Stemming the Obesity Epidemic: A Tantalizing Prospect

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Abstract
VEERMAN, J. LENNERT, JAN J. BARENDREGT, ED F. VAN BEECK, JACOB C. SEIDELL, AND JOHAN P. MACKENBACH. Stemming the obesity epidemic: a tantalizing prospect. *Obesity.* 2007;15:2365–2370.

Objective: Obesity is a growing problem worldwide, but there are no good methods to assess the future course of the epidemic and the potential influence of interventions. We explore the behavior change needed to stop the obesity epidemic in the U.S.

Research Methods and Procedures: We modeled the population distribution of BMI as a log-normal curve of which the mean shifts upward with time due to a positive population energy balance. Interventions that decrease food intake or increase physical activity result in more favorable trends in BMI.

Results: The recently observed trend in average BMI implies that the average U.S. adult over-consumes by ~10 kcal/d. If this trend continues unaltered, obesity prevalence will exceed 40% for men and 45% for women in 2015. To stop the epidemic, it suffices to decrease caloric consumption by ~10 kcal or walk an extra 2 to 3 minutes per day, on average.

Discussion: This leads to a paradox: little behavior change seems sufficient to halt the epidemic, but in practice this proves hard to achieve. The obesogenic environment is the likely culprit. Individuals trying to maintain a healthy weight need to be supported by environments that stimulate physical activity and do not encourage over-consumption. Research should show what measures are effective.

Key words: modeling, epidemiology, public health, energy balance

Introduction

Obesity is a growing health problem worldwide. In the U.S., the prevalence of overweight (defined as a BMI of 25 to 30 kg/m^2) is ~35%, while another 30% of the adult population are obese (BMI ≥30 kg/m^2) (1). As yet, there is no sign of an end to the epidemic. On the contrary, the rate of increase in body weight still seems to be in the accelerating phase (Figure 1), with adolescents and young adults having especially high rates. In a few decades, this generation may experience obesity-related mortality resulting in lowering life expectancy (2). To make matters worse, there are indications that the relative risk of disease may increase with the duration of exposure (3), although uncertainty concerning the magnitude of the problem remains considerable (4).

Obesity results from a mismatch between energy input (caloric intake) and output (of which physical activity is the main factor that can be influenced), or a mismatch between our biology that is geared toward the creation of energy stores for meager times and our current environment in which food is abundant and in which physical activity can easily be avoided. Most experts agree that efforts to stem the epidemic must focus on the "obesogenic" environment (5). In the U.S., the BMI distribution has been shown to be shifting to higher levels across the population, whereby the lower end is changing little but the upper tail is increasingly skewed (6). Although some subgroups are more affected than others, this persisting log-normality of the BMI distribution supports the notion that the obesogenic environment affects the whole U.S. population.

In order to plan interventions and to estimate the need for health services, information about the future course of the obesity epidemic is required. There are methods for estimating the future prevalence of overweight and obesity (5,7,8), but these offer no convenient framework for the assessment of the effect of interventions. We present a framework for effectiveness modeling that uses a population perspective and present an example of a hypothetical

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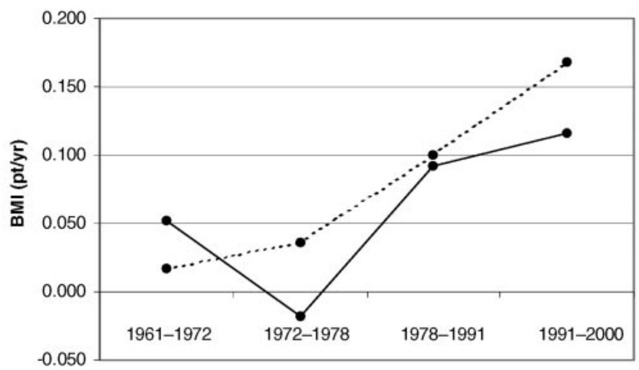

Figure 1: U.S. trend in mean BMI, expressed as BMI-point increase per year, for men (solid line) and women (dashed line) 20 to 74 years of age (10).

