Fueling for Performance

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Context: Proper nutrition is crucial for an athlete to optimize his or her performance for training and competition. Athletes should be able to meet their dietary needs through eating a wide variety of whole food sources.

Evidence Acquisition: PubMed was searched for relevant articles published from 1980 to 2016.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: An athlete should have both daily and activity-specific goals for obtaining the fuel necessary for successful training. Depending on the timing of their season, athletes may be either trying to gain lean muscle mass, lose fat, or maintain their current weight.

Conclusion: An athlete will have different macronutrient goals depending on sport, timing of exercise, and season status. There are no specific athletic micronutrient guidelines, but testing should be considered for athletes with deficiency or injury. Also, some athletes who eliminate certain whole food groups (eg, vegetarian) may need to supplement their diet to avoid deficiencies.

Keywords: sports nutrition; protein; carbohydrate; fat; macronutrient; performance

Athletes have many strategies they can use when fueling for performance. Nutrition can play a crucial role in optimizing training sessions as well as with recovery and metabolic adaptation. Michael Pollen summarized healthy eating in his book *In Defense of Food* with "Eat (real) food, mostly vegetables, not too much."[35] Athletes should be able to obtain both adequate macronutrients (protein, carbohydrates, fats) and micronutrients through a variety of foods. Sports medicine providers should help athletes navigate the many facets of sports nutrition, including food composition, nutrient timing, supplement use, and energy balance. Additionally, athletes' nutritional requirements may vary widely depending on sport, position, timing of season, and training vs rest day. Most athletes will plan to either gain lean muscle mass, lose fat, or maintain their current body composition while not impeding their performance on the field. It can be difficult for an athlete to navigate all the various "fad diets" and "healthy" choices when shopping or eating outside the home. Athletes also need to be educated on the detrimental effects of rapid weight loss strategies for competitive advantage, especially in sports such as wrestling and gymnastics. Detrimental effects include hypohydration and loss of glycogen stores and/or lean muscle mass.[47]

Unfortunately, formal clinical training in nutrition is often lacking. Most US medical schools (71%) do not provide the minimum 25 hours of nutrition education, and 36% provide less than half as much.[1] Therefore, most sports medicine providers are not prepared to work with athletes to maximize their nutrition intake for their specific goals.

ENERGY BALANCE

The first step in counseling athletes on nutrition is approximating their energy requirements per day to maintain their weight or energy balance. Energy balance occurs when energy intake (EI) = total energy expenditure (TEE). The TEE is a summation of basal metabolic rate (BMR) + thermic effect of food (TEF) + thermic effect of activity (TEA). There are many factors that go into an athlete's TEE, and it may vary depending on his or her energy needs for that day. Some factors that may increase demand include training, environmental exposure (heat, cold, or altitude), fat-free mass (FFM), stress, illness, or some medications. Factors that also negatively affect energy requirements include decreased training and FFM. Our energy requirements also decline as we age.

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Table 1. Calculating the resting metabolic rate using the Mifflin–St Jeor equation

Sex	Resting Metabolic Rate (Mifflin–St Jeor Equation)
Male	10 × weight (kg) + 6.25 × height (cm) – 5 × age (years) +5
Female	10 × weight (kg) + 6.25 × height (cm) – 5 × age (years) – 161

Two terms that are used sometimes synonymously are *basal metabolic rate* and *resting metabolic rate* (RMR). BMR is measured in a darkened room after 8 hours of sleep and 12 hours of fasting in a reclined position, whereas RMR measurements are taken in a less restrictive environment and are typically 10% higher than those for BMR. RMR is more practical to use than BMR and represents anywhere from 38% to 80% of an athlete's TEE.[21] There are many equations and estimates that are used for each, with the Harris-Benedict[40] equation for BMR and the Mifflin–St Jeor[8] for RMR being some of the more commonly used. The Mifflin–St Jeor equation is predictive within 10% of calculated RMR.[8,24] The Mifflin–St Jeor equation uses age (years), sex, height (cm), and weight (kg) and is calculated using different formulas for men and women (Table 1).

The thermic effect of food is roughly 3% to 10% of caloric expenditure[38] but may vary depending on the types of food eaten and is not usually incorporated into energy expenditure calculations. This effect reflects the energy it takes for the body to digest food consumed. This is where some advocates have proposed eating small frequent meals to continue to fuel your metabolism, especially when athletes are looking to lose fat while keeping lean mass.

