for at least 20-30 minutes. Aerobic exercise exceeding 90 consecutive minutes in duration qualifies as **endurance exercise.**

Anaerobic exercise recruits **fast twitch, type II** muscles fibers. Type II fibers contract powerfully and immediately, and are sustained by non-oxygen requiring pathways. There are several modes of resistance (or strength) exercise that activate the anaerobic energy systems, such as weight lifting, sprints, and calisthenics. Anaerobic exercises are programmed in intervals, bouts, sets or reps that typically utilize more than 85% of contractile force and capacity, and last anywhere from 30 seconds to two minutes. Anaerobic exercise should be performed at least 2-3 times per week at an intensity high enough to elicit muscle injury.

	% Capacity	Interval Duration	Primary Energy System	PrimaryFuel
Calisthenics	80-90	1-2min	PCR glycolytic	Carb
Sprinting	85-95	1-2min	PCR glycolytic	Carb
Weight trainging	90-100	30sec	PCR	Carb

Figure 12.2 Anaerobic Exercises

Training Diet and Performance Nutrition

There is no set of specific guidelines for how to eat for peak physical performances. A variety of people from all over the world with widely diverse diets excel in sports performances that require vastly different physiologic systems. Even within cultures and sport types, athlete diets vary based on individual performance and body composition goals.

The basic tenants of sports nutrition, though, are grounded in the fact that, during exercise, virtually all muscular failure occurs as a result of **energy system fatigue**. That is, the rate of work within the muscle cannot be maintained because ATP (energy) is in too short supply and the muscle can no longer maintain the same level of contractile capacity and power. Thus, whether one's training is focused on strength or endurance, the training diet generally focuses on more energy nutrients and, perhaps more importantly, on **strategic timing** to support the conditioning and performance of the primary energy system that will engine the activity or sport.

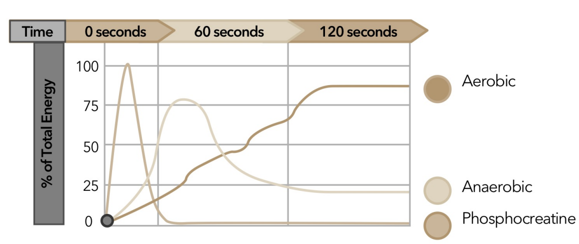


Figure 12.3 The Primary Energy Systems

Additional fluids are required to offset sweat and metabolic water losses incurred during and shortly after exercise. The amount needed is dependent on environmental conditions that influence sweat rate, the metabolic rate (which is directly proportional to exercise intensity and duration), and one's capacity to dissipate heat using non-evaporative mechanisms. In shorter stints of anaerobic exercise, even in higher temperatures, hydration is normally not an issue. However, during events with repeated power-based performances, and for aerobic exercise that is long duration, fluid intake should be methodically dosed and timed before, during and after exercise. For hot weather conditions, the average exercising person performing moderately heavy, exercise is estimated to accumulate approximately 6.88 kcal of heat and to lose nearly 12 g of sweat per minute such that 0.72 L of water per hour must be replaced. In cooler temperatures, just 2 cups of water per hour of exercise is estimated to adequately replace hourly sweat losses.

Energy expended performing physical activities is a highly variable component of total daily energy expenditure (TDEE). The energy expended during physical activities is most accurately estimated using direct calorimetry, whereby the sum of energy expended during physical activities as well as the non-exercise activity thermogenesis (NEAT), and excess post-exercise oxygen consumption (EPOC) are measured and added to the Cunningham equation (RMR) and the thermic effect of digestion. Most validated algorithms yield, for the average sized adult exercising in the moderate intensity range for 30-60 minutes most days of the week, about an additional **300-400 calories** (4-5g/kcal or 8 calories/lb.) per day. However, the Katch-McArdle equation (BMR) may be a more accurate estimate individual calorie needs for people with higher than average lean mass, such as body builders and strength athletes.

DAILY ENERGY EXPENDITURE

♂MEN	864 - (9.72 x age [y])	+PA	(14.2 x weight [kg])	(+ 503 x height [m])
♀WOMEN	387 - (7.31 x age [y])	+PA	(10.9 x weight [kg])	(+ 660.7 x height [m])

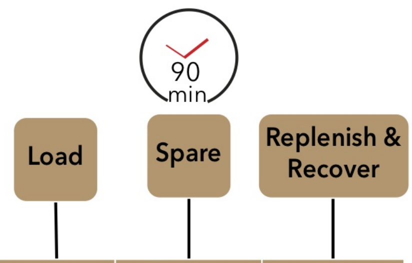
PHYSICAL ACTIVITY LEVEL

	SEDENTARY	LIGHTLY ACTIVE	ACTIVE	VERY ACTIVE
♂MEN	1.00	1.11	1.25	1.48
♀WOMEN	1.00	1.12	1.27	1.45

Figure 12.5 Total Daily Energy Expenditure (i.e., Estimated Energy Requirement)

Carbohydrates typically represent a similar proportion of total calories in the training diet as compared to the regular daily diet. For endurance training, where additional calorie needs are significantly higher, daily carbohydrate needs can reach nearly 70% of total needs as compared to protein and fat. The American College of Sports Medicine has developed guidelines for both moderate (1 hour) and high (1-3 hours) levels of daily exercise that range from 5-10 grams of carbohydrate needs per kg of body weight per day (or, 2-5 grams per pound per day). The timing and amount of carbohydrate intake in the days and hours leading up to a long bout of exercise can delay fatigue onset and improve perception of intensity making exercise more pleasurable. Consuming even a relatively small amount of carbohydrates (30-60 grams) before and after endurance and resistance exercises helps to enhance muscle energy (i.e., glycogen) stores for performance and to promote muscle recovery (i.e., anabolism). A small dose of carbohydrates consumed during exercise can also maximize performance in endurance events that last more than 90 minutes.

