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Review

Chronic Positive Mass Balance is the Actual Etiology of Obesity: Time for A Paradigm Shift?

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Abstract

According to known laws of physics, chronic positive mass balance is the actual etiology of obesity, not positive energy balance. The relevant physical law in terms of body mass regulation is the Law of Conservation of Mass, not the Law of Conservation of Energy. A recently proposed mass balance model (MBM) describes the temporal evolution of body weight and body composition under a wide variety of feeding experiments, and it seems to provide a highly accurate description of the very best human experimental feeding data. By shifting to a mass balance paradigm of obesity, a deeper understanding of this disease may follow in the near future.

Keywords: energy balance theory; mass balance model; body weight regulation

Introduction

”*People are able to break any laws made by humans, but none made by physics*.” – Elon Musk

It is widely assumed that the fundamental cause of obesity is an energy imbalance between calories consumed and calories expended (i.e., the energy balance theory; EBT: ”Calories In, Calories Out”). According to known laws of physics, however, this century-old obesity paradigm must be fallacious. **The relevant physical law in terms of body mass regulation is, obviously, the Law of Conservation of Mass, not the Law of Conservation of Energy.**

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This is not a matter of opinion; rather, it is based on *exact* natural sciences. It is possible for an open system, such as the human body, to be at mass balance while the system experiences a persistent energy imbalance. That is, energy balance may be positive ($\Delta E > 0$) or negative ($\Delta E < 0$) yet the *mass* change that may occur during energy flux is not required by the Law of Conservation of Energy (i.e., the First Law of Thermodynamics) to mirror the energy balance *direction* [1,2,3].

The Law of Conservation of Mass

The Law of Conservation of Mass states that the mass can neither be created nor destroyed by chemical or physical changes. In other words, *total mass is always conserved*. This law dates from Antoine Lavoisier's 1789 discovery *par excellence* that **mass is neither created nor destroyed in any chemical reaction** [4]. Clever Frenchman heated mercuric oxide (HgO) and demonstrated that the amount the chemical's mass decreased was equal to the mass of the oxygen gas released in the chemical reaction. Lavoisier proved that mass must be conserved in chemical reactions, meaning the total amount of mass on each side of a chemical equation is always the same. That is, **the total number of atoms in the reactants must equal the amount in the products**, regardless of the nature of the chemical change. This forms the basis of *stoichiometry*, i.e., the accounting process by which chemical reactions and equations are mathematically balanced in terms of both mass and number of atoms on each side.

As an example, the oxidation of one generic triglyceride molecule:

$C_{55}H_{104}O + 78O_2 \rightarrow 55CO_2 + 52H_2O$ + HEAT 8,084 kcal

Reactants:		*Products:*	
$C_{55}H_{104}O$	860 g	$55CO_2$	2,420 g
$78O_2$	2,496 g	$52H_2O$	936 g

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3,356 g	3,356 g

Note that there is mass only in reactants and products, but not in energy (calories).

The mass-energy equivalence principle

The mass-energy equivalence principle implies that when energy is lost in chemical reactions, the system will also lose a corresponding amount of mass. As far as the regulation of body mass is concerned, however, this equivalence principle has been misunderstood. This **global misconception** requires a detailed clarification.

Here is a very good question from one of my colleagues:

"How is energy intake and expenditure not the governing factors that determines if the body store the food we eat as fat or not? How could one change that? How can the mass of the food change that? If the eventual weight loss is from water, urea, or whatever [it] is still determined by if the body replace it or not, or even store more than was used. **Where is the gap where energy expenditure is not representative of substrate [i.e., mass] being used?**"

In order to see why nutrient mass, not nutritional energy, is the quantity that determines body mass fluctuations one has to unavoidably think in terms of arithmetic and analytical chemistry as shown next. The caloric values of macronutrients are rounded.

Weight gain is the result of mass accumulation, not the result of energy accumulation

Consider two individuals that gain 1 kg of non-water body weight as they accumulate within body cells 1000 g of absorbed macronutrients. The macronutrient distribution of the first subject is as follows:

- 200 g of protein = 200 g x 4 kcal/g = 800 kcal
- 300 g of carbohydrate = 300 g x 4 kcal/g = 1200 kcal
- 500 g of fat = 500 g x 9 kcal/g = 4500 kcal

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Thus, the total stored nutritional energy is 800 kcal + 1200 kcal + 4500 kcal = 6500 kcal.