Once RMR is calculated, you multiply this number by the athlete's physical activity level (PAL), which is an estimate of their TEA. There are many estimates for an athlete's PAL, and one's energy requirements may vary greatly, as some elite athletes when training may require upward of 12,000 kcal per day. The PAL factor will be between 1.4 for sedentary individuals and 2.4 for elite athletes[7] (Table 2 and Appendix 1, available in the online version of this article).

Another energy balance concept that was first studied in women is energy availability (EA). This concept looks at optimal energy for health and function versus energy balance. It is defined as dietary intake minus exercise energy expenditure normalized to FFM, which is the amount of energy available to the body to perform all other functions after the cost of exercise is subtracted.[19] An EA of 45 kcal per kilogram FFM per day is associated with energy balance and optimal health, while that lower than 30 kcal per kilogram FFM per day is associated with impairments of a variety of bodily functions.[27,48] A low EA may occur from low EI, increased activity, or a combination of the two. It may also be associated with disordered eating or high-volume training errors for a specific competition.

Another easy way to estimate baseline caloric needs is to multiply weight (lbs) by 14. One caveat is that this calculation should not be used in athletes with more than 30% body fat, as it would overestimate caloric needs. With any of the above equations, it is important to follow caloric intake and training for a couple weeks and then adjust based on an athlete's progress. Once an estimate for an athlete's total EI is determined, macronutrient needs can be calculated (see Appendix 1).

MACRONUTRIENTS

The 3 main macronutrients are protein, carbohydrate, and fat. It is important for athletes to consume the optimal ratio of macronutrients in their diet based on their training goals, such as gaining muscle or losing fat while maintaining lean mass. Food quality is also very important, as whole foods should be consumed whenever possible versus packaged foods and bars or shakes. Shakes can be a good source of nutrition but should be made with whole ingredients without added sugars. An example of a whole food shake would be the following: 1 cup unsweetened almond milk, 1 cup frozen banana or berries, 1 tablespoon coconut oil, 1 cup plain Greek yogurt, and 1 to 2 scoops of protein powder. This would contain approximately 400 calories and have around 30 g of protein and 30 to 50 g of carbohydrate.

Protein and carbohydrates have 4 kcal per gram, while fat has 9 kcal per gram when calculating an athlete's needs. Alcohol is not a macronutrient but does have 7 kcal per gram and is obviously discouraged for optimal training and health.

Protein

Proteins are important for many body processes. Not only are they the building blocks of muscle, tendons, and other soft tissues, but they also are essential for building enzymes, hormones, and neurotransmitters for many bodily functions.

Proteins are composed of both essential and nonessential amino acids, with the former only being fully obtained through proper nutrition as our bodies cannot produce them. There is much debate on how much protein is needed for athletes. The dietary reference intake (DRI) for protein is 0.8 g per kilogram body weight (0.36 g/lb) for sedentary individuals.[36] This equates to about 56 grams of protein per day for an average man. Many studies have shown that athletes have higher daily protein requirements.[23,33] There are many instances where higher daily protein intake is beneficial for athletes; examples include strength training, maintaining lean mass in a caloric deficit, and during injury recovery. The American College of Sports Medicine (ACSM), International Society for Sports Nutrition (ISSN), and International Olympic Committee (IOC) provide consensus that the daily protein requirements of athletes range between 1.2 and 2.0 g per kilogram body weight per day, which is well above the DRI and would equate to 84 to 140 grams of protein per pound per day for the average man.[36] The IOC recommends 1.8 to 2.7 g per kilogram body weight per day

Table 2. Physical activity factors

Category	Example	PAL Factor
Sedentary to light activity	Walking or yoga	1.4-1.69
Moderate activity	Fitness classes, weight lifting, running, or cycling	1.70-1.99
Vigorous activity	Endurance and elite athletes	2.0-2.4 or higher for elite athletes

PAL, physical activity level.