Although there have been very few studies of the requirement for **protein** for individuals undertaking high levels of exercise, it is commonly believed by athletes and fitness enthusiasts that a higher-than-normal protein intake is required for optimum physical performance. The reality is that for most muscularly-active adults, the additional protein needed to support muscle recovery, atop regular daily protein turnover, can be satisfied with a diet that is12-15% protein calories. Thus, a diet that is 500 to 1000 calories higher to offset exercise would also have a higher protein intake of around 1.2-1.6 grams per /kg/d, and for endurance exercise where calorie expenditure is significantly higher, like 4000 calories per day, protein calories expressed by body weight appears much higher, ranging from 1.8-2.0 g/kg/d. So, while active people do need more protein, it is not disproportional to the increased need for energy.



	Daily	Daily + Exercise
Carbs % calories	45-65	55-70
Fluids	3.7L	+2C per hour exercise
Calories	EER	EER (↑PAL)
Protein grams per kg body weight	.8g	1.0-1.6

	1hr. **Before**	**During** 15-30min	1hr. **After**
Carbs grams	60	15	60
Fluids cups	1.5-2	.5	2per lb. lost
Calories	300		350
Protein grams	10		30

Figure 12.5 Summary of Nutrient Intake Guidelines for Exercise

Dietary fat intake guidelines for exercise training follow the same 25-35% AMDR as recommended for inactive adults, even with increased calorie intake. The quality of fat in the athlete or training diet should also be similar in pattern to the typical diet: that is, being limited in solid fats and adequate in essential fats, particularly **omega 3 fatty acids**. Some experts suggest that for extreme endurance exercise (over 2 hours), several weeks of eating a relatively higher fat diet preceding the event may provide beneficial changes in the utilization and serum levels of free fatty acids. However, there has been less investigation into ergogenic strategies centered on meal timing in regards to fat intake since exercise duration is typically supplied in ample amounts by adipose tissue stores.

Consumption of specific **micronutrients** above the RDA has not been shown to exert any ergogenic effect on performance for the vast majority of athletes and active adults who are healthy and adequately nourished. In fact, research investigations studying many types of sport-demands have shown that competition and exercise regimes do not impose any special demands for any of the 6 major classes of nutrients beyond what is needed to replace exercise losses. For an athlete diet that is inadequate in one or more of the several critical nutrients, nutritional and pharmacologic aids, or even various supplements, may be considered. Ergogenic aids

Nutrients and nutrient-related compounds are included in one of several classes of ergogenic aids that are marketed to provide short- and long-term energy for exercise and to promote muscle tissue growth post-exercise during recovery. Several popular ergogenic nutrient compounds are isolated from whole foods or engineered to mimic fractional food components for dietary supplements. There are also varying amounts of several non-nutritive, **pharmacologic compounds** in natural foods and supplemented to the diet which may have ergogenic benefits. These compounds are most often promoted for enhancing fat burning (e.g., caffeine and carnitine), or for improving the muscle's tolerance to anabolic exercise (e.g., creatine and androgens).

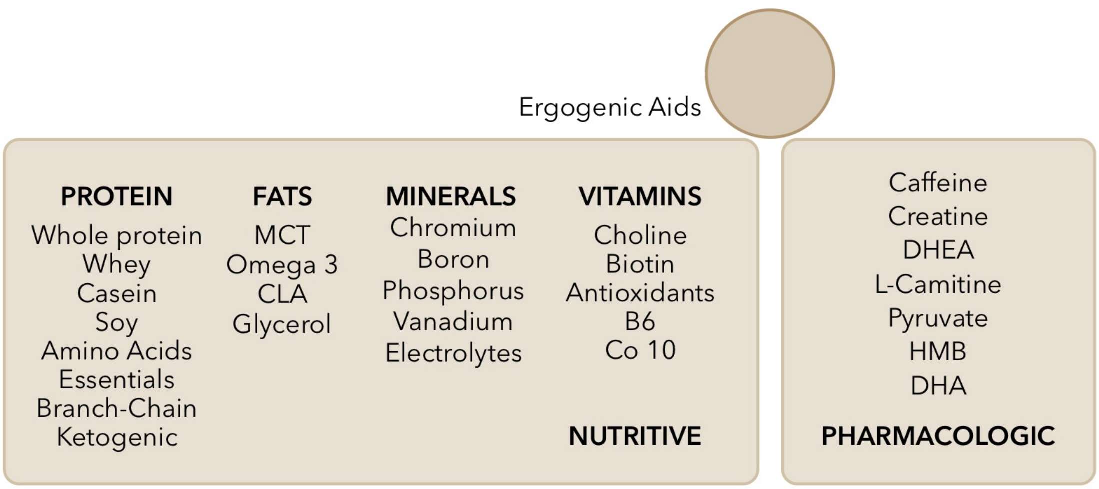


Figure 12.6 Nutritive and Pharmacologic Ergogenic Aids. The brown dot/circle will highlight these compounds in the upcoming transformation section

12.1 Homework 1

Review

What is the lowest exercise intensity that may be effective for improving health related fitness when performed for at least 30 minutes most days of the week.

- A Low intensity
- B Moderate intensity
- C Vigorous intensity
- D Maximal intensity

Explanation

The amount of exercise that elicits health-related fitness is at least 30 minutes per day of moderate intensity activity. The benefits of more vigorous intensity exercise can be seen with only 20 minutes most days of the week.

Show Submitted Answer Show Correct Answer Check My Answer

12.1 Homework 2

Review

Match each activity to a primary energy system

Premise **Response** **Drag and drop to match**

1 Half marathon

2 100 meter swim

3 Weight lifting

Show Submitted Answer Show Correct Answer Check My Answer

12.2 Nutrient Sources for Exercise

Section Objectives

- Reinforce strategies for training and performance diets
- Introduce foods that are easy to include in any training diet
- Extend understanding of nutrient sub groups and introduce potentially ergogenic compounds in foods.