Suppose, next, that the macronutrient distribution of the second subject is as follows:

- 400 g of protein = 400 g x 4 kcal/g =1600 kcal
- 400 g of carbohydrate = 400 g x 4 kcal/g =1600 kcal
- 200 g of fat = 200g x 9 kcal/g =1800 kcal

Thus, the total stored nutritional energy is 1600 kcal + 1600 kcal + 1800 kcal = 5000 kcal.

This example illustrates, therefore, that the property of food related to weight gain is its mass, not energy. The first subject, in effect, has accumulated substantially more nutritional energy than the second one yet both have experienced the same degree of weight gain.

Weight loss is the result of mass elimination, not the result of energy expenditure

Consider the oxidation of 100 g of glucose:

- $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$ + HEAT (720 kcal/mol of $C_6H_{12}O_6$)

This requires the uptake of 107 g of O_2 as 100 g $C_6H_{12}O_6$ x (192 g O_2/180 g $C_6H_{12}O_6$) ≈ 107 g O_2. The Law of Conservation of Mass implies that mass of the products = mass of the reactants. The amount of water and carbon dioxide formed is 207 g as mass of the products = mass of the reactants = 100 g $C_6H_{12}O_6$ + 107 g O_2 = 207 g.

Now, assume that all the produced water and carbon dioxide are used in the following way:

1. Water becomes intracellular water in newborn cells

2. Hydrolysis reactions (i.e., the cleavage of a chemical bond by adding a water molecule which becomes part of the reaction products): for example, the release of thyroid hormones thyroxine (T4) and triiodothyronine (T3) requires a hydrolysis reaction.

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3. Carboxylation reactions (i.e., the addition of carbon dioxide to a molecule): for example, carboxylation of acetyl-CoA during fatty acid synthesis.

Notice that in the aforementioned situation 400 kcal has been expended by oxidizing 100 g of glucose yet body mass will not decrease when heat is dissipated but when the 207 g of reaction products are eliminated which in the described case are not since, as illustrated, oxidation products become part of the body mass.

Energy balance <u>cannot</u> occur at body mass stability

The Law of Conservation of Mass guarantees that body mass stability (i.e., mass balance) can occur ONLY when the mean absorbed mass of each macronutrient equals its respective mean oxidized mass. Otherwise, body mass is increasing (i.e., absorbed mass > oxidized mass) or decreasing (i.e., absorbed mass < oxidized mass).

More specifically, energy balance can occur at body mass stability ONLY if the following three conditions are simultaneously satisfied:

1. Average absorbed fat mass = average oxidized fat mass

2. Avarage absorbed carbohydrate mass = average oxidized carbohydrate mass

3. Average absorbed protein mass = average oxidized protein mass

Obviously, this can never happen; and thus *energy balance is unattainable at body mass stability*.

The regulation of body mass

By now it should be clear that the regulation of body *mass* is all about detailed *mass* balances (”Mass In, Mass Out”), not about energy conservation (”Calories In, Calories Out”). After all, we are talking about body *mass*. A recently proposed **mass balance model** (**MBM**) describes the temporal evolution of body weight and body composition under a wide variety of feeding experiments, and it seems to provide a highly accurate description of the very best human experimental feeding data (e.g., 1,2,3*).* For example, we have compared head-to-head the predictions given by the MBM with the EBT-based model of Hall and coworkers, and the MBM seems to be superior to the EBT-based model [1]. And the ranking of such models is determined by their predictive accuracy. *I would like to emphasize that the MBM not only predicts the change in total body mass but also the change in fat mass*. For a detailed review, please see [3].

The Law of Conservation of Mass guarantees that *1)* the O_2 mass that enters cellular respiration plus *2)* the mass of macronutrients that served as energy fuel absolutely must equal the mass of the excreted oxidation products. *This is not a matter of opinion*. Daily weight loss must, therefore, be the result of daily elimination of oxidation products (CO_2, water, urea, SO_3; "Mass Out"), not a consequence of the heat release upon nutrient combustion (i.e., daily energy expenditure) [5]. And it is macronutrient mass intake ("Mass In") that augments body mass; the absorption of 1 g of glucose, protein or fat increases body mass by exactly 1 g independent of the substrate's Calories, as dictated by the Law of Conservation of Mass. The absorbed nutrient mass cannot be destroyed and, thus, it will contribute to total body mass as long as it remains within the body. Such a contribution ends, however, when the nutrients are eliminated from the body either as products of metabolic oxidation or in other forms (e.g., shedding of dead skin cells).

