Autoregulatory homestatic nature of energy balance[1]

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ABSTRACT   This paper proposes a new theory regarding energy regulation in man. Current theory states that similar adults have similar energy requirements when engaged in similar activities. As a corollary, if activities remain constant and energy intake is altered, weight will change. This theory has been unable to explain the repeated observations that individuals of the same sex and age and engaged in similar work show a mean weekly coefficient of variation in energy intake of about 16% without significant fluctuations in body weight. Furthermore, repeated studies have failed to show any individual "pattern" relating energy intake to output. This lack of pattern has been attributed either to methodological error or to the fact that human energy requirements cannot be determined by current methods. This paper shows that neither case is correct. The explanation lies in the stochastic stationary nature of energy requirements. Because of the nature of significant intraindividual variations noted in all experiments, "requirement" is a dynamic concept, and energy balance will vary as a matter of course about zero. The implications of this for the individual, society, and policy are enormous and are discussed herein.   *Am J Clin Nutr* 1982;35:355–365.

Introduction

Nutrient requirements are traditionally defined as averages which are applicable to a specified category of individuals. Within each category, requirements may differ from person to person, but everyone is assumed to have his or her own fixed level of necessary intake. In a recent paper (1) we examined the validity of this latter assumption and reported that individual protein requirements are controlled in a homeostatic manner and autoregulated over a range of intakes. In biological terms this means that an individual can adapt to a range of protein intakes and still remain healthy. Although the ability to adapt varies with the level of intake and various other factors, the power with which an individual is capable of adapting can be determined. These concepts are striking in that they demonstrate how too much protein can be as bad as too little.

Individuals can also adapt to varying energy intakes, usually ascribed to alterations in activity level. However, our analyses suggest that such adaptation also occurs as a result of changes in efficiency of energy utilization.

These new concepts mean that the theory of fixed requirements must be seriously questioned. This paper will review current thinking in the field of energy requirements, point out the inherent limitations thereof, and present a new theory along with its implications for evaluating nutrition status.

Current theory

The current theory suggests that adults of the same age, sex, and body composition,

with similar lifestyles, ecological settings, and activity patterns, have similar energy requirements. Energy requirements for adults are presumed to be determined by three components: *1)* energy needed for maintenance (basal or resting metabolic rate); *2)* energy needed for physical activity; and *3)* a relatively small increment due to dietary induced thermogenesis. According to this theory, if individuals of similar age, sex, body size, etc. have different energy intakes, they must be engaged in different levels of activity to maintain constant weight and body composition. As a corollary, individuals engaged in similar activities but with different energy intakes will show changes in weight.

It follows, therefore, that a healthy adult who is engaged in similar activities from day-to-day and is maintaining body weight, will have a nearly constant requirement equal to his/her *habitual* intake. (For children, pregnant or lactating women additional calories are needed to insure satisfactory growth or function.) Accordingly, energy requirements can be calculated by measuring the habitual energy intakes of healthy individuals in specified categories of age, sex, and activity level. Obviously, some individuals may need more and others less than the tabulated average, depending upon deviation of their physical activity from the prescribed level, variations in their body weight, and special growth and physiological needs. According to the 1973 FAO/WHO report (2), a given individual's requirement may vary over time, but this will be negligible relative to variation *between* individuals. In this sense the requirements of all individuals are fixed.

Limitations of the current theory

As far back as 1947, Widdowson (3) observed that in a healthy, active population of specified age and sex which is engaged in similar work, there will be two individuals in every 40, one of whom has a mean weekly intake twice as large as the other. This implies a coefficient of variation for mean weekly intake of about 16%. Thus, adult males in a developing country like India who are engaged in moderate activity, have a "reference" body weight of 55 kg and, according to latest FAO/WHO standards, need an average of 2550 kcal, and will be expected to have

a range of energy intakes from 1750 to 3350 kcal. A part of this variation will undoubtedly be due to fluctuation in body weight. However, the correlation between body weight and energy intake is rather small, on the order of 0.5[3] Correcting for the fluctuation in body weight by standardizing intake to "reference" weight, one obtains a range of variation from 1900 to 3200 kcal, indicating that the coefficient of variation is 13% instead of 16%. Thus, Widdowson's data do not support the current theory. Her explanation for this discrepancy is that some individuals are apparently more efficient machines than others. Although the data reported by Chappel (4) and Yudkin (5) were interpreted as showing a constancy of intake from week to week, the data show the same order of variability.

Several more recent studies have combined simultaneous measurement of intake and expenditure. The most extensive and objective of these was carried out by Edholm et al. (6). These investigators used the best available measurement techniques on young army recruits during the 2nd, 5th, and 8th wk of a 9-wk training period at six different depot centers in the United Kingdom. During each week, subjects were engaged in similar group activities such as drill, lectures, meals, and games. Their intake (from a common table) was measured using the "weigh as you eat" method and expenditure was calculated from an integrating motor pneumatacograph by timing activities and estimating the amount of oxygen consumed.

The study confirmed Widdowson's observation that intake varied much more widely than expenditure in subjects engaged in similar work. However, it raised another more serious question. It was observed that even when averaged over a week with allowances made for variation in body weight over time, intake did not balance (equal) expenditure in indidividual subjects. In addition, there was no correlation between daily intake and expenditure.

In a communication to *Nature* in 1973, Durnin et al. (7) interpreted these and other data to mean that either the errors in intake and expenditure measurement were too large to permit comment on balance in the same

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[3] Calculated from various data in the literature, especially Widdowson (3).

individual or that the human requirement for energy is unknown given the present state of knowledge. As we shall show later, the explanation for the phenomenon lies in the stochastic stationary nature of energy requirements.