Learning Outcomes

- Recall ergogenic compounds that are natural to animal foods
- Describe the sugar profile of sports drinks
- Identify food for pre-exercise and mid-exercise nutrition
- Identify critical components of recovery foods

While a healthy diet is no substitute for genetic endowments and physical training, foods and beverages are critical to achieving peak physical fitness and exercise performance. The **daily meal pattern** that is adequate to accommodate most exercise levels is characterized by the adult healthy diet plus 500 extra calories, 75-100 grams of extra carbohydrates and 10-20 grams of extra protein. The foods selected daily should be healthy and wholesome and follow the previously discussed guidelines for the major food groups including emphasizing whole grains, fruits, vegetables, lean dairy and protein sources.

Increasing daily intake by **one-to-two servings** from each major food group is one effective way to obtain the additional energy, vitamins and minerals necessary to support exercise. Maintaining balance and variety is especially important for an “all-natural” training diet that relies solely on whole food sources to supply critical minerals, like chromium and vanadium, and other potentially ergogenic compounds and pre-cursors that in the non-exercise diet, may go unnoticed. Other potentially ergogenic compounds that are synthesized endogenously in animal foods, such as conjugated linoleic acid (CLA), carnitine, creatine and omega 3 fatty acids, are concentrated in beef, lamb, fish, dairy and other natural food sources.

During the **week prior** to an endurance exercise event that will last more than 90 minutes, the diet can be programmed to enhance carbohydrate storage. There are many techniques to accomplish this programming but most begin about 7 days before an event where carbohydrate calories are reduced to around 40% of total calories while exercise is maintained to deplete body stores. Approaching 3 or 4 days before the event, carbohydrate levels are restored to 65-70% of total calories while exercise is tapered off.

Pre-exercise meals consumed **3-4 hours** preceding exercise should be 300-600 calories in a carbohydrate-to-protein ratio of around 3:1. If the exercise will elicit a muscle injury response, like during weight-training, protein from high-quality sources should be emphasized so that an adequate amount of essential amino acids is provided.

Snacks **within an hour of exercise** should provide 25-50 grams of carbohydrates that have a low **glycemic index (GI)** and a moderate **glycemic load (GL**). Lower GI foods that are appropriate to consume before exercise, given restrictions on pre-exercise fat and fiber, include dense, complex carbohydrate sources from, among other foods, fettuccini, chickpeas, strawberries or carrots, which all have lower GIs than other foods in their respective groups. The purpose of choosing foods with a lower GI is to yield a lower total GL, which is the product of GI and carbohydrate grams per standard serving. For example, the GI of raw peeled carrots is 37, and a standard serving provides around 5 grams of carbohydrates, so the GL of carrots is (37x5) / 100 = 2.4. Low GI and GL foods are less important if carbohydrates are adequately supplied during exercise and if exercise duration is less than 30 minutes.

There are several ergogenic foods and supplement additives that are intended for use before exercise. Stimulants like **caffeine**, for example, are marketed to maximize fat burning and glycogen preservation during long duration exercise. Caffeine is a common additive in endurance sports products but can also be consumed in the diet from teas, coffee and caffeinated soft drinks. **Medium chain triglycerides (MCTs)**, which are 6-12 carbon fatty acids that yield 8 kilocalories per gram, are another popularized ergogenic compound that purportedly preserves glycogen when eaten before exercise. MCTs, obtained naturally from coconut milk and other tropical plant oils,

Mid-exercise foods should be simple, palatable, easily digestible carbohydrates that effectively maintain blood glucose levels, while sparing glycogen, in **long duration exercise** (i.e., 90+ minutes). Since 1-1.5 cups (6-12 oz.) of water is also needed every 45-60 minutes of exercise, most athletes will refuel during exercise using fluids that provide carbohydrates. A number of solutions, like calcium-fortified orange juice diluted with water, for example, are effective pre-exercise beverages that feature a good proportion of glucose to fructose (i.e., 55:45). Honey is rich in the disaccharide sugar, isomaltulose, which provides a steady and sustained release of glucose compared to sucrose. Isomaltulose, and other variations like sucromalt, can be produced synthetically from sucrose (and maltose) for use in high-end, expensive endurance products. Typical bottled sport beverages are sweetened with maltodextrins, or shortened chains of glucose, in a solution that is 6-10% of carbohydrates by weight; an amount adequate for endurance without compromising overall taste or palatability.

Post-exercise meals need to replenish glycogen stores used during the workout, optimize protein synthesis to repair damaged muscle tissue, stimulate the development of new tissue, and replace fluids and electrolytes that were lost in sweat. Within 2 hours of short, medium-intensity workouts, meals should have a carbohydrate-to-protein ratio around 2:1, and following high-intensity workouts, closer to 3:1. In addition, protein quality is critical. Animal-derived proteins contained in milk, eggs, meat, and fish with higher biological value are naturally more complete in their amino acid profile. Meeting essential amino demands favorable to protein synthesis using plant proteins takes more strategy as most plant-based proteins (e.g., legumes, nuts and seeds) are incomplete; although others, like soy, quinoa and buckwheat, contain essential amino acids, which are generally considered complete.

Beverages are a great choice for replenishing the body during exercise and a great medium for protein and ergogenic compounds during the post-exercise period. Supplement powders are formulated to be added to milk, juice or water typically featuring whole proteins and free amino acids. **Whey protein** is a whole protein that is the byproduct of the manufacture of cheese. It is a typical ingredient in low-cost commodity protein powders often marketed as having a high biological value. While whey is an adequate protein to sustain a positive nitrogen balance, and may even be superior to some other whole food-proteins for nitrogen retention, it does not appear to increase muscle mass in athletes more than other whole protein sources if total protein intake is adequate.

Single, free **amino acid supplements** and **protein peptide chains** are allegedly distinguishable from whole proteins on the notion that they are absorbed more easily. Although this has not been proven scientifically in healthy, weight- training adults, several such supplements are marketed for anaerobic exercise power and recovery. **Glycine** and **arginine**, for example, are often featured in free amino acid supplements since they are pre-cursors that feed into pathways for creatine phosphate synthesis. Similarly, beta alanine, a non-essential amino acid metabolite needed for acid-buffer carnosine, a neurotransmitter, is also marketed for optimal acute exercise recovery.

