TIMING OF ENERGY AND FLUID INTAKE:

New Concepts for Weight Control and Hydration

by Dan Benardot, Ph.D., R.D., L.D., FACSM

LEARNING OBJECTIVE

- People who exercise may fail to meet the increased requirements for energy, resulting in an adaptive thermogenesis (*i.e.*, an adaptation to the inadequate provision of energy) that improves metabolic efficiency through an undesirable loss of fat-free mass. In addition, energy and fluid intake are often mistimed, failing to take full advantage of an eating and drinking paradigm that will aid in fatigue resistance and attainment of a desired body composition and weight. It is the objective of this article to help the reader understand how eating small, frequent meals and consuming fluid at regular intervals can sustain the hydration state and avoid systematic shifts in within-day energy balance that could be counterproductive to exercise performance and fitness.

Key words:
Energy Balance, Within-Day Energy Balance, Body Composition, Energy Surplus, Energy Deficit, Fluid Timing

It is well-established that physical activity increases the rate of energy expenditure and fluid loss, a fact that mandates the development of strategies for obtaining the needed extra energy and fluids. A failure to consume sufficient food and fluids to support the higher needs created by exercise will inevitably, over time, result in a loss of fat-free mass and will increase dehydration risk (1, 2). It is troubling, therefore, that surveys of physically active people suggest that they neither drink enough nor eat enough to optimally support their needs (3, 4). In addition, it seems that physically active people find it difficult to obtain energy and fluids when they are most needed and can have the greatest benefit (5, 6). It is impossible to keep a car running well without fluid in the radiator, and drinking fluids after dehydration occurs, although important for survival, does little for fatigue resistance during the activity. Therefore, it is important to consider strategies for supplying sufficient energy and fluids to meet demand and also important to consider the timing of intake to optimally satisfy real-time needs.

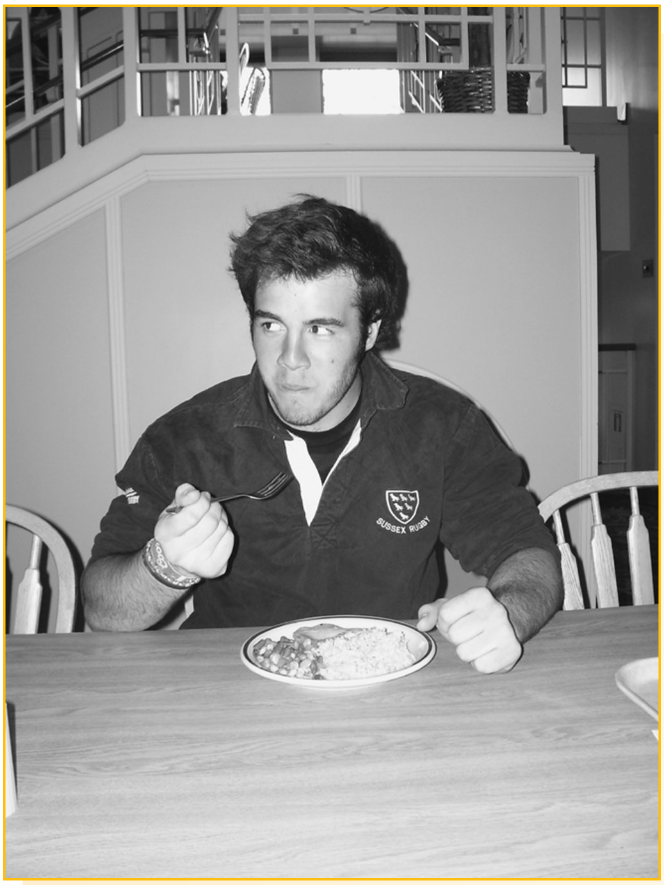
MEETING ENERGY NEEDS

There is a great deal of discussion on how to best distribute the energy substrates (carbohydrate, protein, and fat) to optimize performance, improve body composition, and achieve a desirable target weight. However, years of research suggests that a diet high in complex carbohydrate, moderate in protein, and relatively low in fat is best for both health and physical activity (Figure 1) (7).