U.S.-wide intervention that results in an average of 2 extra minutes of walking per day. We also estimate the magnitude of the behavior change needed to prevent further increases in the prevalence of obesity.

Research Methods and Procedures

Underlying the prevalence of overweight and obesity is the population distribution of BMI, of which the mean predicts the number of deviant individuals (9). It, therefore, makes sense to relate changes in the prevalence of obesity and overweight to the mean BMI of a population (8). We constructed a model that mathematically describes a population in terms of BMI. From this baseline population, two secondary populations are derived, which represent the same population after a specified number of years (Figure 2). The BMI distribution of these populations can be changed by manipulation of mean BMI. With an increase in mean BMI, the variance also increases, such that the lower end of the BMI distribution remains fixed for each age and sex group (6). Mean BMI, in turn, is dependent on a population energy balance. Recent observed trends in BMI reflect the degree of imbalance. The first of the secondary populations is exposed to this trend ("trend population") and acts as a reference scenario. In the second derived population, the observed trend is modified by interventions that affect caloric intake or physical activity via the energy balance theory ("intervention population"). We implemented the model in a spreadsheet.

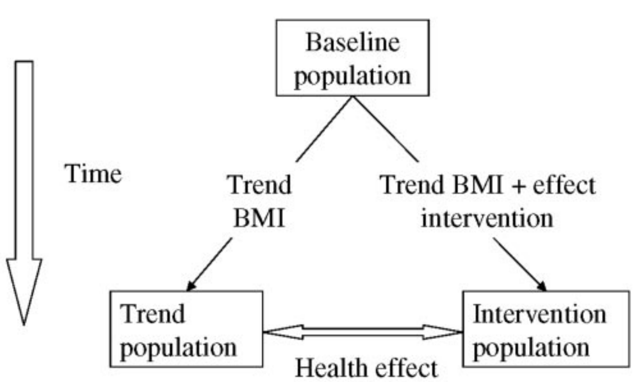

Figure 2: Logical structure of the model.

Data

The baseline population was modeled after the U.S. population in the year 2000. National Health and Nutrition Examination Study-C data (1999 to 2002) on the measured prevalence of overweight, obesity, and extreme obesity in seven age groups (20–29, 30–39, . . . 80+) were fitted to a log-normal distribution using the least squares method. The recent trend in mean BMI (in BMI-points/yr) for adults was calculated from National Health and Nutrition Examination Study-III and National Health and Nutrition Examination Study-C data (10). From the fitted mean BMI and data on the age-specific average height (10), we calculated the age-specific average annual increase in weight (i.e., taking a period perspective). Metabolic calculations of the American College of Sports Medicine, which assume a relationship of ~3500 kcal per pound of body weight (7700 kcal/kg), permitted us to translate the trend into degrees of energy misbalance in kcal/yr (11). We assumed that 10% of energy intake is spent in the digestive process and that it takes a further 10% to store energy as body weight (12). Population numbers from the U.S. Census 2000 were used to compute age-weighted prevalence of overweight and obesity.

Intervention

We constructed two scenarios for developments until the year 2015. In the baseline scenario, the recent trend in mean BMI remains unchanged. This scenario is compared with a second scenario in which a hypothetical policy is implemented that results in an increase in the average daily amount of physical activity by 2 minutes of walking (at 3.1 mL/h or 5 km/h) per day or an equivalent effort. (Depending on body weight, this represents an average increase in energy expenditure of ~6 kcal.) All else remains the same, e.g., people do not eat more to compensate for an increase in physical activity. This intervention is equivalent to a consumption decrease of ~8 kcal/d, on average.

