Sylvia R. Karasu M.D.
The Gravity of Weight

Mathematical Models: Obesity by the Numbers

Toward greater precision in obesity research.

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"How to Be Thin," Color lithograph, English School, 20th century
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"...when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it...your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely advanced to the stage of science..."

So wrote 19th century Irish mathematician and physicist Lord Kelvin, famous for his experiments on heat energy (and for whom the Kelvin scale of absolute temperature was named.) (Lecture, 1883, in *Popular Lectures and Addresses*, 1889, Volume 1.) Kelvin's words are particularly relevant to the study of obesity.

Essentially obesity is a "disorder of energy balance," based on the *First Law of Thermodynamics,* that occurs when we consume more calories than we expend. But, explain researchers Kevin Hall and Juen Guo (*Gastroenterology*, 2017), this is merely a "useful framework" and does not provide any "causal explanation" for why some people are more prone to obesity than others. They clarify, "...obesity prevention is often erroneously portrayed as a simple matter of bookkeeping," i.e., that 3500 kcal equals a pound, but this widespread view, quoted on websites and throughout the media, is "naïve and incorrect" because it does not take into account the complex and dynamic *interdependent* relationship between intake and expenditure. (Hall and Chow, *International Journal of Obesity,* 2013; Thomas et al, *International Journal of Obesity*, 2013) Even in a recently published professional journal, researchers had used this "invalid" rule for their projected calculations of weight change in their study of type 2 diabetes. (See the comments by Andrew W. Brown and colleagues in *BMJ Open Diabetes Research and Care,* 11 September 2018.)

American school, 20th century, Credit: Copyright GraphicaArtis
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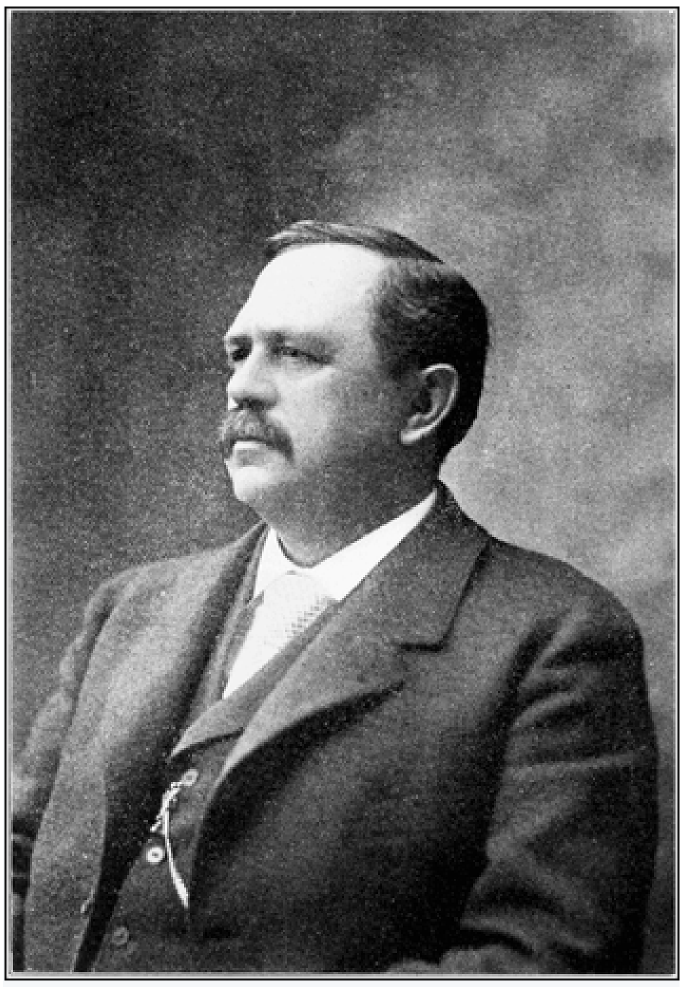
The 3500 kcal rule had been established in the late 1950s by Max Wishnofsky (*American Journal of Clinical Nutrition*, 1958). Wishnofsky acknowledged that weight change was complex, with an irregular "series of ups and downs, with frequent periods of no apparent weight change," and the 3500 kcal rule did depend on several variables, including the length of time of observation, whether someone was fasting, and the body's hydration. His oversimplified conclusion, though, was based on a small sample and short-term observations, as well as a "limited understanding of fundamental metabolic processes," and its inaccuracy has led "many patients wondering why their prescribed weight loss is less than expected." (Thomas et al, *Journal of the American Academy of Nutrition and Dietetics*, 2014) Nevertheless, the 3500 kcal rule, with its "fatal flaws," became gospel, with the result that patients have been blamed and potentially stigmatized or blame themselves for a lack of willpower and motivation. (Hall and Kahan, *Medical Clinics of North America,* 2018)