The distribution of carbohydrate, protein, and fat is not as important as the total energy they supply in meeting weight goals (8). Put simply, an inadequate energy intake will make it more difficult for a physically active person to maintain muscle mass, even if the distribution of energy substrates is ideal. If not provided judiciously and coupled with resistance exercise, an excess energy intake could, over time, result in a greater increase in the fat mass than in the muscle mass, regardless of the energy substrate distribution. Neither scenario is likely to be desirable for the athlete or fitness enthusiast.

There is no magic substrate that makes weight loss efforts easier or better (contrary to the high-fat diet advocates). Weight loss, weight gain, and weight stability are a matter of energy balance. The following principle of energy thermodynamics is always with us and is the

ACSM Photo/Tanya Van Skyock



only valid explanation for weight change. Consuming more energy (*i.e.,* calories) than is burned results in weight gain; consuming less energy than is burned results in weight loss; consuming the same amount of energy that is burned results in weight maintenance (Figure 2) (9).

In fact, weight stability is an excellent sign that the intake of energy closely matches the need for energy. An inadequate energy intake results in weight loss with a reduction in both lean and fat mass. Energy deficiencies often lead to significant losses of the lean (*i.e.,* fat-free) mass to compensate for the inadequate energy by lowering the tissue mass that uses energy (10). Physically active people would find this change in body composition undesirable and rightly so. A lower lean mass translates into decreased physical performance. To make matters worse, the response to this undesirable change in body composition may cause some people to reduce energy intake still further, exacerbating an already bad situation (11). The confusion in what to do may be caused by an inappropriate mixing of terms. High fat does not mean high weight; leanness does not mean thinness; higher weight that is due to a higher lean mass is a good thing because it improves a person's capacity to burn energy.

It also is important to consider that the weight of fat is not the same as the proportion of fat. It is possible for a calorically deficient diet to result in the loss of both lean mass and fat mass, but if this leads to a greater loss of lean mass than fat mass, body fat percent rises. The greater the severity of the energy deficiency, the greater the differential loss of lean mass versus fat mass, resulting in a higher body fat percent even in the presence of a significant weight loss (12). It is this relative increase in fat mass coupled with a decrease in lean mass that is seen as the outcome of adaptive thermogenesis—a stable or higher weight with a lower energy intake. In other words, it should not be assumed that weight loss is synonymous with the loss of only fat.

Therefore, a significant reduction in energy intake (*i.e.,* dieting) will result in a weight loss, but the belief that it also will result in an improved body profile and body composition does not stand up to scrutiny. There is good evidence that weight rebound is a common aspect of dieting (affecting up to 80% of dieters), with the resulting weight composed of less lean and more fat (13). In addition, such low-energy diets are likely to lower the intake of essential vitamins and minerals, which may result in

Carbohydrates • 7 to 8 g/kg body weight per day • Complex carbohydrates rather than sugars are preferred sources (unless provided during or immediately following exercise)
Fats • 2 g/kg body weight per day • Maintain plasma triglycerides at <250 mg/dL
Protein • Adult: 1 – 2 g/kg body weight per day • Child: >2 g/kg body weight per day • Maintain high protein quality to reduce nitrogen excretion
Sources: Burke, L. and E. Coyle. Nutrition for athletes. *Journal of Sports Science* 22(1):39–55, 2004. Joint Position of the American College of Sports Medicine, the American Dietetic Association, and the Dietitians of Canada. Nutrition and athletic performance. *Medicine & Science in Sports & Exercise*® 32(12):2130–2145, 2000.

Figure 1. Recommended distribution of the energy substrates: carbohydrate, fat, and protein.

24-Hour Energy Intake
---------------------------- = Energy Balance
24-Hour Energy Burned

Examples:

3,000 calorie intake over 24 hours
-- = Perfect Energy Balance (weight maintenance)
3,000 calorie burned over 24 hours

3,000 calorie intake over 24 hours
-- = Positive Energy Balance (weight gain)
2,500 calorie burned over 24 hours

2,500 calorie intake over 24 hours
-- = Negative Energy Balance (weight loss)
3,000 calorie burned over 24 hours

Source:
Melby, C.M. and M. Hickey. Energy balance and body weight regulation. *Sports Science Exchange* 18:2, 2005.