Animals, including humans, ingest food to get both energy and mass. While energy refers to capacity to do work, mass is used to build all bodily structures. Not a single gram of body mass is gained due to the energy intake. Calories represent the *heat* release upon food oxidation, and as such, Calories have no impact on body mass. Heat does not produce mass. Consequently, the *only* food property that can augment body mass is its nutrient mass, not its energy content (i.e., Calories).

It follows that any anti-obesity intervention must

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1) ***Decrease intake of energy-providing mass*** (EPM) ("Mass In"), i.e., satiating effect. EPM is the daily intake of carbohydrate, fat, protein, soluble fiber and alcohol.

2) ***Increase elimination of oxidation products*** ("Mass Out"). Each day we experience a weight loss given by the weight of the energy expenditure-dependent mass loss (EEDML) plus the weight of the energy expenditure-independent mass loss (EEIML) [3]. EEDML refers to the daily excretion of EPM oxidation byproducts (CO_2, water, urea, SO_3), whereas EEIML represents the daily weight loss that results from *i)* the daily elimination of non-metabolically produced water; *ii)* minerals lost in sweat and urine; *iii)* fecal matter elimination; and *iv)* mass lost from renewal of skin, hair and nails [3]. Or

3) ***Both***.

A low-carbohydrate diet *vs.* an isocaloric high-carbohydrate diet

A highly significant practical application of a mass balance approach is that **a low-carbohydrate/high-fat diet leads to a greater body mass and fat mass loss than an isocaloric high-carbohydrate/low-fat diet because it provides less nutrient mass** [1,2,3]. When the energy fraction from dietary fat increases, while energy intake is clamped (i.e., fixed), mass intake decreases due to the significantly higher energy density of fat compared with other energy substrates. Such a difference in mass intake translates into greater body mass and fat loss in a low-carbohydrate diet *vs.* an isocaloric high-carbohydrate diet. If such a feeding response is not observed, then it is simply not a well-controlled study, as alternative results would indicate a violation of the Law of Conversation of Mass.

If two persons eliminate body mass at the same daily rate, then the one ingesting less nutrient mass will express a greater daily body mass and fat loss. For example, daily energy intake of 2,500 kcal distributed as 30% fat (9.4 kcal/g), 55% carbohydrate (4.2 kcal/g) and 15% protein (4.7 kcal/g) corresponds to a mass intake of ~487g, whereas the same

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energy intake sorted as 60% fat, 30% carbohydrate, and 10% protein reduces mass ingestion by ~96g. This is not a small difference in the long run.

In **Figure 1**, I present two hypothetical overweight individuals whose body composition and total energy intake are identical, but the distribution of macronutrients is clearly different.