Table 3. Summary of daily carbohydrate requirements

Organization	Physical Activity Level	g/kg BW per day
ACSM	Athletes	6-10
ISSN	General physical activity, 30-60 min/d, 3-4 times a week	3-5
	Moderate- to high-intensity volume, 2-3 h/d, 5-6 times a week	5-8
	High-volume, intense exercise, 3-6 h/d, 1-2 sessions, 5-6 times a week	8-10
IOC	Low-intensity or skill-based activities	3-5
	Moderate exercise program, ~1 h/d	5-7
	Endurance program, moderate to high intensity, 1-3 h/d	6-10
	Strength-trained athletes	4-7
	Extreme commitment, moderate to high intensity, >4-5 h/d	8-12

ACSM, American College of Sports Medicine; BW, body weight; IOC, International Olympic Committee; ISSN, International Society for Sports Nutrition.

when an athlete is trying to lose fat while gaining lean mass in a slight caloric deficit and proper training program.[33]

Overall, athletes should consume approximately 15% to 30% of their calories from protein sources. Some authors have discussed the deleterious effects from high-protein diets including kidney failure and osteoporosis, but there are no well-done studies to support this at this time.[20,22] Protein-restricted diets are reserved for those with decreased renal function, as an athlete with normal kidney function should be able to eat the amount of protein using the above guidelines without deleterious effects. Recommended sources of protein for athletes include lean meats and fish, cottage cheese, eggs, plain Greek yogurt, and protein shakes. Good sources of protein for vegan athletes include lentils, tempeh, chickpeas, black beans, quinoa, almonds, and plant-based protein shakes.

Carbohydrates

Carbohydrates are the main energy source during high-intensity activity for the central nervous system as well as muscular work. Carbohydrates have been vilified in the media lately with their link to the obesity epidemic and possible gut inflammation. This has also led to the explosion of available gluten-free products, but the vast majority of people do not need to avoid gluten as there are many health benefits to eating a diet rich in whole grains.[17] This can lead to a lot of confusion for an athlete trying to make good food choices to fuel his or her body. Carbohydrates are not all created equal, as there is a vast difference between eating a bowl of oatmeal versus a bowl of ice cream. Whole grains, fruits, vegetables, and legumes are highly nutritious foods that are rich in antioxidants, fiber, vitamins, and minerals, while processed sugars abundant in the Western diet can be quite detrimental to health.[17]

Athletes have varied carbohydrate requirements based on training intensity, type of workout, and timing during their season. In general, athletes will need to consume 3 to 5 g per kilogram body weight daily for light activity and upward of 8 to 12 g per kilogram body weight per day for intense training. A summary of requirements based on the ACSM, ISSN, and IOC recommendations is listed in Table 3.

Fat

Fat requirements for athletes are similar to those for nonathletes (20%-35% total daily calories should come from healthy fats).[36] The IOC does not recommend consuming less than 15% to 20%

of total calories from fat because it is essential for many processes in the body, including cell membrane structure, absorption of fat-soluble vitamins, hormone regulation, brain health, and energy for muscle metabolism.[36] Athletes should focus on good sources of fat that are high in unsaturated fats and essential fatty acids. Trans fats should be avoided, and saturated fat should be less than 10% of total consumption.[51] Healthy sources of fat include salmon, nuts and nut butters, and avocado, as well as coconut and olive oil. Athletes may also consider taking omega-3 supplements as they can also counteract inflammatory and free radical formation sustained from training.[46]

There has been renewed interest in eating high-fat, low-carbohydrate diets in low-intensity and endurance exercise. Fat, in the form of plasma-free fatty acids, intramuscular triglycerides, and adipose tissue, provides a fuel substrate that is both relatively plentiful and increased in availability to the muscle as a result of endurance training.[48] The body cannot extract the energy from fats fast enough for high-intensity exercise, hence the high carbohydrate mantra for athletes.[29] However, our bodies store thousands of calories of fats that can be metabolized at an adequate rate for energy during endurance exercise. Essentially, athletes use these diets to change their metabolism so their body will preferentially burn fat for fuel. This would be beneficial for ultra-endurance events to prevent some athletes from "bonking" or "hitting the wall" when their glycogen stores are depleted because of their metabolism being geared for burning carbohydrates versus fat for fuel. Athletes consuming less than 10% of their calories from carbohydrates are able to oxidize fat between 1.2 and 1.5 g/min during progressive-intensity exercise near 65% VO_2 max.[34,52] A fat-burning adapted Ironman triathlete is able to use the fat stores in his or her body to fuel the race effectively at that oxidation rate for the entire race compared with a carbohydrate-burning athlete who would need to consume another 90 to 105 g per hour to maintain performance.[5,14]