Figure 2. Traditional view of energy balance.

nutrient deficiencies that increase injury and disease risks. For instance, inadequate calcium intake may lead to a higher risk for stress fractures, and a chronically low iron intake increases the risk for iron-deficiency anemia.

A closer view of the energy balance issue may enable a better understanding of how to best provide energy to achieve a more desirable weight, better body composition, and ultimately, enhanced fitness. Consider this example: a car with a 15-gallon fuel tank must go on a trip that requires 45 gallons of fuel. The fuel requirement would be the same whether all the fuel could be provided at once or whether the fuel were provided in three 15-gallon increments. The limitation on how much fuel can be provided is a function of the size of the fuel tank. Trying to provide all 45 gallons at once to a car with a 15-gallon capacity would be impossible without increasing the size of the car's gas tank. This would be analogous to eating too much energy at a meal, even if the total energy consumed during the entire course of the day was precisely the amount needed to sustain a state of energy balance. In human terms, enlarging the gas tank means enlarging the fat mass to store the excess energy.

ACSM Photo/Don Distel

An important study sheds some light on this issue. The researchers found that the athletes (female gymnasts and runners) who had the greatest energy deficits from predicted energy balance during the day had the highest body fat levels (14). This finding has important implications for physically active people because so many of them have diets that are characterized by energy deficits during the day with an emphasis on a large end-of-day meal to satisfy the earlier need for energy. This "backloading" of energy intake could be counterproductive in achieving desirable weight and body composition goals and, in the long run, may result in making normal eating more difficult. Even if this eating pattern was associated with an energy-balanced state, the within-day energy imbalances would likely be characterized by weight stability over time but with lower lean mass and a higher body fat percent, a potentially undesirable state for achieving peak athletic potential.

Another study that assessed eating frequency on athletes came to the same conclusion. The more frequent the eating pattern, the lower the body fat and the higher the muscle mass (15). Frequent eating with smaller meals reduces the size of within-day energy deficits and surpluses, helps to stabilize blood glucose, and also results in a lower overall insulin release than calorically equivalent large meals (16,17). Excess weight and obesity are significantly more common among people who consume three or fewer meals per day than those having five or more daily eating/snacking opportunities (18). In general, these findings all imply that the dynamics of energy intake and energy expenditure should be closely matched during the day.

DYNAMICS OF BLOOD GLUCOSE MAINTENANCE

Blood glucose peaks about an hour after a meal and returns to premeal levels in approximately 2 to 3 hours (19). Delayed eating can result in a further reduction in blood glucose to a level below the reference range, a condition referred to as hypoglycemia. This fasting hypoglycemia is associated with symptoms that include headache, loss of concentration, and fatigue, and if not corrected, may initiate the internal production of glucose (gluconeogenesis) from noncarbohydrate substances. These substances, which include lactate, alanine, glycerol, and pyruvate, come mainly from the working muscle. The amino acid alanine, a breakdown product of muscle, can be converted to glucose in the liver via the glucose-alanine cycle. After only 40 minutes of strenuous activity, the amount of free alanine can increase by 60% to 96% (20). Although converting alanine to glucose helps provide some stability to blood glucose, it does so at the cost of the muscle mass. The amount of muscle mass lost as a result of any individual case of alanine-derived gluconeogenesis is likely to be small, but the additive effect of chronically allowing blood glucose to drop from delayed eating may be important. Investigators have found that providing the same energy level for 2 wk in two groups of boxers resulted in a significantly greater muscle protein loss in those consuming the energy in two meals per day when compared with those consuming the same energy level in 6 meals per day (15). The most common cause of hyperinsulinemia is a rapid rise in blood glucose from refined carbohydrates. However, consumption of large meals or eating when in a hypoglycemic state also are associated with hyperinsulinemia (21). Regardless of the cause, excess insulin production encourages fat synthesis (22). Therefore, a pattern of delayed eating that is followed by an excessively large meal seems to be an ideal strategy for lowering muscle mass and increasing fat mass.