Another very popular position for free amino acid supplements is the growth hormone category. **Arginine, lysine, glutamine** and **ornithine** supplements, for instance, all purport to have growth hormone effects. Additionally, the grouping of **branch chained amino acids** (i.e., valine, leucine, and isoleucine) are touted for their role in stimulating muscle tissue synthesis following resistance exercises. Other pharmacological compounds, like androgens, that have testosterone-like effects – or other stimulators of MPS such as DHEA, HMB and dihydroxyacetone (DHA) are also often included in dietary supplements.

12.2 Homework 1

Review

A pre-workout snack within an hour of exercise should feature around _______________ grams of carbohydrate and _______________ grams of protein.

- A 5 grams, 20
- B 50 grams, 25 grams
- C 100 grams, 100 grams
- D 150 grams, 25 grams

Explanation

Correct

Show Submitted Answer

Show Correct Answer

Check My Answer

12.2 Homework 2

Review

Which type of carbohydrates are better for snacking before a work-out?

- A High-glycemic
- B Low glycemic
- C High fiber
- D High sugar

Explanation

Yes, lower glycemic to perturb the during exercise insulin response

Show Submitted Answer

Show Correct Answer

Check My Answer

12.2 Homework 3
Review

Select 2 responses that are TRUE regarding Sports Drinks

Multiple answers: You can select more than one option

- A 6-10% carbohydrate
- B 30% calories from protein
- C Best for resistance exercise (weight training)
- D Contains electrolytes
- E Easy to absorb
- F Spares glycogen

Explanation

Yes, these drinks are designed to replace electrolytes and carbohydrates - glycogen sparing is not needed fro resistance training since glycogen depletion is unlikely

Show Submitted Answer Show Correct Answer Check My Answer

12.3 Nutrient Processing During and Following Exercise

Section Objectives

- Reinforce and extend understanding of major nutrient processing systems
- Introduce gastro-intestinal complications that occur as a result of exercise
- Present a logical flow of physiological activities that occur before, during and after exercise

Learning Outcomes

- Differentiate between the aerobic and anaerobic energy systems and what nutrients fuel each major pathway
- Explain the cardio-respiratory response to exercise onset
- Describe the process in which muscle growth is stimulated
- Match ergogenic compounds to processing systems that are underlie their mechanics

Gastrointestinal Systems During Exercise

Blood flow and neuromuscular signaling is reduced by as much as 80% at the onset of exercise which, to varying degrees, based on training and exercise type, can compromise intestinal nutrient and fluid absorption. Pre-competition anxiety can trigger the release of catecholamine hormones and speed the rate of transit, resulting in incomplete absorption of the pre-meal, which can cause gastrointestinal discomfort, flatulence and loose stool (i.e., diarrhea). Postural changes, like aero positioning during cycling, can have the same effects from intra-luminal pressure imbalances. Mechanical damage to the intestinal walls from repetitive high-impact running, for example, can also cause cramping and even light bleeding. Even swallowing too much air as a result of increased respiration while drinking from water bottles can result in mild-to-moderate stomach distress.

Gastric motor activity, and consequently gastric emptying, are governed by neural receptors found in the gastric musculature of the proximal small intestine. The rate of gastric emptying during exercise depends on exercise intensity and duration. It is also influenced by a variety of factors including, but not limited to, the caloric content, volume, osmolality, temperature and pH of the ingested food or fluid matter.

While it seems that during **light-to-moderate exercise** gastric emptying occurs at a rate similar to that during rest (on average, 2.0-2.5 kcal/min), during more intense exercise, gastric emptying may be inhibited. Fluid absorption in the small intestine is stimulated by glucose and sodium and, to a lesser extent, by fructose and other electrolytes. Glucose and sodium are absorbed via a common membrane carrier in the mucosal epithelium of the proximal small intestine so that the potentiation establishes an osmotic gradient for fluid absorption.

Exercise Onset and the Neuromuscular System

Exercise begins with a signal from the **neuromuscular system**. A nervous impulse (i.e., action potential) arrives at the neuromuscular junction, which causes a release of a chemical called acetylcholine. Acetylcholine causes the depolarization of the motor end plate which travels throughout the muscle by the transverse tubules. This stimulates the sarcoplasmic reticulum to release calcium into the muscle cell. **Calcium** floods into the muscle cell and binds with troponin, changing its shape, which moves tropomyosin from the active site of the actin so that the myosin filaments can attach to the actin, forming a cross-bridge.

The breakdown of ATP releases energy which enables the myosin to pull the actin filaments inwards and so shortening the length of the muscle fiber. When ATP is broken down, the myosin head can, again, attach to an actin binding site further along the actin filament and repeat the 'power stroke.' Once the nerve impulse stimulus stops, the calcium is pumped back to the sarcoplasmic reticulum, breaking the link between actin and myosin, and the actin returns to its resting position/unbound state causing the muscle to lengthen and relax. This process of muscular contraction can last for as long as there is adequate calcium and ATP stores.

Exercise Onset and the Anaerobic Energy Systems

Skeletal muscle contraction is fueled by a recyclable chemical stored in muscle called adenosine triphosphate (ATP). ATP is recycled in the muscle by one of three energy yielding pathways that transfer chemical energy. **Creatine phosphate (CrP)** supplies most of the energy for short-term, maximal effort-type exercise. In fast-twitch skeletal muscles, a large pool of CrP and high cytosolic creatine kinase (CK) activity are present. CK locally regenerates ATP using CrP at a rate sufficient to keep ATP and ADP virtually constant over several seconds of high intensity contractions. Free creatine is re-phosphorylated to CrP by CK using stored mitochondrial ATP in the in the intermembrane space. Liberated ADP is transported back to the mitochondrial matrix and re-phosphorylated to ATP, and CrP diffuses out of the mitochondria through the cytosol to the sites of ATP consumption thereby closing the cycle. This quick cycle "buffers" the cells phosphorylation potential until the nutrient combustion system can kick in and will remain the primary system for up to 30 seconds of moderate-to-high intensity muscle contractions.