Studies addressing the effects of low-carbohydrate diets on the ease of weight control in athletes, the capacity to train and recover, immune function and injury risk, or hand-eye coordination or capacity to concentrate in sports are lacking.[29] Additionally, some endurance athletes can be insulin resistant, and eating a diet high in carbohydrates may not be best for their long-term health.[4,37] Some studies show that marathon runners with lower coronary risk factors have marked atherosclerosis.[25,26,28,43]

MICRONUTRIENTS

Athletes stress many of the metabolic pathways during training and may have increased micronutrient (vitamin and mineral) requirements. Most athletes should be able to obtain sufficient micronutrients through a well-balanced diet, but athletes who practice extreme dietary or weight-loss patterns or eliminate whole food groups may be at risk for certain deficiencies. Examples would be restricting EI, vegetarians, illness, injury recovery, or those with specific medical conditions. Athletes should be evaluated on an individual basis if there is concern for possible deficiency based on symptoms or performance decline. Hence, there are no general micronutrient guidelines for athletes. Common deficiencies include iron, vitamin D, calcium, and some antioxidants such as vitamins E and C.[48] Vegetarians may require vitamin B_{12}, iron, calcium, vitamin D, riboflavin, and zinc supplementation based on their food preferences.[36] It is important to note that micronutrients are important for optimum health but are not considered to have ergogenic properties.

Iron

Iron serves as a key component in oxygen transport via hemoglobin and myoglobin in energy pathways throughout the body. Female endurance athletes are the most common group of athletes with iron deficiency, although any athlete, including males, may become iron deficient.[6] Iron deficiency can occur from many causes, including heavy menstruation, inadequate dietary intake, gastrointestinal losses, and training losses both intravascularly and via sweat. Most experts agree that athletes' requirements for iron are greater than the recommended daily allowance of >18 mg for women and >8 mg for men. Furthermore, a female athlete's requirement may be as high as 70% more than the average.[6]

At-risk athletes should be tested for iron deficiency, with the most common tests being serum ferritin and hemoglobin. Serum ferritin is the best indicator of iron stores but can be falsely elevated as it is an acute-phase reactant and can increase during inflammatory states.[6] There has also been debate as to what serum level constitutes iron deficiency. Serum ferritin levels between <35 and <10 ng/mL have been used along with a hemoglobin of <12 g/dL to describe iron deficiency with or without anemia.[31] Many athletes can be iron deficient without anemia. If they are anemic, they often have a mean corpuscular volume in the microcytic range. Athletes may also have transient dilutional anemia when initiating a training program. This is an adaptation to training and should be taken into account when evaluating athletes for anemia.

Treatments for iron deficiency include dietary intake, oral supplementation, and intravenous or intramuscular injections. Side effects of supplementation include gastrointestinal discomfort, constipation, and nausea. Athletes' iron levels should be monitored at regular intervals as it can take 3 to 6 months to correct their deficiency. Increasing dietary iron should be the first-line treatment in athletes without anemia, with heme iron (from meats) being the most bioavailable source. Oral iron supplementation should be taken with vitamin C for better absorption, and polyphenolic (coffee and tea) compounds should be avoided. Dosages remain controversial, but 100 mg of $FeSO_4$ (approximately 20 mg of elemental iron per day) along with nutritional counseling appears to be sufficient over 6 to 8 weeks to improve status and/or prevent decline.[6] Intramuscular and/or intravenous injections should be reserved for those with severe deficiency or those who do not respond to dietary and oral supplementation.

Table 4. Nutrient intake surrounding activity

When	Protein	Carbohydrate	Fat	Comment
Preexercise	20-30 g, especially for resistance training	200-300 g	Limit due to gastrointestinal distress	If an athlete is carbohydrate loading, he/she may consume 8-10 g/kg body weight/day for 1-3 days prior to competition
During exercise	Not needed	30-60 to 90 g/h depending on length of activity	Not needed	Hydration only if activity under 60 minutes. Should be liquid/ gel-form carbohydrates for easy digestibility
Postexercise	20-30 g within 30 minutes	60-120 g within 30 minutes (1:3-4 ratio with protein)	In normal ratio with protein and carbohydrates	Continue refeeding with postworkout meal for regular refueling needs depending on exercise intensity

Vitamin D

Vitamin D is an important fat-soluble vitamin that helps regulate many metabolic pathways in bone health, inflammation, and muscle function.[48] Some studies have also shown decreased risk of stress fracture and positive effects in injury prevention and rehabilitation.[11,18,41] Athletes requiring vitamin D testing are those with a history of stress fracture, signs of overtraining, muscle pain or weakness, and a lifestyle involving low exposure to ultraviolet-B (UVB).