Hypoglycemia is associated with hunger, but people often try to dispel the hunger sensation by consuming caffeinated low- or no-calorie beverages. This strategy may stimulate the central nervous system to temporarily correct the feeling of hunger but does nothing to resolve the very real physiological need for blood glucose. Masking the sensation of hunger may further reduce blood glucose because the impetus to eat is temporarily removed. However, when people are eventually presented with real food after this excessive delay in caloric provision, they tend to overeat because the sensation of hunger becomes even more extreme (23,24). A good strategy for managing hunger is to maintain normal blood glucose through the consumption of 150 to 200 calories between meals. This is not a new strategy, as this is precisely what people did when morning and afternoon tea (with a cookie or cracker) was a societal norm. These between-meal snacks aid in hunger control, which results in the consumption of smaller regular meals. An added benefit is that increased meal frequency is associated with lower serum lipids and lower cortisol (a catabolic hormone) production (25). The between-meal snacking is unlikely to tip the energy balance equation in favor of a large energy surplus. On the contrary, an eating pattern that controls blood glucose is more likely to result in better control of energy intake (26).

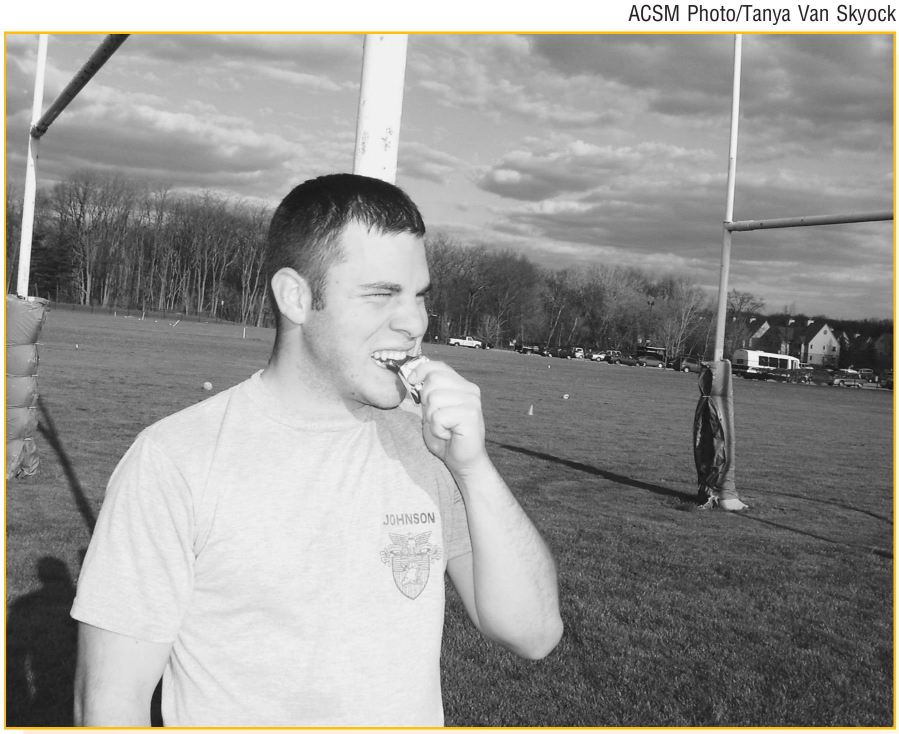
Clearly, a negative energy balance is necessary for weight loss to occur, but the magnitude of the daily energy deficit should be sufficiently subtle (perhaps −300 to −400 calories) so that normal appetite controls are maintained and body composition is improved (Figure 3). It helps, of course, to have a regular exercise program to provide a motive for the body's muscles to sustain themselves, but the exerciser should beware of creating too large an energy deficit or the tissues meant to be enhanced through exercise may be diminished (14,27,28).

MEETING FLUID NEEDS

Sustaining blood volume is critical for maintaining the delivery of nutrients to cells, removal of metabolic byproducts from cells, and sustaining the sweat rate during physical activity. Nevertheless, it has been shown that physically active people with ready access to fluids experience a blood volume–lowering degree of dehydration (29).