Uncertainty Analysis

Bootstrapping is used to assess the cumulative uncertainty in the estimates that results from the BMI mean (10), the trend in average BMI (±0.02 BMI points/yr), and the measure linking caloric mis-balance to body mass (±10%). The results are expressed as 95% uncertainty intervals.

Results

The recent U.S. trend in average BMI is an increase of ~0.116 BMI points/yr for men and 0.168 for women (Fig-

Table 1. Predicted U.S. obesity prevalence in 2015

	2000	2015 (trend)	2015 (2 minutes extra physical activity/d)
Men			
% overweight	41.9 (41.2–42.4)	35.9 (34.8–37.0)	41.5 (40.3–42.6)
% obese	25.0 (23.5–26.5)	39.0 (36.2–41.6)	26.3 (22.7–29.3)
Women			
% overweight	28.0 (27.6–28.3)	23.9 (23.4–24.4)	26.5 (25.9–27.2)
% obese	32.2 (31.1–33.3)	44.5 (43.0–46.2)	37.1 (35.1–39.1)

Data are modeled prevalences of overweight and obesity in the U.S. population in the year 2000, with estimates for 2015 assuming that the recently observed trend in average BMI continues and an alternative scenario that results in lower trends, with 95% uncertainty intervals in parentheses.

ure 1). Depending on age, this implies that the energy balance is positive by 7.2 to 7.7 kcal/d for the U.S. male population and 8.8 to 9.5 kcal/d for women. In the baseline scenario, this trend results in a prevalence of obesity of 39% in men and 44.5% in women in 2015, an increase of ~13% compared with the year 2000 (Table 1).

Overall, it is the prevalence of obesity that is expected to rise, while the prevalence of overweight tends to decrease with a higher expected upward trend in average BMI. Uncertainty in the estimates is higher for the prevalence of obesity than for the prevalence of overweight.

In the scenario in which the total population walks an average of 2 minutes per day extra, adult obesity prevalence in 2015 rises to 26.3% for men and 37.1% for women. This is 12.7% and 7.4% lower, respectively, than otherwise expected if the current trend continues unabated (Table 1). For men, this nearly amounts to a stabilization in the prevalence of obesity (Figure 3).

To stop the increase in obesity prevalence in the U.S., energy expenditure should increase, energy intake should decrease, or a combination of both. Physical activity has to increase by, on average, an equivalent of 2.2 (95% uncertainty interval, 1.8 to 2.6) minutes of walking at 3.1 mph per day for men and 3.2 (2.7 to 3.6) minutes for women, with the condition that this is not compensated for by extra energy intake. Conversely, assuming energy expenditure constant and taking into account the energy cost of digestion and conversion to body mass, energy intake has to decrease by 9.1 (7.3 to 10.9) kcal per day for men and 11.2 (9.6 to 12.9) for women, less than a can of soft drink per week.

Discussion

The assumptions of a log-normal distribution of BMI and an energy balance at the population level provide a framework for predictions of the prevalence of overweight and obesity. Applying this framework to the U.S. adult population, we estimate that the average American over-consumes by ~10 kcal/d. If current trends continue unchecked, obesity prevalence in 2015 could exceed 40% among U.S. men and 45% among women. Modest increases in physical activity or decreases in caloric intake can mitigate this scenario or even reverse the upward trend in obesity prevalence.

Limitations

The two crucial assumptions in this model are the log-normality of the BMI distribution and the population-level energy balance. The log-normal distribution seems to be a reasonable approximation of the data, although it underestimates the prevalence of extreme obesity. Since we look at only three broad categories of BMI (<25, 25 to 29.9, 30+ kg/m^2), this is unlikely to influence the results much. If anything, the method tends to underestimate the prevalence of obesity. This is also the reason that the estimates of obesity prevalence in the year 2000 reported in Table 1 are below Centers for Disease Control and Prevention estimates (1). We modeled the lower end of the BMI distribution such that it remains fixed over time, which is in agreement with observations in the original data for most sex and age groups (Figure 4) (6).