Insufficiency has usually been defined as <30 ng/mL, and deficiency as <20 ng/mL vitamin D 25(OH).[48] Diet alone is usually not sufficient to correct low vitamin D status, as oral supplementation either daily (2000-4000 IU) or weekly (25,000-50,000 IU) may be considered with interval follow-up testing in 8 weeks to avoid toxicity, since it is a fat-soluble vitamin and may accumulate in the body. Symptoms of vitamin D toxicity include nausea, vomiting, poor appetite, constipation, weakness, weight loss, mental confusion, irregularities in cardiac rhythm, and calcification of soft tissues.

Calcium

Calcium is important for many metabolic processes, including bone health (with vitamin D) and muscle contraction, nerve conduction, and clotting functions.[48] Low dietary calcium intake is often associated with disordered eating and low energy availability in female athletes, which is another factor leading to stress fractures and low bone mineral density in this group. The IOC recommends 1500 mg per day of calcium along with 1500 to 2000 IU vitamin D to optimize bone health for at-risk athletes.[27]

Antioxidants

During exercise, oxygen consumption in muscle can increase 15-fold, leading to production of free radicals (or reactive oxygen species) that overwhelm the antioxidant protection system.[44] High concentration of these species can be harmful to many cellular tissues, although some reactive molecules such as hydrogen peroxide and nitric oxide may serve functions in cellular signaling and as secondary messengers in moderate concentrations.[3] Athletes should avoid foods that may increase oxidative stress and increase foods that are higher in antioxidants such as vitamins C and E. Two examples would be the Mediterranean diet, which has a favorable effect on blood lipids and also protects against oxidative stress,[9] and a diet high in fruits and vegetables, which raises plasma levels of antioxidants and protects against many chronic diseases.[3] Vitamin C promotes collagen synthesis, facilitates glycogen storage, and may prevent exercise-induced oxidative changes.[2] Vitamin E prohibits propagation of free radical formation. At high doses, vitamins C and E can be pro-oxidant, and large doses of vitamin E can also impede vitamin K metabolism and platelet function.[3]

There is little evidence that antioxidant supplementation enhances athletic performance,[32] although it may be beneficial in athletes recovering from injury. Athletes at greatest risk for poor antioxidant intake are those restricting EI, on a chronic low-fat diet, or limiting dietary intake of fruits, vegetables, and whole grains.[39]

NUTRIENT TIMING

Timing of nutrient intake depends on many variables, including the type of training (practice, strength, conditioning, or recovery), schedule, and the individual athlete's dietary preferences. Other variables include intensity and length of training, an active vs recovery day, and timing leading up to competition. Some endurance athletes may prefer a low-carbohydrate, high-fat diet as well. Intermittent fasting is also available to some athletes who are looking to lose fat and their training is later in the day or they may supplement if their first training session is a resistance workout. Macronutrient timing is summarized in Table 4.

Table 5. Summary of hydration guidelines

When	How Much to Consume	Comment
Preexercise	12-20 oz water or sport drink, 8 oz just prior to event	Consider small salty snack for fluid retention
During exercise	6-12 oz of water or sport drink every 15-30 minutes	No energy drinks. Consider sodium replacement in endurance events
Postexercise	16-24 oz of fluid for every pound lost	May obtain sodium and electrolyte replacement from a wide variety of foods

HYDRATION

Proper hydration is important for optimized performance, prevention of metabolic strain, and thermoregulation during exercise.[12] Athletes should have a proper hydration strategy before, during, and after exercise based on their specific needs and fluid losses. Most authorities support athletes losing <2% body weight during activity, as more than that decreases cognitive function and performance.[10,15,42,45] Thirst is often not a good indicator of dehydration as an athlete can sometimes lose 1.5 L before thirst is perceived.[12]

Athletes may lose anywhere from 0.3 to 2.4 L per hour of sweat, and rates vary widely based on environment, sex, body size, and length of activity.[48] Sweat comprises water, sodium, potassium, calcium, magnesium, and chloride, so athletes should replace both fluids and electrolytes with their recovery strategy. Hydration guidelines are summarized in Table 5.