Heat dissipation through the evaporation of sweat is the primary mechanism for removing exercise-associated heat. About 75% to 80% of the energy burned for muscular work is lost as heat and can result in a 20-times higher heat production during exercise than at rest. At the very time working muscles require a greater blood flow, there is a need to shift blood away

ACSM Photo/Tanya Van Skyock



from muscles to assure an optimal sweat rate and to cool the blood itself. Should dehydration be allowed to occur, the resulting low blood volume would hinder these systems, leading to confusion, fatigue, and potentially, heat illness. The evaporation of a single milliliter of sweat can disperse about 0.58 calories of heat (assuming that all the sweat evaporates from the skin), so an intense indoor workout session that results in 300 calories of heat during 30 minutes would require about 500 mL of sweat (assuming sweat evaporation is the primary avenue of heat loss). The same exercise done outdoors on a hot and humid day would require even more sweat loss to remove the excess heat because the evaporation of sweat is less efficient with high humidity. It is not uncommon for the fluid requirement of some athletes on such days to exceed 3 L per hour (30).

An inhibitor to the natural consumption of fluid is that the sensation of thirst occurs after a loss of about 1.5 L of body water. Thirst is a warning sensation that encourages drinking before body water drops to a critically low level. The strategy for fluid consumption is similar to that for assuring the maintenance of blood glucose—drink small amounts frequently to avoid the sensation of thirst. Although water is an excellent fluid to consume when foods are consumed, the loss of sodium in sweat and the high utilization of blood glucose during physical activity require the consumption of a sodium- and

