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Obesity Energetics: Body Weight Regulation and the Effects of Diet Composition

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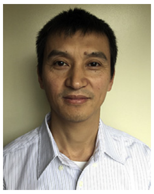

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Weight changes are accompanied by imbalances between calorie intake and expenditure. This fact is often misinterpreted to suggest that obesity is caused by gluttony and sloth and can be treated by simply advising people to eat less and move more. Rather various components of energy balance are dynamically interrelated and weight loss is resisted by counterbalancing physiological processes. While low-carbohydrate diets have been suggested to partially subvert these processes by increasing energy expenditure and promoting fat loss, our meta-analysis of 32 controlled feeding studies with isocaloric substitution of carbohydrate for fat found that both energy expenditure (26 kcal/d; *P* <.0001) and fat loss (16 g/d; *P* <.0001) were greater with lower fat diets. We review the components of energy balance and the mechanisms acting to resist weight loss in the context of static, settling point, and set-point models of body weight regulation, with the set-point model being most commensurate with current data.

Keywords: Body Weight Regulation; Energy Intake; Energy Expenditure; Macronutrients.

Obesity is often described as a disorder of energy balance arising from consuming calories in excess to the energy expended to maintain life and perform physical work. While this energy balance concept is a useful framework for investigating obesity, it does not provide a causal explanation for why some people have obesity or what to do about it.

In particular, obesity prevention is often erroneously portrayed as a simple matter of bookkeeping whereby calorie intake must be balanced by calorie expenditure.[1] Under this "calories in, calories out" model, treating obesity amounts to advising people to simply eat less and move more, thereby tipping the scales of calorie balance and resulting in steady weight loss that accumulates according to the widely known, but erroneous, 3500 kcal per pound rule.[2,3] Therefore, failure to experience substantial weight loss implies that an individual lacks the willpower to adhere to a modest lifestyle intervention over a sufficient period of time.

However, this naïve view is incorrect because it considers energy intake and expenditure to be independent parameters that can be adjusted at will and thereafter remain static without being influenced by homeostatic signals related to weight loss.[3] We now understand that energy intake and expenditure are interdependent variables that are dynamically influenced by each other and body weight.[4] Attempts to alter energy balance through diet or exercise are countered by physiological adaptations that resist weight loss.[5]

This review focuses on our current understanding of the components of human energy balance and the counterbalancing physiological processes that act to resist weight loss. Furthermore, we address the question of whether all diet calories are created equal regarding the effects of carbohydrate, fat, and protein on energy balance, body weight, and composition. Finally, we compare 3 conceptual models of energy balance regulation and examine the implications for human body weight dynamics and the treatment of obesity.

Components of Daily Energy Expenditure

There are 3 components of daily energy expenditure: the thermic effect of food, physical activity expenditure, and resting energy expenditure (REE) (Figure 1*A*).

Thermic Effect of Food

The smallest component of daily energy expenditure in humans is the thermic effect of food (also called *diet induced thermogenesis* or *specific dynamic action*), which is defined as the increase of metabolic rate observed for several hours following the ingestion of a meal.[6,7] The thermic effect of food is believed to represent the energy cost of digestion, absorption, storage, and metabolic fate of dietary

