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ABSTRACT

Obesity is the costliest preventable health problem in the United States. Understanding and applying the first law of thermodynamics will help students prevent and treat this all-too-common problem.

Key Words: *Obesity; first law of thermodynamics; secondary education.*

Failure to understand the first law of thermodynamics impairs our nation's health. Students need to learn that obesity is caused simply by consuming more calories than the body expends. People offer many excuses for obesity: hormone imbalance, slow metabolism, genetics, big bones, willpower deficiency, limited access to healthy foods, poverty, and fear of looking too thin. Biologists also contribute to the complexity of obesity by discovering new hormones and signaling pathways involved in the regulation of body weight. Obesity is fundamentally, however, about calories in versus calories out. With obesity come significant health risks, including heart disease, hypertension, sleep apnea, and arthritis. Two thirds of adults in the United States are overweight (body mass index [BMI] > 25), and almost half of these overweight adults are obese (BMI > 30). Despite the above excuses, most people who are overweight are aware of their weight and want to shed pounds. It is incumbent on science teachers to bring physics into the biology class and combat excuses with the first law of thermodynamics. A simple exercise for students who have a good understanding of the first law is to apply it in as many ways as possible to the energy balance in the body.

The first law of thermodynamics states that energy is conserved, or that energy in closed systems cannot be created or destroyed. A beautiful introduction is given by Richard Feynman (1995) in the book *Six Easy Pieces*, in the chapter on conservation of energy. The conservation of indestructible children's toy blocks, and the intuitive formulation of equations to account for missing blocks, is a wonderful analogy for the unit of energy used with nutrition, the

Calorie. Once growth is completed, any excess energy not needed to maintain body temperature, cellular work, and body movements is converted to fat. Eating less than is needed for body metabolism leads to the breakdown of this body fat for energy. This body-fat storage of excess food intake represents the first refrigerator and was an adaptation when food sources were unpredictable. In developed countries today, where food is plentiful, easily accessed, and easily digested, this human refrigerator is often overstocked.

Students should be familiar with the energy unit used in nutrition. I will not use the SI units for energy and weight in this article, because the Calorie is used instead of the joule, and the pound instead of the kilogram, in most of the labeling and dieting literature to which students are exposed. The capital "C" calorie used in nutrition is the equivalent of 1000 small "c" calories used in

the physical sciences. Some quick conversions are useful. A pound of fat on the human body contains 3500 Calories. A 12-ounce can of soda has about 150 Calories. One can of soda a day, for 1 year, is equivalent to eating six 5-pound bags of table sugar over the year, and, if that one can a day is ingested in excess of Calories needed, results in the storage of 16 pounds of fat. If an adult is 5 feet 4 inches

tall, to go from a healthy normal BMI of 25 at 145 pounds to a BMI of 40 at a weight of 232 pounds, in the morbidly obese range, entails the ingestion of 3500 Calories per pound of fat times the extra 87 pounds, or 304,500 Calories. A 20-year-old would only have to have eaten 42 Calories a day more than the body needed over his or her lifetime to achieve this excess weight. That's the Calorie amount in only 4 ounces of soda. As should be clear, it's all about the Calorie. One can understand student misconceptions about energy by examining cans of popular drinks, like Monster Energy Lo-Carb, which has only 20 Calories in the 16-ounce can and 160 mg of caffeine. Another is 5 Hour Energy Drink, often sold at fitness centers, that sells for \$2 for a 2-ounce bottle and has caffeine but only 4 Calories (there is also an oxymoronic Calorie-free 5 Hour Energy Drink!). If a 1-mile run burns up 100 Calories,

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Table 1. Five approaches to legal and safe weight loss.

Approaches	How
Decrease input	Eat less food: habits, social groups Bariatric surgery: restrictive Appetite-suppressing drugs: lorcaserin; phentermine/topiramate (both FDA approved 2012)
Decrease food absorption	Bariatric surgery: malabsorptive Malabsorptive drugs Carbohydrates: Acarbose Fats: Orlistat, bile acid sequestrants Cholesterol: Ezetimibe Change gut flora?
Increase excretion	Glycosuria: potential drugs to inhibit renal reabsorption of glucose
Convert calories to heat	Eat ice Activate brown fat; cold, exercise
Increase output	Move

then that 4-Calorie 5 Hour Energy drink will supply the energy for only the first 200 feet.

Students should be able to apply this information, and what they have heard about dieting and obesity, to come up with a scientific approach to weight loss. Table 1 outlines five approaches to legal and safe weight loss using the first law of thermodynamics as a framework. These will be discussed in order.