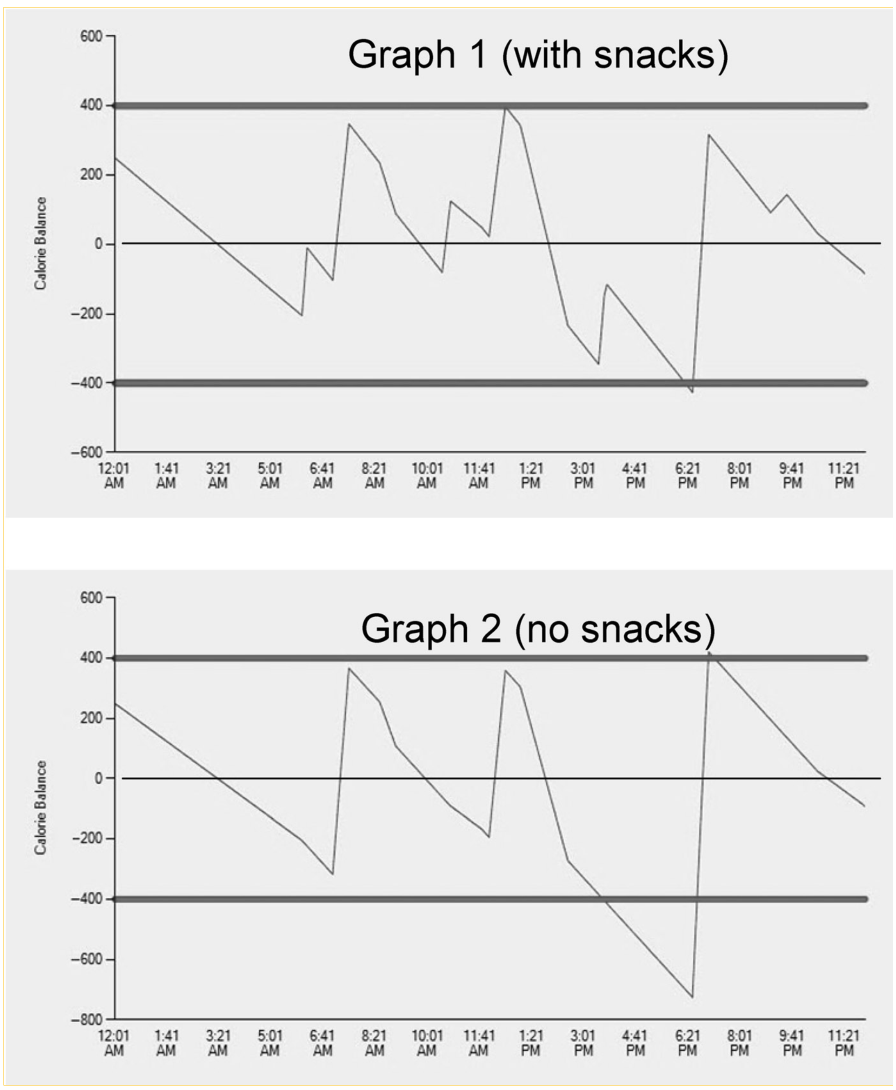


Figure 3. Comparison of within-day energy balance deviations in a 2500-calorie diet consumed with prebreakfast, prelunch, predinner, and postdinner snacks (graph 1) or the same 2500-calorie diet without snacks (the snacks were incorporated into a three-meal per day pattern to keep caloric intake the same). The zero (0) line represents the point of perfect energy balance (energy intake precisely matches energy expenditure). The lines at ±400 calories represent the hypothetical bounds for staying within a desirable energy balance during the day (these bounds may be smaller or larger, depending on individual factors). Note that (1) snacking helps to maintain a better energy balance during the day and (2) the energy deficit achieved before dinner at 6 p.m. without snacking is far greater without snacks. These values are based on an active 160-lb male who worked on a weight machine in the morning, rode a bicycle for 1 hour before lunch, and played tennis for 2.5 hours in the afternoon.

Before Exercise	• Drink plenty of fluids for the 24-hour period prior to exercise • Drink approximately 500 mL (about 16 ounces) of fluid 2 to 3 hours before exercise
During Exercise	• Drink between 150 to 350 mL (about 6 to 12 ounces) of fluid every 15 to 20 minutes during exercise. • Fluids should contain 4% to 8% carbohydrate and 0.5 to 0.7 g/L sodium if lasting 1 hour or more (water is fine for exercise of less than 1 hour)
Following Exercise	• Consume up to 150% of weight loss in exercise as fluid (1 lb body weight = 500 mL or about 16 ounces of fluid) • Consuming additional salt may aid rehydration and return of plasma volume.
Source: Joint Position of the American College of Sports Medicine, the American Dietetic Association, and the Dietitians of Canada. Nutrition and athletic performance. *Medicine & Science in Sports & Exercise*® 32(12):2130–2145, 2000.	

Figure 4. Hydration strategy before, during, and after exercise.

carbohydrate-containing beverage (typically 3 to 8 ounces every 10 to 15 minutes of a sodium-containing, 6% to 7% carbohydrate solution). Besides helping to sustain blood volume, sodium in beverages also encourages the desire to drink—an important factor in drinking enough to avoid dehydration. It is recommended that physically active people begin exercise in a well-hydrated state and take measures to sustain the hydration state during exercise; and because few athletes consume sufficient fluids during exercise, it also is recommended that a rehydration strategy be a common part of the postexercise period (Figure 4) (7).

SUMMARY

Studies suggest that there are several good reasons for considering the timing of energy and fluid intake:

1. Infrequent meals increase the risk that blood glucose will drop, resulting in an increase in the body's manufacture of glucose in the liver to sustain a minimally acceptable level of blood glucose. A primary source of substrate used to create glucose is the amino acid alanine, which is found in muscle. Therefore, allowing blood glucose to drop results in gluconeogenesis that, over time, may lower the mass that is responsible for burning energy.
2. Consumption of excess calories at a single meal encourages the storage of fat. Infrequent eating patterns mandate that more energy will be consumed at each meal to satisfy the total need for energy. However, there is a limit to how much energy cells can properly process at one time, so the excess energy is stored as fat. In addition, large meals are more likely to initiate excess insulin release than smaller meals, and high blood insulin levels are associated with high body fat levels.
3. Because infrequent eating patterns are associated with a loss of lean mass and an enlargement of the fat mass, the resultant change in body composition tends to favor a fat gain process. Excess body fat is associated with a hyperinsulinemic response to eating, regardless of food composition, making additional fat storage likely. In addition, the hunger associated with restrained eating is associated with higher stress hormone production (*i.e.,* cortisol), making the loss of lean mass more likely. In simple terms, hunger, which is partially the result of a lowering of blood glucose, should be avoided because the body composition changes that result are counterproductive. A lowering of the lean (metabolic) mass makes it more difficult for people to eat the way they were accustomed to eating without gaining weight. A loss of lean mass results in a lower metabolic mass and a lower energy expenditure. Lowering energy expenditure with the same energy intake results in an energy surplus and an increase in weight.
4. Inadequate fluid consumption, particularly during bouts of physical activity, that results in dehydration may inhibit the delivery of nutrients to cells and inhibit the removal of metabolic by-products from cells, both of which are factors in early exercise fatigue.
5. Physical activity is associated with the requirement to lose excess heat through the evaporation of sweat. A failure to remove this excess heat because of a poor hydration state may result in heat stress illness.

