Time to Correctly Predict the Amount of Weight Loss with Dieting

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MAX WISHNOFSKY ASKED IN A 1958 REPORT, "What is the caloric equivalent of one pound of body weight gained or lost?"[1] After a thoughtful analysis of the existing literature, Wishnofsky concluded that "the caloric equivalent of one pound of body weight lost" or "gained will be 3,500." Fifty years later and with thousands of citations in the scientific literature and the lay press, Hill and his colleagues repeated the often-used statement "an energy deficit of approximately 3,500 kcal is needed to lose 1 lb of body weight" in the authoritative textbook, *Modern Nutrition in Health and Disease.*[2] Hill and colleagues are not alone, with the same rule of thumb posted more recently on the Mayo Clinic,[3] Livestrong,[4] and countless other websites. But Wishnofsky's Rule as applied is inaccurate, leaving many counseled patients wondering why their prescribed weight loss is far less than expected, even when they rigorously adhere to their registered dietitian nutritionist's recommendations.

Only rarely is the actual report by Wishnofsky[1] appropriately referenced, and the original concept is frequently mutated (eg, "weight" replaced with "fat" gain or loss) as it spreads virally across the Internet. What exactly is inaccurate and even scientifically incorrect with this half-century-old dictum?

The decade after World War II saw profound growth in knowledge about how humans gain and lose weight with changes in energy balance. Disturbances in energy balance that occur with famines, chronic wasting illnesses, and obesity were just coming into focus and subjected to experimental study. A small but scientifically rigorous experimental and analytical literature was available to Wishnofsky as he began his quest to find a simple rule governing weight loss or gain. He first drew on the 1911 chemical analysis of Bozenrad,[5] showing that 87% of human adipose tissue is "fat," the remainder is water and nonfat solids. We now recognize that most of adipose tissue fat is triglyceride and Wishnofsky correctly assigned this lipid fraction a bomb-calorimetry energy density of 9.5 kcal/g. Wishnofsky then reasoned 1 lb (454 g) of adipose tissue has an energy content of 3,750 kcal. He then turned to published experimental human weight-loss studies and carefully distinguished between protocols that prescribed fasting vs those providing a low-calorie and/or high-protein diet. Wishnofsky understood the critical importance of this distinction, as with fasting there are disproportionally large losses of body carbohydrate (glycogen) and protein with associated bound water. Turning to the 1930 classic, 59-day, very-low-calorie diet studies of Strang and colleagues,[6] Wishnofsky used the estimated daily energy and weight balance (−2,100 kcal/day and −0.6 lb/day) to derive the energy content of weight change as 3,500 kcal/lb. This result was "in striking agreement with the value of 3,700 kcal obtained" from computations based on Bozenrad's adipose tissue samples.[5]

Applying Wishnofsky's rule to predict the amount of weight loss in pounds resulting from reducing energy intake (E_I, kcal/day) or increasing exercise generated energy output (E_O, kcal/day) is simple: multiply the imposed deficit in energy stores (E_S, kcal/day) by duration of diet (in days) and divide by 3,500 kcal/lb. Several fundamental assumptions form the basis of Wishnofsky's rule: that the subject maintains a constant prescribed E_I; that weight loss is not influenced by changes in E_O; that on a low-calorie, balanced diet the main loss of body mass is derived from adipose tissue fat; and the energy content of weight loss is constant at 3,500 kcal/lb or 7,700 kcal/kg. Under what conditions do these assumptions hold? We now critically examine this question on the path to discovering why modern applications of Wishnofsky's rule provide an incomplete description of weight-loss kinetics.

WHY WISHNOFSKY'S RULE IS INACCURATE

To understand why Wishnofsky's rule as applied (3,500 kcal deficit→1 lb weight loss or 7,700 kcal→1 kg weight loss) is outdated and inaccurate, we need to first consider what we know about energy balance and weight loss with low-calorie dieting today. When a subject in weight equilibrium reduces energy intake without changing voluntary energy expenditure (eg, by increasing or decreasing physical activity), a period of negative energy balance follows that draws on energy stores. Assuming the subject is ingesting a low-calorie macronutrient-balanced diet, weight loss will proceed in two distinct phases; a rapid weight-loss phase during the first few days or weeks, followed by a slower weight-loss phase lasting up to 2 years.[7,8]

LOST WEIGHT NOT EQUAL TO 3,500 KCAL/LB AND ENERGY OUTPUT IS NOT CONSTANT

The early weight-reduction phase lasting several days or weeks[7,8] is characterized by relatively rapid loss in body mass consisting of a small carbohydrate (glycogen) pool, protein, and, to a lesser extent, fat as sources of energy. Water balance is also negative during this period, as carbohydrate and protein coupled with associated water are released with their oxidation, and fluid balance readjusts with changes in dietary sodium intake. Water is also a byproduct of carbohydrate and protein oxidation. The high fluid content and low proportion of weight loss as fat during the evolving early weight-loss phase is accompanied by an energy content of weight change that is not constant and considerably less than 3,500 kcal/lb.[7,8] As a contemporary example, men and women participants in the Comprehensive Assessment of Long-Term Effects of Reducing Intake of Energy (CALERIE I) study at Pennington Biomedical Research Center prescribed low-calorie (25% below baseline energy requirements) and very-low-calorie (890 kcal/day for 3 months followed by weight maintenance) diets had intensive monitoring of actual energy intake with doubly-labeled water and dual-energy x-ray absorptiometry body composition measurements during the 24-week weight-loss phase.[8,9] At week 4, the measured energy content of weight change was (mean$\pm$standard error of mean) 4,858$\pm$388 kcal/kg (2,208 kcal/lb), far lower than Wishnofsky's value of 7,700 kcal/kg (3,500 kcal/lb).