The next burst of energy to support muscle contractions at exercise onset is sustained by the **glycolytic system**. This system uses local cellular glucose to produce two molecules of pyruvate, which can be used to re-synthesize 2 net ATP, or if myoglobin is adequate, 36 ATP from the TCA cycle. This energy supports the first 2-10 seconds of high-intensity, powerful contractions. During that short period, cellular oxygen is insufficient so that most of the pyruvate is fermented into **lactic acid** in a process called **anaerobic glycolysis**. Lactic acid is cleared from the muscle into the bloodstream relatively quickly when the muscle relaxes but will accumulate if high intensity contractions are sustained or contractions are repeated before lactate is cleared. **Buffers**, such as bicarbonate and glutamine, neutralize lactic acid in the blood so that the hydrogen ions are stable, but this buffering system is very limited in capacity. By around 10-15 seconds following the onset of high intensity exercise, epinephrine, a central nervous system stimulant, stimulates local **muscle glycogenolysis** to immobilize glucose, especially in type II, fast twitch fibers which are more glycogen-rich than their type I counterparts. Some free glucose is used to continue sustaining anaerobic glycolysis until the CNS stimulation of cardiorespiratory responses is adequate to sustain oxygen-requiring pathways.

Sustained Exercise and the Cardio-Ventilation System

Sustained exercise is supported by the cardiovascular system and a series of physiological adjustments aimed at supplying oxygen, fuel and cell messengers to the working muscle. Immediately before or at the onset of exercise, there is a rise in **heart rate** due to the release of **epinephrine** (i.e., adrenaline) from the adrenal medulla, located on the top of the kidneys. This rise in heart rate is linear to exercise intensity until approaching maximal effort, at which point, HR will plateau even if exercise intensity continues to increase. The highest value observed at the point of fatigue is referred to as maximal HR (HRmax), which is used to set exercise training zones. HRmax is estimated using the formula: 220 – age (in years).

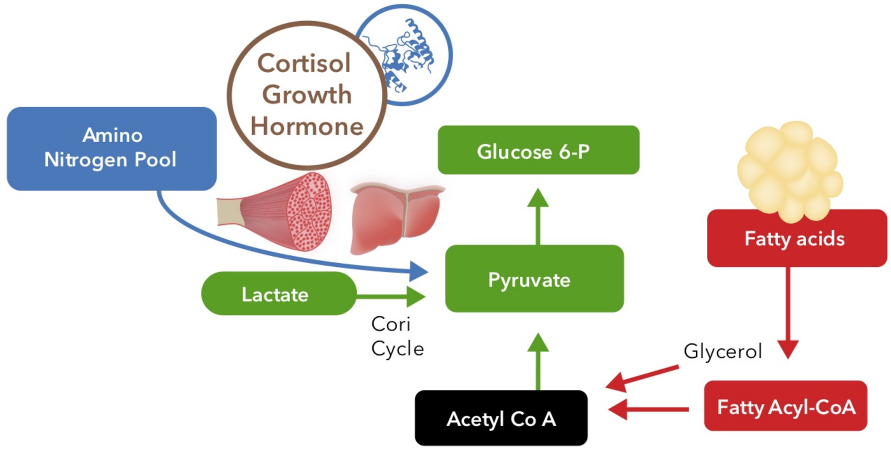
Mean arterial **blood pressure** increases immediately in the transition from rest to exercise to an extent directly related to exercise intensity. Blood pressure responses to **resistance exercise**, however, are significantly greater reaching up to 480/350 mmHg due to high internal pressures within the chest cavity that result from the **Valsalva maneuver**—a natural tendency to stop breathing while lifting, pushing or pulling a heavy weight.

Exercise results in a redistribution of **blood flow** by the cardiovascular system away from vital organs and to active muscle tissues. Approximately 15-20% of total blood flow is directed to muscles at rest, but during maximal intensity exercise, this figure increases to 80-85%. Several mechanisms work together to redistribute blood flow during exercise: chiefly, the **vasodilation** of blood vessels surrounding muscles and the vasoconstriction of blood vessels elsewhere. The vasodilation of capillaries increases blood flow, the surface area for gaseous exchange of O_2 and CO_2, the delivery of nutrients, and the removal of metabolic waste. Due to increased muscle blood flow and enhanced local circulation, tissues are able to take up more oxygen per 100 mL of circulating blood, a value known as the arterial-mixed venous oxygen difference. This difference gradient is expanded by at least three times that of resting values during exercise to supply more oxygen. At the onset of exercise, oxygen consumption also increases proportionally with heart rate until it plateaus, at which point, ATP supply and demand are at equilibrium. Oxygen consumption will continue to rise with increased exercise intensity until VO_2max is reached. Then, oxygen consumption cannot increase as the delivery and utilization of O_2 by working muscles has reached a maximal level. If intensity remains low enough, **steady state** aerobic exercise ensues.

Continued Exercise and Anaerobic Energy Systems

As exercise duration surpasses 1-2 minutes, contributions from the oxygen pathways become more important to sustaining muscle contraction. Lower intensity contractions that recruit slow-twitch fibers, will continue with **aerobic glycolysis** using local muscle glycogen and a steady supply from blood glucose. Muscle glucose proceeds in aerobic glycolysis to yield Acetyl Co A, which is subsequently oxidized in the TCA cycle and oxidative phosphorylation in the electron transport chain to yield 36 ATP. As blood sugar drops, the hormone glucagon initiates the hydrolysis of stored glycogen in the liver, which will be released into general circulation to restore blood sugar levels.

In longer endurance exercise when muscle and liver glycogen levels start becoming depleted, liver **gluconeogenesis** kicks in for continued restoration of blood sugar levels. This process uses glycogenic compounds, such as **pyruvate** and **lactate** from non-working muscles, and glycogenic amino acids such as glutamine and alanine to make glucose to sustain blood glucose for the brain and working muscles.