Dan Benardot, Ph.D., R.D., L.D., FACSM, is an associate professor in the Division of Nutrition, School of Health Professions, and an associate professor in the Department of Kinesiology and Health at Georgia State University. He serves as co-director of the Laboratory for Elite Athlete Performance, where athletes receive training and nutrition plans that assist them in their pursuit of athletic excellence.

References

1. Leibel, R.L., M. Rosenbaum, and J. Hirsch. Changes in energy expenditure resulting from altered body weight. *New England Journal of Medicine* 332(10):621–628, 1995.
2. Feinman, R.D., and E.J. Fine. "A calorie is a calorie" violates the second law of thermodynamics. *Nutrition Journal* 3:9, 2004.
3. Burke, L.M. Energy needs of athletes. *Canadian Journal of Applied Physiology* 26(Suppl):S202–S219, 2001.
4. Maughan, R.J., and T.D. Noakes. Fluid replacement and exercise stress. A brief review of studies on fluid replacement and some guidelines for the athlete. *Sports Medicine* 12:16–31, 1997.
5. Hawley, J.A., and L.M. Burke. Meal frequency and physical performance. *British Journal of Nutrition* 77:S91–S103, 1997.
6. Hubbard, R.W., P.C. Szlyk, and L.E. Armstrong. Influence of thirst and fluid palatability on fluid ingestion during exercise. In: *Fluid*

Homeostasis During Exercise, C.V. Gisolfi, and D.R. Lamb (Editors). Carmel, IN: Benchmark Press, 1990:39–95.