NUTRITION DURING INJURY RECOVERY

As a way to facilitate healing, nutrition is often neglected. Athletes may often decrease intake in fear of weight gain during the recovery period. Nutrition can be an excellent tool to help attenuate muscle loss; limit fat gain; aid in muscle, bone, and collagen synthesis; as well as manage inflammation. While it is possible that caloric expenditure will be less during recovery, energy expenditure may initially increase 20% if the injury is severe[49] because of mobility modifications. For example, using crutches during immobilization uses 2 to 3 times the energy compared with walking.[53]

Athletes need to monitor caloric intake to decrease the loss of muscle mass during periods of decreased activity.[49] This is especially important with immobilization, which is associated with decreases in muscle protein synthesis and anabolic resistance.[49] Athletes should consider protein sources such as lean meats, dairy, and soy throughout the day. Those sources along with whey protein are also high in leucine, which aids in muscle synthesis.[33] Athletes should consider increasing protein intake during this time 1.2 to 1.5 times their usual level to help build healing tissue and limit muscle loss.[33] Once athletes begin active rehabilitation, they may resume normal training levels of calories and protein. Athletes may consider consuming 20 to 30 g of protein after rehabilitation sessions as they would with normal strength training sessions.[33] Limiting or eliminating alcohol is beneficial as alcohol can impair muscle protein synthesis.[30] Creatine supplementation may also help attenuate muscle loss during immobilization, but more research is needed.[13,16]

For bone healing and stress fractures, athletes should have adequate intake of calcium and vitamin D. For athletes with multiple stress fractures, clinicians should consider evaluating vitamin D and other laboratory studies as well as assessing female athletes for disordered eating practices. Zinc, vitamin A, vitamin C, and other micronutrients have a clear association with wound healing, tissue repair, and growth.[50]

Although inflammation is a necessary response to acute injury and is needed in the first phases of healing, prolonged inflammation may decrease recovery, and athletes should consider a diet higher in omega-3 oils such as salmon, flaxseed, and chia seeds.[49] Athletes should also look for foods high in vitamin C as it has anti-inflammatory properties and also has been shown to promote collagen synthesis.[50] Foods high in vitamin C include citrus fruits, red and yellow bell peppers, dark leafy greens, kiwi, broccoli, berries, tomatoes, mango, and papaya.

CONCLUSION

Sports nutrition is a key component for optimizing training, performance, injury prevention, and injury recovery. Nutritional recommendations need to be individualized for each athlete; thus, clinicians should be well informed to help determine proper caloric, macronutrient, micronutrient, and hydration intake based on the athlete's sport demands and training goals. An athlete's RMR along with his or her weight goals (loss, maintenance, or gain) are used to determine training macronutrient levels for protein, carbohydrate, and fat ratios. Micronutrient intake or supplementation should be determined based on identified nutrient deficiencies and/or dietary restrictions (eg, vegan, vegetarian) to assist with injury prevention and enhance injury recovery. Educating athletes on how to effectively fuel and hydrate for training sessions and competition based on the concept of nutrient timing is important to maximize performance. A comprehensive understanding of sports nutrition is crucial for clinicians to provide individualized and optimized recommendations.