In slow twitch muscle fibers, the significantly higher number of mitochondria allows for catabolism of high-energy yielding fatty acids that are both stored locally in the muscle and imported from body fat stores. Fatty acids are liberated from glycerol and released from adipose stores by the action of hormone-stimulated lipolysis.

Carnitine, a locally produced and stored compound, transports fatty acid into mitochondria for beta oxidation where they are cleaved into two carbon units of Acetyl Co A and oxidized by the TCA cycle and ETC chain to produce 460 ATP. After 15-20 minutes of sustained low-intensity exercise, fat is immobilized from adipose stores through the action of epinephrine, which greatly contributes to muscle ATP production.

As exercise intensity increases, ATP production relies more heavily on carbohydrates than fats. Fuel utilization is estimated using metabolic gas analysis whereby the ratio of exchanged oxygen and carbon dioxide are determined by the type of fuel used.

Post-Exercise Oxygen Consumption

Following maximal effort of 30 to 60 second-anaerobic exercise (e.g., a set) the body will continue to increase oxygen consumption above pre-exercise levels. Post-exercise oxygen consumption (EPOC), is associated with an oxygen debt, needed to pay back the oxygen “borrowed” from the anaerobic system at the onset of exercise (i.e., the oxygen deficit). During short bouts of exercise and recovery, the “rapid,” or immediate, portion of EPOC fuels creatine phosphate and ATP re-synthesis and restores O2 stores. After longer duration exercise, following rapid EPOC, the “slow” portion of EPOC facilitates lactate oxidation and returns heart rate, respiration, body temperature, and hormone (i.e., epinephrine and norepinephrine) levels to baseline values.

Post-Exercise Endocrine Response

High-intensity exercise stimulates the release of **growth hormone (GH)** from the anterior pituitary gland. Release levels are highly dependent on exercise intensity. Growth hormone directly stimulates the uptake and incorporation of amino acids into protein in skeletal muscle and increases the inflammatory immune response. **Inflammatory cytokines** stimulate amino acid uptake, and along with testosterone enhance satellite cell activation in the damaged muscle area via neurotransmitters at the fiber site. Fibroblast growth factor (FGF) is enhanced by the presence of GH, which signals and initiates the revascularization process (i.e., the formation of new blood capillaries) during muscle regeneration. **Insulin** response stimulates muscle growth by enhancing protein synthesis and facilitating the entry of glucose into cells. The satellite cells use glucose as a fuel substrate to enable their cell growth activities.

Post-Exercise Anabolism

During the rapid phase (i.e., the 30 to 60-minute post-exercise recovery period), most of the glucose for glycogenesis is supplied by food intake. The rate of glycogenesis varies from 20 to 50 mmol per kg/muscle per hour, depending on the degree of glycogen depletion during exercise and the extent of insulin activation of glycogen synthase, which varies with post-exercise carbohydrate intake. Glycogenesis continues in slow phase for several hours after exercise.

Proteogenesis (i.e., protein synthesis) is stimulated by mechanical loading and subsequent stress in the muscle. In fast twitch muscle fibers, stress is created by high-intensity exercise whereas, in slow twitch fibers, even regular daily activities elicit stress-induced proteogenesis. In both fibers, if the hormonal response is normal and nutritional conditions are adequate, production of both globular and fibrous proteins will result.

The rate of fibrous **muscle protein synthesis** is highest within 20 to 30 minutes post-exercise and continues at higher-than-pre-exercise levels for up to 6 to 24 hours after exercise. Muscle cell proliferation is a process that begins with damage caused from high-intensity **resistance training**. The injury disrupts the muscle cell organelles and activates satellite cells (i.e., stem cells) located on the outside of the muscle fibers between the plasma and basement membranes. Some of the satellite cells differentiate to form new muscle protein strands called myofibrils, but most cells fuse together to repair the damaged myofibriliar tissue. Oxidative, type I muscle fibers have a higher number of satellite cells compared to fast-twitch muscle fibers within the same muscle, as they are regularly going through cell maintenance repair from daily activities that are low intensity.

The process of satellite cells differentiation involves mTOR, which is technically two nuclear gene-proteins that function as sensors controlling protein synthesis. The activity of mTORC1 is regulated by insulin, growth factors, certain amino acids and their derivatives (e.g., leucine and B-hydroxy methylbutyric acid), mechanical stimuli and oxidative stress. Stress and stimulus elicited by resistance exercise triggers phosphorylation of mTORC1's immediate target (i.e., p70S6 kinase) and synthesis of F-actin stress fibers in the muscle cell ribosome, whereas in **aerobic exercise** the protein synthesis pathways elicit **mitochondrial biogenesis**.

12.3 Homework 1

Review

Powerful, high intensity, muscle contractions, like the type elicited during a sprint will primarily recruit what type of muscle fibers?

- A type I
- B slow-twitch
- C fast-twitch
- D oxidative

Show Submitted Answer Show Correct Answer Check My Answer

12.3 Homework 2
Review

What mineral stimulates muscle contraction?

- A iron
- B calcium
- C potassium
- D sodium

Show Submitted Answer | Show Correct Answer | Check My Answer

12.3 Homework 3
Review

What amino acid stimulates the muscle protein synthesis pathway?

- A glutamine
- B leucine
- C alanine
- D glucose

Explanation

Yes, Leucine is needed for the mTor pathway to kick-off

Show Submitted Answer | Show Correct Answer | Check My Answer

12.3 Homework 4
Review

Match a supplement compound to the ergogenic functional claim

Premise **Response** **Drag and drop to match**

1 Glycerin →

2 Creatine →

3 Branch Chain Amino Acids →

4 Caffeine →

Show Submitted Answer Show Correct Answer Check My Answer

12.4 Nutrient Functions for Exercise

Section Objectives

- Extend understanding of basic nutrient functions to include their impact on the physiologic gains incurred from performing exercise

Learning Outcomes

- Identify critical muscle protein synthesis nutrients and compounds
- Recall the practices and dietary compounds that are related to glycogen sparing
- Explain how nutrition can delay fatigue during exercise and maximize recovery following exercise
- Match ergogenic compounds to probability of effectiveness

The impact of healthy cellular and whole-body nutrition status is apparent on all types of exercise performance outcomes and at every level of the human body system. At the cellular level, macronutrients fuel the ATP recycling pathways; micronutrients facilitate the enzymatic activity that sustains muscle contraction; and the cell organelle structures that enhance the oxidative capacity and maximal contractile force of every muscle are synthesized directly from nutrients absorbed from the diet. A more holistic perspective of how nutrition enhances the exercise outcomes, though, revolves around the synergy between diet and exercise for weight management and disease prevention, and the focus of this chapter, for a more physically fit musculoskeletal system.