7. Joint Position of the American College of Sports Medicine, the American Dietetic Association, and the Dietitians of Canada. Nutrition and athletic performance. *Medicine & Science in Sports & Exercise®* 32(12):2130–2145, 2000.
8. Buchholz, A.C., and D.A. Schoeller. Is a calorie a calorie? *American Journal of Clinical Nutrition* 79(5):899S–906S, 2004.
9. Melby, C.M., and M. Hickey. Energy balance and body weight regulation. *Sports Science Exchange* 18:2, 2005.
10. Saltzman, E., and S.B. Roberts. The role of energy expenditure in regulation: findings from a decade of research. *Nutrition Reviews* 53(8):209–220, 1995.
11. Dulloo, A.G., and C. Girardier. Adaptive changes in energy expenditure during refeeding following low-calorie intake: evidence for a specific metabolic component favoring fat storage. *American Journal of Clinical Nutrition* 52:415–420, 1990.
12. Louis-Sylvestre, J., A. Lluch, F. Neant, et al. Highlighting the positive impact of increasing feeding frequency on metabolism and weight management. *Forum Nutrition* 56:126–128, 2003.
13. Wing, R.R., and S. Phelan. Long-term weight loss maintenance. *The American Journal of Clinical Nutrition* 82(1 Suppl.):222S–225S, 2005.
14. Deutz, B., D. Benardot, D. Martin, et al. Relationship between energy deficits and body composition in elite female gymnasts and runners. *Medicine & Science in Sports & Exercise®* 32(3):659–668, 2000.
15. Iwao, S., K. Mori, and Y. Sato. Effects of meal frequency on body composition during weight control in boxers. *Scandinavian Journal of Medicine & Science in Sports* 6(5):265–272, 1996.
16. Fogteloo, A.J., H. Pijl, F. Roelfsema, et al. Impact of meal time and frequency on the twenty-four–hour leptin rhythm. *Hormone Research* 62(2):71–78, 2004.
17. Steinacker, J.M., W. Lormes, S. Reissnecker, et al. New aspects of the hormone and cytokine response to training. *European Journal of Applied Physiology* 91(4):382–391, 2004.
18. Drummond, S., N. Crombie, and T. Kirk. A critique of the effects of snacking on body weight status. *European Journal of Clinical Nutrition* 50:779–783, 1996.
19. American Diabetes Association. Postprandial blood glucose. *Diabetes Care* 24(4):775–778, 2001.
20. Felig, P., and J. Wahren. Amino acid metabolism in exercising man. *The Journal of Clinical Investigation* 50:2703–2714, 1971.
21. Fábry, P., and J. Tepperman. Meal frequency–a possible factor in human pathology. *The American Journal of Clinical Nutrition* 23(8):1059–1068, 1970.
22. Cohn, C., S. Berger, and M. Norton. Relationship between meal size and frequency and plasma insulin response in man. *Diabetes* 17(2):72–75, 1968.
23. Hagan, M.M., P.C. Chandler, P.K. Wauford, et al. The role of palatable food and hunger as trigger factors in an animal model of stress induced binge eating. *The International Journal of Eating Disorders*. 34(2):183–97, 2003.
24. Mela, D.J. Determinants of food choice: relationships with obesity and weight control. *Obesity Research* 9(Suppl 4):249S–255S, 2001.
25. Jenkins, D.J., T.M. Wolever, V. Vuksan, et al. Nibbling versus gorging: metabolic advantages of increased meal frequency. *New England Journal of Medicine* 321(14):929–934, 1989.
26. Roberts, S.B. High-glycemic index foods, hunger, and obesity: is there a connection? *Nutrition Reviews* 58(6):163–169, 2000.
27. Blackburn, G.L., G.T. Wilson, B.S. Kanders, et al. Weight cycling: the experience of human dieters. *The American Journal of Clinical Nutrition* 49(5):1105–1109, 1989.
28. Benardot, D., D.E. Martin, W.R. Thompson, et al. Between-meal energy intake effects on body composition, performance and total caloric consumption in athletes. *Medicine & Science in Sports & Exercise®* 37(5):S339, 2005.
29. Maresh, C.M., C.L. Gabaree-Boulant, L.E. Armstrong, et al. Effect of hydration status on thirst, drinking, and related hormonal responses during low-intensity exercise in the heat. *Journal of Applied Physiology* 97(1):39–44, 2004.
30. Shirreffs, S.M., M.N. Sawka, and M. Stone. Water and electrolyte needs for football training and match play. *Journal of Sports Sciences* 24(7):699–707, 2006.

CONDENSED VERSION AND BOTTOM LINE

People should consider the following to enable body composition, weight, and hydration states that are associated with better fitness and health:

1. Obtaining sufficient total energy and fluids to support needs.
2. Timing the intake of energy and fluids to maximize their benefit in supporting athletic performance, fitness, body composition, and weight.
3. Modifying the diet so as to supply the best distribution of carbohydrate, protein, fat, and fluids to optimally support health and performance.
4. Matching the dynamics of energy intake and energy expenditure throughout the day to optimize fuel utilization. On a practical level, people could initiate a frequent eating/drinking strategy by taking a proportion of each meal, (*i.e.,* 200 calories) and consuming it (*i.e.,* 3 hours) after the meal. Because exercise quickly uses energy and fluids, some provision for avoiding hunger and thirst before, during, and immediately after exercise should be made. Foods such as energy bars and sports beverages may be useful in this regard.
5. Matching the dynamics of fluid intake and fluid loss throughout the day to optimize the hydration state. On a practical level, people with great sweat rates should become accustomed to carrying fluids with them so they are always available, and should practice sipping fluids, whether they are thirsty or not, to avoid thirst.