REFERENCES

1. Adams KM, Butsch WS, Kohlmeier M. The state of nutrition education at US medical schools. *J Biomed Educ*. 2015;2015:357627.
2. Ashton T, Young IS, Peters JR, et al. Electron spin resonance spectroscopy, exercise, and oxidative stress: an ascorbic acid intervention study. *J Appl Physiol (1985)*. 1999;87:2032-2036.
3. Atalay M, Lappalainen J, Sen CK. Dietary antioxidants for the athlete. *Curr Sports Med Rep*. 2006;5:182-186.
4. Brukner P. Challenging beliefs in sports nutrition: are two 'core principles' proving to be myths ripe for busting? *Br J Sports Med*. 2013;47:663-664.
5. Burke LM, Hawley JA, Wong SH, Jeukendrup AE. Carbohydrates for training and competition. *J Sports Sci*. 2011;29(suppl 1):S17-S27.
6. DellaValle DM. Iron supplementation for female athletes: effects on iron status and performance outcomes. *Curr Sports Med Rep*. 2013;12:234-239.
7. Food and Agriculture Organization of the United Nations. *Human Energy Requirements: Energy Requirements for Adults* (Report of a Joint FAO/WHO/UNU Expert Consultation). Rome, Italy: Food and Agriculture Organization of the United Nations; 2004.
8. Frankenfield D, Roth-Yousey L, Compher C. Comparison of predictive equations for resting metabolic rate in healthy non-obese and obese adults: a systematic review. *J Am Diet Assoc*. 2005;105:775-789.
9. Galli C, Visioli F. Antioxidant properties of Mediterranean diet. *Int J Vitam Nutr Res*. 2001;71:185-188.
10. Goulet ED. Dehydration and endurance performance in competitive athletes. *Nutr Rev*. 2012;70(suppl 2):S132-S136.
11. Halliday TM, Peterson NJ, Thomas JJ, Kleppinger K, Hollis BW, Larson- Meyer DE. Vitamin D status relative to diet, lifestyle, injury, and illness in college athletes. *Med Sci Sports Exerc*. 2011;43:335-343.
12. Herring SA, Kibler WB, Putukian M, et al. Selected issues for nutrition and the athlete: a team physician consensus statement. *Med Sci Sports Exerc*. 2013;45:2378-2386.
13. Hespel P, Op't Eijnde B, Van Leemputte M, et al. Oral creatine supplementation facilitates the rehabilitation of disuse atrophy and alters the expression of muscle myogenic factors in humans. *J Physiol*. 2001;536(pt 2):625-633.
14. Jeukendrup A. The new carbohydrate intake recommendations. *Nestle Nutr Inst Workshop Ser*. 2013;75:63-71.
15. Jeukendrup A, Carter J, Maughan RJ. Competition fluid and fuel. In: Burke L, Deakin V, eds. *Clinical Sports Nutrition*. 5th ed. Sydney, New South Wales, Australia: McGraw-Hill; 2015:377-419.
16. Johnston AP, Burke DG, MacNeil LG, Candow DG. Effect of creatine supplementation during cast-induced immobilization on the preservation of muscle mass, strength, and endurance. *J Strength Cond Res*. 2009;23:116-120.
17. Katz DL, Meller S. Can we say what diet is best for health? *Annu Rev Public Health*. 2014;35:83-103.
18. Larson-Meyer DE, Willis KS. Vitamin D and athletes. *Curr Sports Med Rep*. 2010;9:220-226.
19. Loucks AB. Energy balance and energy availability. In: Maughan RJ, ed. *Sports Nutrition, The Encyclopaedia of Sports Medicine, an IOC Medical Commission Publication*. Chichester, England: Wiley; 2013:72-87.
20. Manninen A. High protein weight loss diets and purported adverse effects: where is the evidence? *J Int Soc Sports Nutr*. 2004;1:45-51.
21. Manore M, Thompson J. Energy requirements of the athlete: assessment and evidence of energy efficiency. In: Burke L, Deakin V, eds. *Clinical Sports Nutrition*. 5th ed. Sydney, New South Wales, Australia: McGraw-Hill; 2015:114-139.
22. Martin WF, Armstrong LE, Rodriguez NR. Dietary protein intake and renal function. *Nutr Metab (Lond)*. 2005;2:25.
23. Mettler S, Mitchell N, Tipton KD. Increased protein intake reduces lean body mass loss during weight loss in athletes. *Med Sci Sports Exerc*. 2010;42:326-337.
24. Mifflin MD, St Jeor ST, Hill LA, Scott BJ, Daugherty SA, Koh YO. A new predictive equation for resting energy expenditure in healthy individuals. *Am J Clin Nutr*. 1990;51:241-247.
25. Möhlenkamp S, Böse D, Mahabadi AA, Heusch G, Erbel R. On the paradox of exercise: coronary atherosclerosis in an apparently healthy marathon runner. *Nat Clin Pract Cardiovasc Med*. 2007;4:396-401.