Nutrition enhances physical fitness by directly supporting **strength gains** that occur as a result of **myofibriliar hypertrophy**, or increased myofibril size. Resistance training stimulates muscle protein synthesis (MPS) to levels exceeding breakdown for a period of up to 48 hours following exercise. Ingestion of a meal, particularly with carbohydrates, at any point during this period, will enhance muscle protein synthesis and suppress tissue breakdown. The anabolic environment after eating is created by an insulin response and is supported by amino acids and other important nutrients like chromium and vanadium, for example, which are thought to act like insulin to stimulate anabolism and amino acid uptake. These insulin-like effects also contribute to sarcoplasmic hypertrophy, which occurs as a result of increased muscle glycogen storage. While this type of hypertrophy does not contribute to the strength of the muscle, it does add considerable mass and size to myofibril tissue gained each week from resistance training.

Dietary protein not only enhances myofibrilliar protein gains and subsequent gains in strength, but also in the production of several **non-protein products** that are needed for exercise. For instance, single amino lysine is needed to synthesize carnitine, the fat transporter; and methionine, glycine and arginine are used to the synthesize creatine, the anabolic energy buffer. Amino acids are pre-cursors to many other critical biological compounds, including those needed for the neurotransmitters that stimulate lipolysis and fat mobilization to sustain long exercise.

Even the downstream metabolites of amino acids may have a muscle-enhancing effect through **protein sparing**. HMB, short for beta-hydroxy-beta-methylbutyrate, is a metabolite of leucine that supplies a needed component (HMG Co-A) that is used for cholesterol synthesis within the muscle cell. Since muscle cells cannot use blood cholesterol effectively and need to manufacture it internally, especially in stressful conditions like during high-intensity exercise, additional HMB stored in the muscle may be helpful to prevent muscle cell catabolism that would otherwise be needed to accommodate the new tissue membrane synthesis. While most research does not support the notion that HMB increases muscle growth, in energy restricted diets, such as those used to "cut weight," HMB could help spare protein tissue. Conjugated linolenic acid, or CLA may have similar protein-sparing effects but, instead, through a mechanism whereby CLA, itself, is integrated into muscle membranes which is thought to inhibit the action of catabolic hormones.

Iron is integrated into the protein heme as a critical oxygen binding component needed for muscle **oxygen delivery**. However, before oxygen-dependent systems are effective, the anaerobic systems fuel the muscle. **Recovery** of the phosphocreatine system depends on muscle creatine levels, which are provided directly from dietary sources, like animal meats and supplements, and also from the amino acids, glycine and arginine. Creatine supplementation using a dosage protocol that includes a loading phase of 20-25 grams per day for 5-7 days, then a maintenance phase of 5 grams per day, has been utilized for different types of high-power exercises that elicit maximal power output such as cycling or sprints. However, in many studies, creatine supplementation has exhibited no or minimal ergogenic effects on strength, sprint performance, and endurance exercise. Creatine supplementation may also increase fat-free mass (FFM), but the contribution from protein synthesis as compared to fluid retention (i.e., sarcoplasmic hypertrophy) is debatable.

Training diets that are higher in carbohydrates can enhance carbohydrate utilization and muscle **glycogen storing** capacity. Glycogen stores promote **anabolic recovery** in repeated high-intensity activities like 400-meter sprints, and **delay fatigue** during long-duration, glycogen-reliant exercises such as a five to ten-mile run. Carbohydrates consumed immediately before exercise will be absorbed into the blood which will **spare glycogen** so that, later in exercise, there is still glycogen to sustain blood glucose. Medium chain triglycerides are water soluble and readily absorbed into the hepatic system via the portal vein. Since they are oxidized at a similar rate as glucose during endurance exercises, MCT milks are very popular in both aerobic and anaerobic fitness markets; however, the majority of current research does not support a major ergogenic effect.

Post-exercise carbohydrate intake stimulates glycogen replenishment, which may help **prevent overtraining syndrome**. Other natural dietary compounds that may promote muscular endurance through glycogen sparing include caffeine, which acts as a central nervous system stimulant to increase fat breakdown and utilization; and L-carnitine, a short-chained carboxylic acid that facilitates the transport of long-chain fatty acids into the mitochondria for oxidation.

Hydration and Temperature Regulation

Fluid intake is needed to support exercise performance. Heat generated in exercise must be dissipated to avoid heat storage. For the average person performing moderately heavy (metabolic rate ≈ 600 W) exercise in the heat, the estimated rate of fluid loss is approximately 12 g of sweat per minute. Glycerol (i.e., glycerin) is a clear, syrupy, sweet liquid that is rapidly absorbed into the body and evenly distributes throughout body fluids. It attracts and holds water, which can increase the volume of fluid between and within cells so that, during exercise, plasma volume is maintained and body temperature increases are blunted. Glycerol hyperhydration may have an ergogenic effect by reducing heat stress of moderate exercise performed in the heat by allowing **greater sweat loss**, improved endurance, and lower heart rate. The benefits associated with glycerol hyperhydration are attributed to an increased stroke volume and expanded plasma volume, but the research supporting the effectiveness of glycerol as an ergogenic aid is mixed.

12.4 Homework 1
Review

How can protein and carbohydrate rich foods eaten before or after resistance exercise facilitate muscle hypertrophy ?