Wilbur O. Atwater, early 20th century obesity researcher established energy values for protein, fat, and carbohydrates
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It was Wilbur O. Atwater, an early 20th century researcher, who confirmed the law of conservation of energy in humans and established the energy values, still in use today, for protein (4 cal/gram); carbohydrate (4 cal/gram); fat (9 cal/gram); and alcohol (7 cal/gram). (Heymsfield et al, *European Journal of Clinical Nutrition*, 2017) But, say Allison and his colleagues, “Few dietary components are surrounded by more misinformation and myths than the calorie,” in part related to our “lack of accurate and practical methods” for assessing caloric intake and for establishing our caloric requirements over time. (Heymsfield et al, *American Journal of Clinical Nutrition*, 1995)

For years, researchers have accepted the self-reports of subjects for their caloric intake, as well as for their height and weight measurements and even their physical activity. What has now been established unequivocally is that these self-reports are often grossly inaccurate and lead to “questions of data validity.” Dhurandhar and colleagues (*International Journal of Obesity*, 2015), in response to the use of self-reports, have emphasized, "...something is *not* better than nothing." Reasons for this misreporting include inaccurate food labeling; inaccurate estimates of portions; psychological denial and self-deception; faulty memory; or even wanting to present themselves more favorably. (Heymsfield et al, 1995)

French artist Robert Delaunay, The Runners, 1926, Private Collection
Source: Wikimedia Commons/Public Domain

As a replacement for self-reports, we now have better measurement tools, such as the doubly labeled water method, a technique developed for “free-living” humans in the early 1980s to assess our metabolic rate and total daily expenditure over a few weeks, and the dual-energy X-ray absorptiometry—the DXA scan--developed in the 1970s to measure body composition, but even these are not completely free from error. (Thomas et al, *American Journal of Clinical Nutrition*, 2014; Thomas et al, *European Journal of Clinical Nutrition*, 2018; Heymsfield et al, *Obesity Reviews*, 2018) Further, in free-living situations, using our current methods, we are limited to observation periods--"snapshots"-- of about two weeks. (Hall et al, *American Journal of Clinical Nutrition*, 2012)

Maurice Brazil Prendergast, American artist, Large Boston Public Garden Sketchbook: Design for a Bicycle, 1895-97

More recently, though, researchers are now using “validated mathematical models,” and they have established, for example, that the so-called *diet plateau* that occurs after six months of dieting, in which weight loss seems to stop, is actually much more a function of patients “experiencing an exponential decay of diet adherence.” (Freedhoff and Hall, *The Lancet*, 2016; Hall and Guo, 2017) For reasons that are not fully understood, diet adherence, including "sustaining dietary choices and behaviors," is "so challenging that it is poor even in short-term studies when all food is provided." (Freedhoff and Hall, 2016) The researchers, though, do emphasize that there is considerable individual variability and while weight loss and maintenance are difficult, there are many anecdotal stories of successful dieters. Further, although there is some metabolic adaptation to weight loss, and losing weight can slow down metabolism for complex reasons, including that caloric expenditure declines with weight loss (Hall, *Obesity*, 2018), Source: Metropolitan Museum of New York, Public Domain, Robert lehman Collection, 1975

hormonal "mediators" of appetite change (Heymsfield et al, *Obesity*, 2017) and considerable physical activity is required to maintain the loss, (Hall, 2018) this does not explain the six-month plateau described by many dieters. It is the "seemingly innocuous intermittent loss" of diet adherence--i.e., the "behavioral fatigue" (Hall and Kahan, 2018)--that is mostly responsible. (Thomas et al, *American Journal of Clinical Nutrition*, 2014)

A Race in Ancient Greece
Source: Wikimedia Commons/Public Domain

Mathematical models can also be particularly useful in simulating experimental designs that would not be ethical or practical. Another "novel application" is their use to predict, from short-term results, which patients will be more successful in their weight loss over the long-term, i.e., to determine who are the "responders" to a particular intervention and if not, to suggest a change in strategy, according to Allison and colleagues (Dawson et al, *Advances in Nutrition*, 2014.) Further, researchers have used a mathematical model to evaluate the complex interactions between genetic and non-genetic modes of transmission of obesity and to assess prevalence rates. (Ejima et al, *Obesity*, 2018) This model has predicted that obesity prevalence unfortunately will reach 41% of the U.S. population by 2030.