The use of a population-level energy balance theory is supported by the notion that environmental factors shift the BMI distribution of entire populations. For individuals, the validity of the energy balance theory and the assumption that it takes an over-consumption relative to energy expenditure of ~3500 kcal to gain a pound of body weight are generally accepted. The validity of this measure for use on population mean BMI seems plausible but is difficult, if not impossible, to support empirically. The uncertainty in the measurement of caloric intake and energy expenditure in the open population does not allow reliable estimation of the

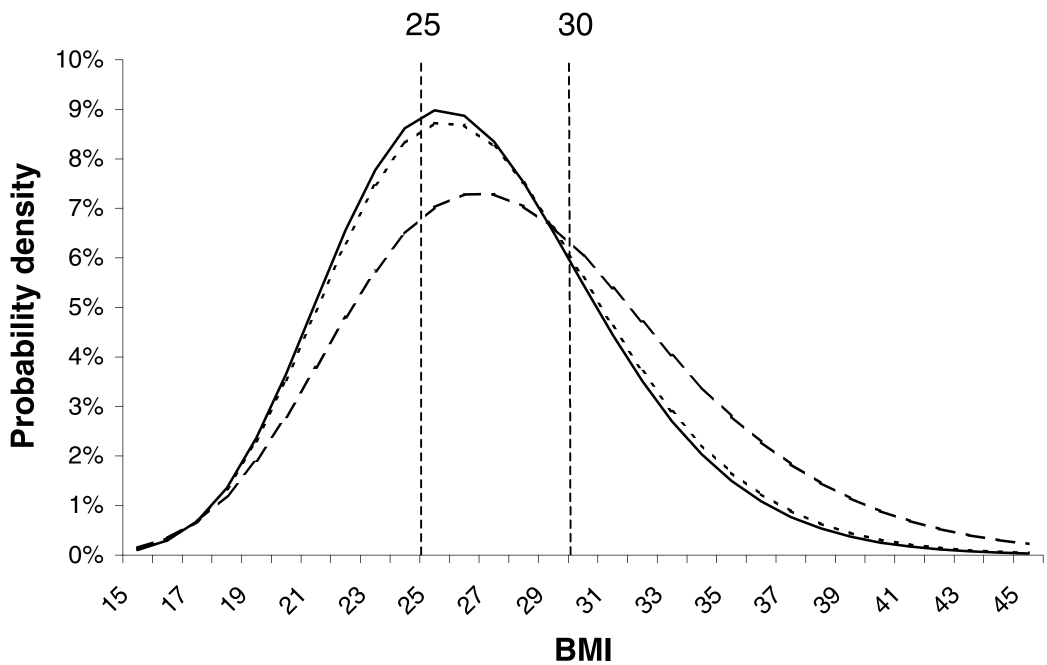

Figure 3: Modeled BMI distribution of U.S. men 30 to 39 years of age. The continuous line depicts the situation in the year 2000, whereas the dashed line indicates the distribution in 2015 if the current trend in mean BMI continues. The dotted line in between shows the distribution in 2015 assuming that this trend is mitigated by an intervention, in this case a 2-minute increase in average daily walking (at 3.1 mph). Intermittent vertical lines show the cutoff points between normal-weight, overweight, and obesity.

population energy balance, considering that we are looking for a mismatch in the order of a few kilocalories per day (13). In the calculation of the uncertainty intervals, we tentatively estimated the uncertainty in this parameter at ±10% (i.e., standard deviation = 5%).

A further limitation of the model is that the age groups are modeled taking a period perspective and independently, whereas in reality, individuals age and move to a higher category, taking their accumulated body mass with them. However, since the trend is similar for all age groups, it is not possible to distinguish cohort and period effects; therefore, this will not affect the results (14,15).