Abbreviations used in this paper: **REE, resting energy expenditure.**

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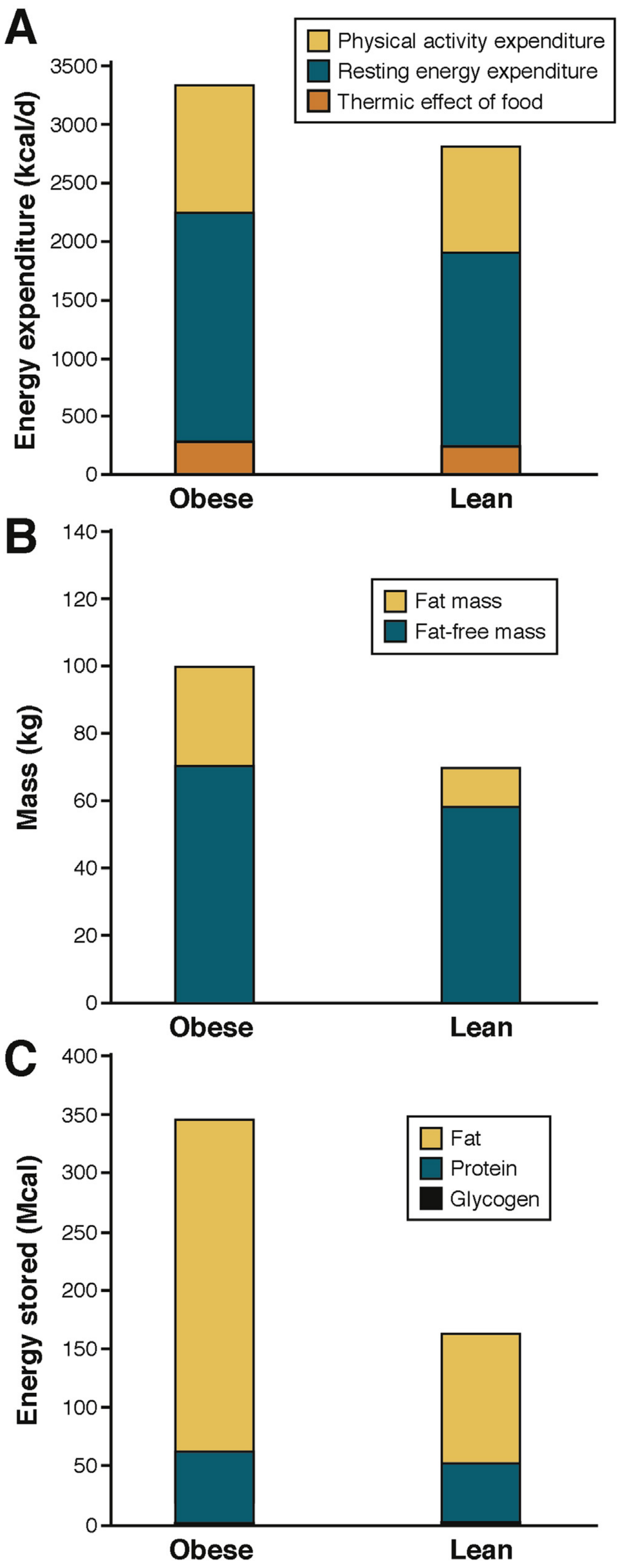
macronutrients.[7] While the precise mechanisms underlying the thermic effect of food are not fully understood, there is a clear macronutrient hierarchy, with protein causing a greater energy expenditure increment than carbohydrate, which is greater than that of fat.[7] For typical diet compositions, the thermic effect of food is approximated to be about 10% of energy intake (Figure 1*A*).



Resting Energy Expenditure

REE corresponds to the energy expended when not performing physical work and is typically the largest contribution to daily energy expenditure. Contrary to popular belief, people with obesity generally have a higher absolute REE (Figure 1*A*).[8] It has long been recognized that fat-free mass comprises the metabolically active tissues of the body and therefore contributes more to REE than body fat. Fat-free mass is elevated in obesity, along with body fat, resulting in increased REE compared with lean subjects (Figure 1*B*). Across a wide range of weights, REE is linearly related to both fat-free mass and body fat,[8] such that the elevated REE with obesity is generally in line with what is expected for the body weight and composition.

While fat-free mass, and to a lesser extent fat mass, are good predictors of REE, these variables explain only about 70% of inter-individual REE variability, such that for a given body composition the REE residual standard deviation is about 300 kcal/d.[8] Because the organs that contribute to the fat-free mass have a wide range of metabolic rates,[9] some of the residual REE variability after accounting for body fat and fat-free mass may be caused by variations in organ masses. Magnetic resonance imaging methodologies have been used to quantify organ sizes and REE prediction equations that sum the individual metabolic rates of various organs explain about 80% of the REE variability.[10,11]

Another potentially important contributor to REE involves fluxes through various energy-requiring metabolic pathways. Major macronutrient fluxes such as gluconeogenesis, de novo lipogenesis, triglyceride synthesis, and protein turnover all require energy and these flux rates can be significantly influenced by both the energy content of the diet as well as its composition.[12]

Physical Activity Expenditure

Physical activity expenditure can be subdivided into volitional exercise and the activities of daily living, also

Figure 1. Components of human energy expenditure and body composition in average 100-kg and 70-kg men. (*A*) Daily energy expenditure comprises the energy cost of digesting and processing food, called the thermic effect of food, the energy expended in physical activity, and the energy expended at rest to maintain life. People with obesity have a higher thermic effect of food because of greater food intake. Furthermore, people with obesity may expend comparable energy for physical activity despite typically moving around less than a lean individual because physical activity expenditure is proportional to body weight. Energy expended at rest is also greater in people with obesity because they have more metabolically active fat-free mass in addition to greater body fat as depicted in (*B*). (*C*) Body fat represents the vast majority of energy stores in the body compared with the energy content of body protein and glycogen. People with obesity can have vast quantities of stored energy in the form of body fat that represents several months of energy expenditure.