- A Provides materials (building blocks)
- B Stimulates muscle protein synthesis
- C Stimulates anabolic hormones like insulin
- D All of the above

Explanation

Yes, all of the above help stimulate and promote lean muscle gains

Show Submitted Answer Show Correct Answer Check My Answer

12.4 Homework 2
Review

What is the main outcome of carbohydrate consumption **during** long duration, or endurance exercise?

- A maximized glycogen stores
- B spared glycogen stores
- C enhanced glycogen storage capacity

Explanation

Yes, Glycogen storage is a between exercise period thing - during exercise, glycogen is used unless carbohydrates are consumed, in which case, glycogen is spared

Show Submitted Answer Show Correct Answer Check My Answer

12.5 Nutrient Status and Exercise Assessment Measures

Section Objectives

- Extend understanding of anthropometry to the measures best for sports and exercise science
- Introduce the major symptoms and stages of nutrient depletion during exercise
- Heighten awareness about over-consuming supplemental nutrients for exercise training

Learning Outcomes

- Recall protein status based on nitrogen balance data (positive or negative)
- Recall the effects and stages of carbohydrate depletion during exercise
- Identify compounds that may elicit deleterious effects on exercise performance

Physical fitness can be quantified by one's perceived level of exertion or enjoyment during exercise (RPE) or by more objective measures, like **muscular strength and endurance** via heart rate max and one repetition maximum. For athletes, these measures translate to performance outcomes like pitching speed, drive distance, or vertical jump height.

The effects of nutrition on strength is most evident in the enhancement of **muscle mass**. Lean muscle mass can be assessed by total body weight or, more specifically, by muscle diameter or size. There are also special instruments and methods that measure body conductivity and water and electrolyte content to estimate lean body mass, such as total body water-isotopic dilution, bioelectrical impedance and total body electrical conductivity techniques. Muscle mass gains can also be confirmed more definitively by muscle biopsies where myofibril tissues are examined, or, more commonly, by measuring **urinary nitrogen** to determine whether nitrogen intake is higher than excretion, thereby indicating a positive nitrogen balance and protein synthesis.

A negative nitrogen balance is indicative of catabolism, or muscle breakdown. Retaining too little protein or too few carbohydrate calories can have a negative impact on body composition and resistance training outcomes by inhibiting muscle and strength gains and hampering the immune system. For example, skeletal and plasma glutamine, which can be essential during times of metabolic stress, is lowered by prolonged endurance exercise. Since glutamine is critical for optimal functioning of the immune system, a decreased plasma glutamine concentration may impair immune function and increase the risk of infection.

As all types of physical activity are sustained by food and nutrients, dietary imbalances that compromise nutritional status may lead to unfavorable performance outcomes. For instance, if too little **glycogen** is available at the onset of high-intensity exercise, **muscle fatigue** occurs as a result of oxygen debt, and lactic acid buildup follows. In longer-duration exercises, muscle fatigue usually occurs as a result of insufficient energy to re-phosphorylate ATP. Blood sugar levels during exercise are maintained by liver glycogen which, along with absorbed carbohydrates, is adequate to replenish blood glucose during exercise. If carbohydrates are not available, the liver can supply about one hour of 70% oxygen consumption capacity (i.e., VO2max) moderate exercise, at which time, liver glycogen levels are about half-used, and the rates of hepatic breakdown and output are steadily reduced. At that point, blood sugar levels drop and "**bonking**" occurs, which results in extreme exhaustion and energy loss. Continued prioritization of blood, and ensuing muscle glycogen depletion, is known as "**hitting the wall**."

Dehydration can alter cardiovascular, thermoregulatory, central nervous system and metabolic functions in ways that adversely influence aerobic- and endurance-type exercise performance. Greater body water deficits may result in more severe performance reductions, which are often further accentuated by heat stress. Dehydration affects performances by lowering blood volume and decreasing cardiac output and is typically associated with a **dark urine color**.

Performance may also be impaired by poorly timed meals. For instance, insoluble fiber eaten prior to exercise may cause bowel movements during exercise, which may accelerate fluid loss. Consuming soluble fiber before exercise may result in added gas production causing **flatulence** and **cramping**. Poorly chosen fluids or re-fuel can also affect GI comfort and blood sugar levels. By way of example, concentrated carbohydrate solutions consumed before or during exercise may cause gastrointestinal problems because carbohydrate absorption during exercise is limited to about 60 grams per hour, so that beverages with high density osmolarities (i.e., >500 mOsm/L), like the type that are found in drinks that contain >12 g sugar/100 ml of carbohydrate, will most likely result in accumulation of carbohydrates in the intestine. This may lead to cramping, diarrhea, or even **rebound hypoglycemia**.

Toxic supplement doses of some micronutrients and other questionable dietary compounds thought to have ergogenic effects may cause GI distress. Vanadyl sulfate and boron are good examples of non-essential, trace minerals that are taken as supplements and not included in the RDA that may cause loss of appetite and symptoms of gastrointestinal distress including transient diarrhea, abdominal cramps and nausea. Medium chain triglycerides may also cause GI distress which limits their potential usefulness as an ergogenic aid. Glycerol supplementation, likewise, includes potential side-effects of bloating, nausea, and vomiting, and should not be used by anyone who suffers from diabetes, high blood pressure, or kidney disorders.

Although caffeine is relatively safe, side effects of high caffeine consumption include nausea, muscle tremors, palpitations and headaches. Athletes who are sensitive to caffeine can experience these symptoms at low doses. Athletes should also be aware that the reported ergogenic effect of some over-the-counter supplements might be a result of the caffeine content.

Many anecdotal reports exist linking creatine supplementation with increased incidences of muscle cramps, muscle and tendon pulls, and muscular injuries. However, none of the studies evaluating highly-trained athletes during heavy training periods have reported these side effects. While there is also concern that creatine supplementation may place added stress on the kidneys or liver, this has not been reported in healthy individuals at the doses studied. Currently, the only documented side effect of creatine is increased total body weight, but more research needs to be done to determine whether long-term use is safe, and whether certain individuals might be predisposed to negative side effects.