We used BMI as the measure of obesity, whereas it seems that it is visceral adiposity that confers most of the health

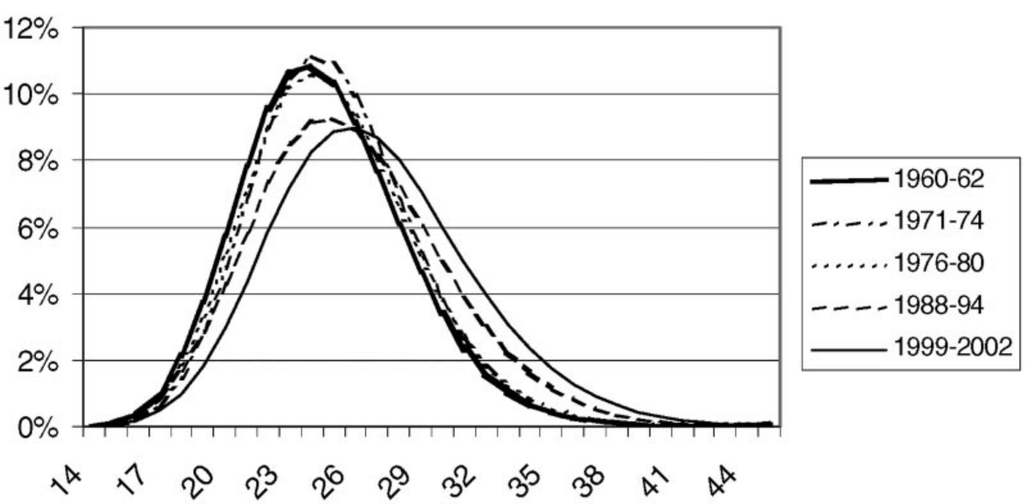

Figure 4: Log-normally fitted BMI curves for the U.S. male population based on successive cross-sectional surveys (1,18). After about 1980, the curve shifted to the right with increased skew while the lower end remained “fixed.”

risk. For an individual, BMI is a rather poor indicator of visceral adiposity, especially at young and old age (16). However, for monitoring populations, BMI is still useful because 1) it is reported widely and because it is easier to measure and less error-prone than, for example, waist circumference; and 2) it is more valid for following populations through time than for comparing individuals. While muscular individuals with a relatively high BMI bias the results at the individual level when it comes to assessing health risks, at the population level, we compare 50-year-old men in 2000 with 50-year-old men in 2015. In the absence of a clear trend in physical exercise at the population level, it seems reasonable to assume that most of the differences in body mass between these groups of 50-year-olds would be due to a difference in fat mass, of which a proportion will be abdominal visceral fat.

It should be noted that a higher body mass requires a higher energy consumption in the order of 7 to 11 kcal per pound (15 to 25 kcal/kg), so that a surplus energy intake of 10 kcal/d results in an extra consumption of ~117 to 190 kcal/d at the end of a 15-year period, used mostly to maintain an extra body weight of ~15.5 pounds (7 kg) (17).

Lastly, our estimate of the average amount of extra physical activity needed may be a bit optimistic, because activity may increase appetite and consumption, so that it may take more than a few minutes of extra activity to prevent weight gain.

Other Predictions

Published models that predict the future course of the obesity epidemic are few. Arterburn et al. examined obesity prevalence by birth cohort and predicted a rise in the prevalence of obesity in elderly Americans from 32.0% in 2000 to 39.6% in 2010 if the current trends continue (7). Our model predicts a slightly higher prevalence of 40.6% (95% uncertainty interval, 38.8 to 42.6; results not shown), which can be explained by the shape of the BMI distribution. Figure 3 shows that the increase in obesity prevalence with increasing mean BMI is not linear; a small increase in mean BMI pushes a disproportionate percentage of the population over the 30 kg/m^2 threshold. A second prediction method is the formula used in the World Health Organization Comparative Risk Assessment study (8). This formula is not applicable to the future U.S. population because it considers the proportion of overweight and obesity separately, without taking account of the underlying BMI distribution. As mean BMI approaches or exceeds 30, this results in overestimation of the percentage of overweight individuals. In contrast, our model predicts the prevalence of overweight to decrease with increasing mean BMI when mean BMI exceeds 30. Figure 3 shows that, as average BMI goes up, there are more overweight people shifting over the upper boundary of 30 kg/m^2 to become obese than there are normal-weight people crossing the lower boundary of 25 kg/m^2 to become overweight.