Although the timing of metabolic adaptations with low-calorie dieting is not exactly clear with respect to the early phase of weight loss, there develops over time hormonal and neural regulatory mechanisms that trigger reductions in resting energy expenditure, protein turnover, and other metabolic processes.[10,11] A reduced energy intake also leads to lowering of the thermic effects of feeding and perhaps to levels of nonexercise activity thermogenesis.[10] Taken collectively, exhaustion of the available glycogen pool and metabolic adaptations reduce the rates of protein catabolism and energy expenditure with a shift to increasing levels of fat oxidation.[7] The combined effects of these processes slows the rate of weight loss and leads into the second, slower weight-loss phase.

The second weight-loss phase extends for months or years, although very few supervised studies go beyond 6 months to 1 year that can be used to critically evaluate theoretically derived energy balance relations.[7] Because glycogen is largely depleted, oxidized carbohydrate comes mainly from the diet and glucogenic amino acids in protein. Nitrogen (ie, protein) balance approaches zero, the steady-state level depending on energy and protein intake.[12] Adipose tissue triglycerides constitute the main energy source during this period, with the rate of weight loss substantially reduced from the early diet period. By 24 weeks, the measured energy content of weight change observed in CALERIE I study participants had increased from the mean 4-week value (4,858$\pm$388 kcal/kg) to 6,569$\pm$272 kcal/kg (2,986 kcal/lb).[8,9]

As with the early phase of dieting, the composition (and energy content) of weight change during the later phase of weight loss evolves as defined by subject baseline characteristics, degree of prescribed energy deficit, and duration of dieting.[12,13] An important feature of this phase of weight loss is the slowing of energy output.[10] As noted earlier, resting energy expenditure, the thermic effect of feeding, nonexercise activity thermogenesis, and even activity thermogenesis are, or can be, reduced compared with baseline. In addition, decreasing body mass is accompanied by a reduced amount of metabolically active tissue and a lower energy cost of activity. The subject now notices a gradual slowing of weight loss, at some point almost imperceptible, and eventually cessation of weight loss occurs when energy equilibrium is restored at a new lower level.

MODERN APPROACHES TO WEIGHT-LOSS PREDICTION

Wishnofsky's views of weight-change dynamics were based on the limited understanding of fundamental metabolic processes at the time and his simple formulation was framed with impressions gained from short-term dieting studies completed in small samples of obese women.[6]

Today we view the kinetics of weight change with low-calorie diets or overeating in the larger context of energy metabolism and thermodynamics. The three main components of simple thermodynamic models are E_I, E_O, and E_S. Wishnofsky's focus was on the relationship between E_S (ie, $E_I - E_O$) and changes in body weight, with E_S/ΔWeight$=$ 3,500 kcal/lb based on Bozenrad's chemical analysis of adipose tissue.[5] Let us take an example from the Internet to see how Wishnofsky's rule is commonly applied and why it is inaccurate: "To get an idea of how much weight you could lose, remember that to lose one pound you need to reduce your caloric intake by 3,500 calories. So, if you replace your soda with water, and don't replace those calories elsewhere in your diet, your potential weight loss could be substantial." "Replace your 12 ounce can of [sugar-sweetened soda] with water every day and save 51,100 calories per year or about 15 pounds per year."[14]

A 12-oz can of soda is 140 kcal, so after 365 days (1 year) without that can of soda, E_S is $-$51,100 kcal ($-$140 kcal/day$\times$ 365 days) and this value divided by 3,500 kcal/lb is equal to approximately 15 lb, rounded to the nearest integer. Let us begin our critical analysis by assuming that the subject's E_I decreases by 140 kcal/day by reducing intake by one can of sugar-sweetened soda each day. Under these conditions, E_I is constant (ie, baseline $E_I - 140$ kcal/day), but rather than E_O and E_S/ΔWeight being constant as implied by Wishnofsky, both change over time. First, E_O decreases during negative energy balance for the reasons mentioned earlier; the presence of metabolic adaptations, reduced thermic effect of food and nonexercise activity thermogenesis, possible reductions in physical activity; and a loss of body heat producing lean tissues. When the reduction in E_O from baseline reaches exactly 140 kcal/day, the subject's weight loss will plateau at a new reduced weight. To reach a stable weight plateau often takes months or even years.[10]

Likewise, the energy content of weight change ($E_S/\Delta W$) is not constant at 3,500 kcal/lb, but is changing over time. Values are considerably less than 3,500 kcal/lb during the early, rapid weight-loss phase and approach 3,500 kcal/lb or 7,700 kcal/g during the second, slower weight-loss phase.[8] Both fat and lean tissues are lost and in a predictable way, as the body remodels to a new weight-loss plateau.[13,15]

Given these complex thermodynamic and metabolic effects from simply reducing one's energy intake by 140 kcal/day