26. Möhlenkamp S, Leineweber K, Lehmann N, et al. Coronary atherosclerosis burden, but not transient troponin elevation, predicts long-term outcome in recreational marathon runners. *Basic Res Cardiol*. 2014;109:391.
27. Mountjoy M, Sundgot-Borgen J, Burke L, et al. The IOC consensus statement: beyond the female athlete triad—relative energy deficiency in sport (RED-S). *Br J Sports Med*. 2014;48:491-497.
28. Noakes T. Time to quit that marathon running? Not quite yet! *Basic Res Cardiol*. 2014;109:395.
29. Noakes T, Volek JS, Phinney SD. Low-carbohydrate diets for athletes: what evidence? *Br J Sports Med* 2014;48:1077-1078.
30. Parr E, Camera D, Areta J, et al. Alcohol ingestion impairs maximal post-exercise rates of myofibrillar protein synthesis following a single bout of concurrent training. *PLoS One*. 2014;9:e88384.
31. Peeling P, Dawson B, Goodman C, Landers G, Trinder D. Athletic induced iron deficiency: new insights into the role of inflammation, cytokines and hormones. *Eur J Appl Physiol*. 2008;103:381-391.
32. Peternelj TT, Coombes JS. Antioxidant supplementation during exercise training: beneficial or detrimental? *Sports Med*. 2011;41:1043-1069.
33. Phillips SM, Van Loon LJ. Dietary protein for athletes: from requirements to optimum adaptation. *J Sports Sci*. 2011;29(suppl 1):S29-S38.
34. Phinney SD, Bistrian BR, Evans WJ, Gervino E, Blackburn GL. The human metabolic response to chronic ketosis without caloric restriction: preservation of submaximal exercise capability with reduced carbohydrate oxidation. *Metabolism*. 1983;32:769-776.
35. Pollan M. *In Defense of Food: An Eater's Manifesto*. New York, NY: Penguin Press; 2008.
36. Potgieter S. Sport nutrition: a review of the latest guidelines for exercise and sport nutrition from the American College of Sport Nutrition, the International Olympic Committee and the International Society for Sports Nutrition. *S Afr J Clin Nutr*. 2013;26:6-16.
37. Reaven G. Insulin resistance and coronary heart disease in nondiabetic individuals. *Arterioscler Thromb Vasc Biol*. 2012;32:1754-1759.
38. Reed GW, Hill JO. Measuring the thermic effect of food. *Am J Clin Nutr*. 1996;63:164-169.
39. Rosenbloom CA, Coleman EJ. *Sports Nutrition: A Practice Manual for Professionals*. Chicago, IL: Academy of Nutrition and Dietetics; 2012.
40. Roza AM, Shizgal HM. The Harris Benedict equation reevaluated: resting energy requirements and the body cell mass. *Am J Clin Nutr*. 1984;40:168-182.
41. Ruohola JP, Laaksi I, Ylikomi T, et al. Association between serum 25(OH)D concentrations and bone stress fractures in Finnish young men. *J Bone Miner Res*. 2006;21:1483-1488.
42. Sawka MN, Burke LM, Eichner ER, et al. American College of Sports Medicine position stand. Exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39:377-390.
43. Schwartz RS, Kraus SM, Schwartz JG, et al. Study finds that long-term participation in marathon training/racing is paradoxically associated with increased coronary plaque volume. *Missouri Med*. 2014;March/April.
44. Sen CK, Packer L, Hänninen O. *Handbook of Oxidants and Antioxidants in Exercise*. Amsterdam, Netherlands: Elsevier; 2000.
45. Shirreffs SM, Sawka MN. Fluid and electrolyte needs for training, competition, and recovery. *J Sports Sci*. 2011;29(suppl 1):S39-S46.
46. Simopoulos A. Omega-3 fatty acids and athletics. *Curr Sports Med Rep*. 2007;6:230-236.
47. Sundgot-Borgen J, Garthe I. Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. *J Sports Sci*. 2011;29(suppl 1):S101-S114.
48. Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. *J Acad Nutr Diet*. 2016;116:501-528.
49. Tipton KD. Dietary strategies to attenuate muscle loss during recovery from injury. *Nestle Nutr Inst Workshop Ser*. 2013;75:51-61.
50. Tipton KD. Nutritional support for exercise-induced injuries. *Sports Med*. 2015;45(suppl 1):S93-S104.
51. US Department of Health and Human Services, US Department of Agriculture. *2015-2020 Dietary Guidelines for Americans*. 8th ed. Washington, DC: US Department of Health and Human Services; 2015.
52. Volek JS, Noakes TD, Phinney SD. Rethinking fat as a performance fuel. *Eur J Sport Sci*. 2015;15:13-20.
53. Waters RI, Campbell J, Perry J. Energy cost of three-point crutch ambulation in fracture patients. *J Orthop Trauma*. 1987;1:170-173.