How Much Change Is Needed?

Our estimate of the magnitude of the behavior change that the U.S. population needs to make to stop the obesity epidemic is more optimistic than that of Hill et al. (5). They estimate that affecting the energy balance by 100 kcal/d would suffice to stop weight gain in 90% of the population. Since they assume that only 50% of excess caloric intake is accumulated as body mass, where others assume that 90% is stored (18), this is likely to be an overestimate of the behavioral change that the average U.S. citizen needs to make. We assumed that digestion and conversion to body fat each costs 10% of the caloric intake. Since all relationships in our model are linear, if 60% instead of 20% of excess energy intake is needed to store the excess intake, then the net excess energy that is stored is halved. Consequently, the consumption change that is needed would double. It would not affect the amount of extra physical activity required. Furthermore, the goal of Hill et al. (5) is to stop weight gain in each individual, whereas our approach aims to stabilize the population mean BMI. For example, we compare men 50 years of age in the year 2000 with men 50 years of age in 2015, while the comparable cohort of Hill et al. (5) would be 65 years of age in 2015. Since the average BMI increases up to about age 60 in the U.S. population, our approach allows individuals some weight gain up to that age to keep the population mean BMI stable. To achieve weight loss, sustained behavioral changes larger than those cited here are required.

Paradox

This leads to an interesting paradox: little behavior change seems sufficient to halt the epidemic, but, in practice, this proves hard to achieve. Part of this paradox may be explained by the fact that the model works with averages; some individuals would have to change considerably more to avoid further weight gain, and this is compounded by the fact that the body resists weight loss more than it resists weight gain (19). Current trends are toward less physical activity and higher consumption levels, so achieving the small behavior changes needed to stop the obesity epidemic requires a reversal of these trends. Underneath these small changes, powerful environmental determinants make people eat more and/or move less than would be healthful. The difficulty individuals have in changing their behavior on a permanent basis (20) points to the need for changes in our environment that encourage physical activity and decrease the stimulus for over-consumption. Such population-targeted interventions have the additional benefit of not stigmatizing overweight individuals. Examples of such interventions are the construction of cycling lanes and safe walking routes, increasing fuel taxation to discourage the use of cars, and regulating food advertising aimed at children (21). The difficulty is that many potentially effective interventions demand sacrifices, while their effectiveness is unclear. Little research effort has been made to assess the effects of population-targeted interventions. The research record mainly shows that targeting individuals has little impact on the obesity epidemic; we now need research that shows how effective population interventions are (22).

Clinical Relevance

For an individual patient with overweight, it is of little use to know that small changes in population averages could stop the obesity epidemic from advancing further, and a clinician's first responsibility is to provide optimal treatment and counseling to his or her patients. The medical profession, however, has a broader responsibility. Physicians should realize that the obesity epidemic will not be cured in the consultation room and should press for measures that make the living and working conditions of their patients less obesogenic.

In summary, the recent increase in the prevalence of overweight and obesity is expected to result in considerable morbidity and mortality in the future. Public health action is necessary to stem the current upward trend in body weight. The framework described in this paper can aid planning by creating scenarios of future developments in obesity prevalence. The difference between the current upward trend in obesity and a downward trend is estimated to be $\sim$10 calories or a 3-minute walk per day, on average, but achieving this change proves a tantalizing challenge. Empowering individuals has met with limited success so far and needs to be supplemented with changes in the environment that stimulate physical activity and encourage a healthy diet. Increased research into the effectiveness of population-targeted interventions should guide this process of societal change.

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