Fewer Calories going into the closed system of the body is one obvious solution. This takes some willpower, because the body thinks it is starving rather than dieting and sends strong signals to eat. Simple habits like only eating at the table and using smaller plates will help. Forming social ties to thinner people also may help (Christakis & Fowler, 2007). Surgery for obesity is of three types: restrictive surgery that makes the stomach smaller so that satiety is reached sooner; malabsorptive types that link up the intestines so that most of the digesting and absorbing surface of the small intestine is bypassed; and a combination of both (Karmali et al., 2010). It is the restrictive type that results in decreased oral intake, because satiety is reached earlier. Two drugs were approved in 2012 to suppress the appetite by effects on the central nervous system, but after a year the median weight loss is only 10% for the better of the two drugs (Colman et al., 2012).

Once food enters the mouth, there are several strategies to prevent absorption. Malabsorptive type bariatric surgeries are mentioned above. No matter how much is ingested, the intestinal enzymes are bypassed so that digestion is minimized. Nutrients are passed into the stool. Intentional drug-mediated malabsorption is also possible (Powell et al., 2011). Acarbose is an oral drug that inhibits the intestinal enzyme alpha glucosidase, which releases glucose from polysaccharides, thus decreasing the digestion and absorption of carbohydrates. Orlistat (sold by prescription as Xenical and over the counter as Alli) inhibits pancreatic lipase, thus decreasing digestion and absorption of fats. Bile acid sequestrants like cholestyramine bind bile, thus diminishing its emulsifying effect and decreasing fat absorption. Ezetimibe specifically prevents the absorption of cholesterol by binding to a critical cholesterol receptor on the brush border of the intestine, and so it is used primarily for treatment of

hypercholesterolemia, but it also would have a small effect on weight loss. As of yet, there are no intestinal peptidase inhibitors used therapeutically. There is some evidence that the bacterial ecology of the intestine influences the absorption of nutrients, so that one potential treatment could be an alteration of the flora to cause less efficient absorption (Tilg et al., 2009). All these malabsorptive strategies are expensive and associated with side effects, including bloating, gas, and vitamin deficiencies. Students can discuss the ethics of taking medications or having surgery to decrease food absorption in the United States when Third World countries are struggling with basic nutrition and health needs.

Normally, any glucose in the glomerular filtrate in the kidneys is reabsorbed, leaving little or no glucose in the final urine product. Families have been found that have a mutation in a renal sodium–glucose co-transporter gene that codes for a protein called SGLT2 (Calado et al., 2006).

These phenotypes tend to lose glucose in the urine and also tend to be thin. In 2009, the FDA declined to approve a drug for diabetes, called dapaglifozin, which was an inhibitor of SGLT2, because it was linked to bladder cancers and genital yeast infections. This is an open avenue of research, because SGLT2 inhibitors block ~25% of renal glucose reabsorption, which amounts to ~70 g of glucose and 280 Calories per day (Chao, 2011).

Students can review their physical science courses by figuring out how much weight they would lose by eating a given amount of ice every day. The heat of fusion of ice is 80 calories (small “c”) per gram. The specific heat of water is 1 calorie per gram. Students can do the calculations to determine that eating 66 pounds of ice at zero degrees Celsius, and converting it to body-temperature water would require ~3500 Calories, which is the energy equivalent of 1 pound of fat.

Brown fat is a histological type of fat that is primarily used in thermoregulation rather than energy storage. UCP1 (uncoupling protein 1) is a protein activated in brown fat cells that allows hydrogen ions to pass through the inner mitochondrial membrane without generating ATP in the process. The potential energy stored in the chemiosmotic gradient is wasted as heat. Adrenaline and thyroxine are hormones that cause activation of uncoupling protein, but long-term use of these two hormones has negative health effects in the absence of a deficiency. Brown fat can be activated by regular exercise and by a cold environment (Celi, 2009). Turning down the thermostat in the house and exercising can both activate brown fat and help with weight loss. These steps are good for the body and good for the environment. There is an interesting benign tumor of brown fat cells, called a hibernoma, which is often associated with heat intolerance, night sweats, and leanness (Furlong et al., 2001).

Energy in food can be converted to the energy of motion through work and exercise. As described above, muscular activity not only burns through the energy in yellow fat deposits, but it also activates brown fat so that energy is burned as heat even after the physical activity. There are online calculators for determination of Calorie expenditure for a given type of exercise.

Obesity needs to be seen as a problem of energy balance rather than as a character defect. Approaching the topic in a scientific way will help students avoid making excuses and develop simple strategies, like eating less and exercising more, to be healthier.

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