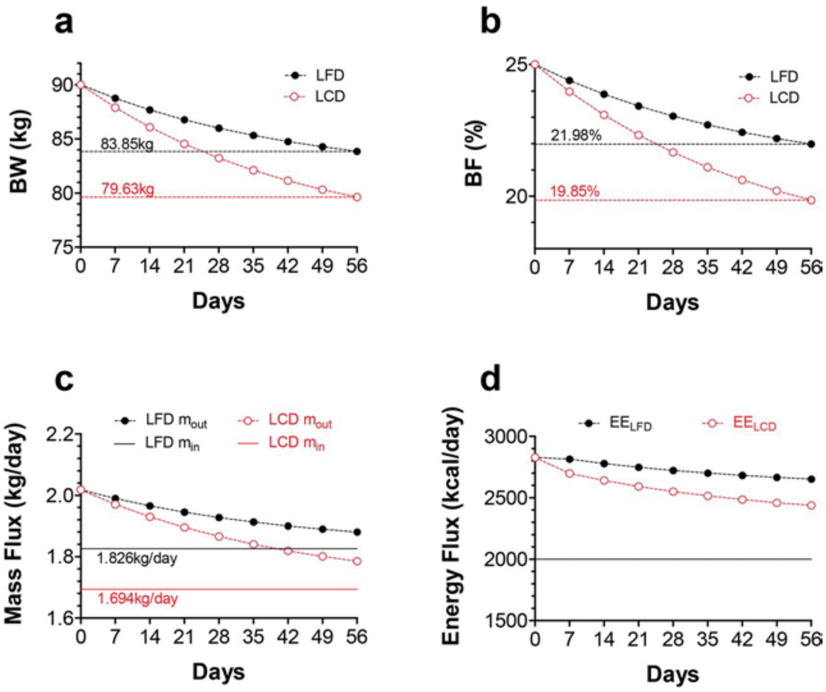

Figure 1. *MBM-based simulation of two hypothetical overweight (90 kg) individuals whose body composition and total energy intake are identical, but macronutrient distribution is clearly different*. In the initial situation, the nutrient intake is as follows: energy intake 2 750 kcal/day; 35% fat (F), 50% carbohydrate (C), 15% protein (P). Next, these individuals start following either a 2 000 kcal high-carbohydrate/low-fat diet (LFD) or a 2 000 kcal low-carbohydrate/high-fat diet (LCD), whose macronutrient distribution is as follows: LFD = 20% F, 65% C, 15% P or LCD = 70% F, 15% C, 15% P. The MBM predicts that the LCD results in greater body mass and fat mass loss compared with the LFD. As demonstrated, the nutrient mass intake (m_{in}) is smaller compared with the eliminated mass (m_{out}); and thus the net daily mass loss is larger (i.e., $m_{in} - m_{out}$|).

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Epidemiological data supporting the MBM

As recently pointed out by Mozaffarian [7], **the National Health and Nutrition Examination Survey (NHANES) data do NOT show any increase in energy consumption or availability over ≥20 years,** a time period when obesity has steadily risen (See Figure 1 in [7]). In fact, NHANES data suggest small but statistically significant *declines* in energy intake over this period [7]. Such a phenomenon can be explained by the fact that the dietary recommendations started to focus on carbohydrates and urged to reduce fat. In this case, the intake of nutrient mass increases while the calorie intake remains the same. Thus, such a phenomenon is perfectly consistent with the MBM.

The Nutrition Facts label

The Nutrition Facts label on packaged foods was updated in 2016 ”to reflect updated scientific information, including information about the link between diet and chronic diseases, such as obesity and heart disease.” [6}. One of the most prominent updates of the new food labeling regulations released by the Food and Drug Administration (FDA) is found on the calorie line; the font for calories has been significantly enlarged as well as emboldened for first-glance reference. The idea behind this well-meaning update was that Caloric values can be very simply understood without having to look very deeply into the food label. Humans need, of course, energy (i.e., the capacity to do work) but Calories have no impact on body mass. Thus, **the calorie line should be replaced, or complemented, with the mass line** (e.g., “Nutrient Mass” or just “Mass”).

It is also worth noting that the concept of ”light product” is very misleading. In reality, these products are often ”heavy products”. When the energy fraction from dietary fat increases, while energy content remains the same, mass intake decreases due to the significantly higher energy density of fat compared with other energy substrates. Thus, ***a high-***

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carbohydrate "light product" containing 200 kcal provides more mass than a high-fat product containing 200 kcal. This fact should have a significant impact on the prevailing legislation and the operation of the food industry.

Behavioral aspects of obesity

The MBM makes no claims regarding the behavioral aspects of obesity whatsoever. Rather, it describes the actual etiology of obesity. Further discussion of this topic is thus clearly outside of a scoop of my paper.

Conclusions

I would like to propose a new paradigm that paints a more accurate picture of the evolution of body weight: **Chronic positive mass balance is the actual etiology of obesity, not positive energy balance**, possibly opening up a completely new era in obesity research. By shifting to a mass balance paradigm of obesity, a deeper understanding of this disease may follow in the near future. The immediate consequence of such a shift is that feeding studies will become much more accurate and significantly less expensive as mass measurements are cheaper and do not suffer from all the problems that energy measurements do.

For further details, please see, including Supplementary Files, [1], [2] and [3]. Please note that only the most important references are listed for this article, as the others can be found in the aforementioned papers.

Conflict of interest

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List of abbreviations

MBM = mass balance model; EBT = energy balance theory; EPM = energy-providing mass; EEDML = energy expenditure-dependent mass loss; EEIML = energy expenditure-independent mass loss; NHANES = National Health and Nutrition Examination Survey; FDA = Food and Drug Administration.

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