Allison and colleagues (Ivanescu et al, *International Journal of Obesity*, 2016), though, appreciate the importance of validating their mathematical models. For example, a model derived from one finite sample will not always predict as well on the overall population from which the sample was taken or on a new sample from a different population--a phenomenon they call *validity shrinkage*. To validate a model, new datasets are required. For an excellent example of how researchers used four different classical studies, including those by Claude Bouchard and Ancel Keys, to validate their model, see Thomas and her colleagues in the *American Journal of Clinical Nutrition,* 2014.

"Calorie Count," (Computer Graphics), 2008, by Diana Ong
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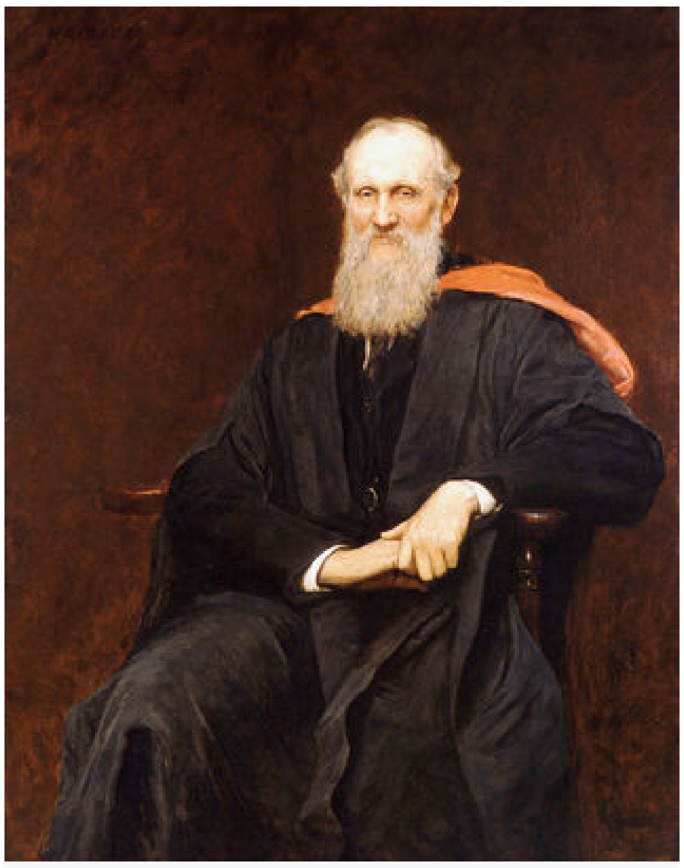
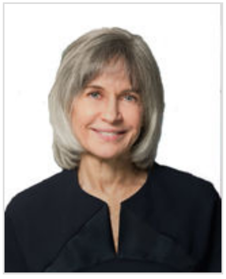
Bottom line: For years, obesity research has suffered from severe methodological deficiencies that have led some investigators to emphasize the need for better, not necessarily more, research. For example, when people think they are adhering to diets, they may, even unconsciously, not be doing so. Further, countless studies have relied, not on accurate measurement, but on notoriously inaccurate self-reports of caloric intake, caloric expenditure, height and weight. Even the rule of thumb in which 3500 kcal equals one pound is simplistic and erroneous. To remedy these defects, researchers have begun to generate mathematical models in an attempt to create greater precision in measurement and clarify why it is so difficult for people to lose weight and particularly, to maintain that loss over time. No model is perfect: models may have what investigators call *validity shrinkage*, and even mathematical models are only as good as the data from which they are originally derived. All research is a work-in-progress. Nevertheless, these mathematical models are a vast improvement over years of inaccurate data, and obesity investigators will benefit considerably from incorporating them into their research. Lord Kelvin would approve.

Note: For one web-based tool to estimate weight loss over time, refer to the Body Weight Planner. (Hall and Kahan, 2018)



Portrait of Lord Kelvin, Irish mathematician and physicist, before 1907, by Hubert von Herkomer. Glasgow Museum. Source: Wikimedia Commons/Public Domain

About the Author



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