Nature of errors in energy balance

The expectation that mean weekly (habitual) intake must equal expenditure in an adult maintaining body weight assumes that measurement errors are primarily chance or random and that successive observations are independent. However, the data reported by Edholm et al. (6) do not support this. In their study of army recruits they attempted to examine carefully intakes and energy outputs for periods of 7, 6, or 5 days at six depot centers. In **Table 1** we have reconstructed the published data and original records for five of the six depots in Edholm's study. One depot (F) was not used because daily body weights were not available at this center. Table 1 shows the analysis of variance for data at the five centers (indicated by the letters A, B, C, D, E). A, B, and C are separated into one group and D and E into another because whereas the data at centers A, B, and C were reported for the entire week, those at centers D and F were reported for 7 days and at center E for 5 days. The mean square between weeks for intake is significantly larger than the mean square between days within weeks. The implication of this finding is that even when the daily intake is averaged over several days, the differences from week to week in the same individual continue to be large. In particular, the coefficient of variation of mean weekly intake is about 15%. If day-to-day variations were random (resulting from errors of measurement), the coefficient of variation would be much smaller. We cannot, therefore, assume that the variation over time in the same individual is random. Rather, the data must be taken to indicate that successive observations of intake in humans maintaining body weight are autocorrelated.

Unlike intake, the differences in energy expenditure from week to week are small; the coefficient of variation is approximately 7 to 8%. There is some suggestion that small as the variation is, day-to-day variation is also nonrandom at centers D and E. This is what we would expect from individuals engaged in uniform activity from week-to-week but who had free choice of intake. Clearly, part of the variation which Widdowson ascribes to differences in efficiency between individuals must be due to individual variations in intake, even after averaging over several days. In other words, the data of Edholm et al. (6) do not support the assumption that an averaged week's intake is equal to habitual or usual intake in humans maintaining body weight and engaged in similar activities from day to day. The data of Edholm et al. (6) thus suggest that the body regulates its energy balance by adjusting either intake or expenditure or both and that consequently the requirements cannot be considered as fixed and equal to habitual intake.

The same conclusions can also be reached by examining recent data reported by Acheson and colleagues (8, 9) even though the authors actually interpreted the errors as random (**Table 2**). The study was conducted on six subjects at Halley Bay in Antarctica. This

TABLE 1
Analysis of variance of daily energy intake and expenditure over time in army recruits in depot centers A, B, and C and D, E, and F

Source	df	Intake (kcal/day/kg)		df	Expenditure (kcal/day/kg)	
		Mean square	F ratio		Mean square	F ratio
Centers A, B, and C						
Between wk within recruits	34	358.0	2.2	34	93.8	1.1
Between days within wk	306	164.7		306	87.0	
Centers D and E*						
Between periods†	18	239.8	2.3	18	79.6	2.2
Between days within periods	108	106.1		108	35.3	

* Data on daily body weight were not available for depot F. Therefore, these data could not be included.
† Period was 5 days from Monday through Friday.

TABLE 2
SD of daily intake and expenditure in kcal/day compared with those of daily means based on 1, 2, 3, and 4 weekly periods

	Daily	1 wk	2 wk	3 wk	4 wk
Intake	646	370	286	259	243
Expenditure	725	441	303	262	233

was a unique setting where the individuals lived free lives which were sufficiently similar and controlled so as to simulate laboratory conditions. Of the six subjects, number 4 was studied daily for intake and expenditure for 315 days while the others were studied for 7 consecutive days every month. Table 2 compares the SD of daily intake with the SD of the weekly means on subject 4. It also includes the SD obtained from the mean intakes for 2, 3, and 4 wk. Although the SD calculated from weekly means is less than the SD calculated from the daily mean, it is much larger than would be expected if the successive observations were independent. The data confirm that the so-called customary weekly food intake and expenditure have a coefficient of variation approximately equal to 12%. There was no obvious trend in either intake or expenditure, but body weight fell in the first 4 months, plateaued during the winter and early spring, and fell again during the summer. **Figure 1** is modified from the thesis of Acheson (8) and demonstrates a rhythm characteristic of autoregulation.

We might ask why Edholm and Acheson did not find any relationship between energy intake and expenditure if the successive values of balance are correlated. The answer lies in the data situation, which is different from the calculations of coefficient of variation. Specifically, we have a set of numbers (x_i, with i going from 1 to n). When an observation is made on the ith unit (whether for determining height, weight, intake and/or expenditure), it is a unique number (x_i) in the sense that the error of measurement of x is negligible relative to the magnitude of the true values of X. In other words, the model will be represented by

$$x_t = X + e_t \ldots (R)$$

where x_t represents the value observed on the tth day, X is the true unknown value, and e_t is the error of measurement assumed to be negligible relative to X. With characteristics like height or body size, it is not difficult to demonstrate the validity of this assumption. We need only repeat the observation on successive days to see that the variance of the mean weekly height or weight in an individual over time is negligible relative to the absolute magnitude of body weight or height. However, there are no data to warrant such assumptions in the case of intake and expenditure, even in the most controlled studies. Determining intake and expenditure for any day is difficult and involves measurement errors which are too large to be made negligible relative to the true differences between successive days. For this reason, the problem is to separate regulatory messages (if any) from the underlying errors (noise) using what are known as stationary stochastic processes developed in the theory of communications.
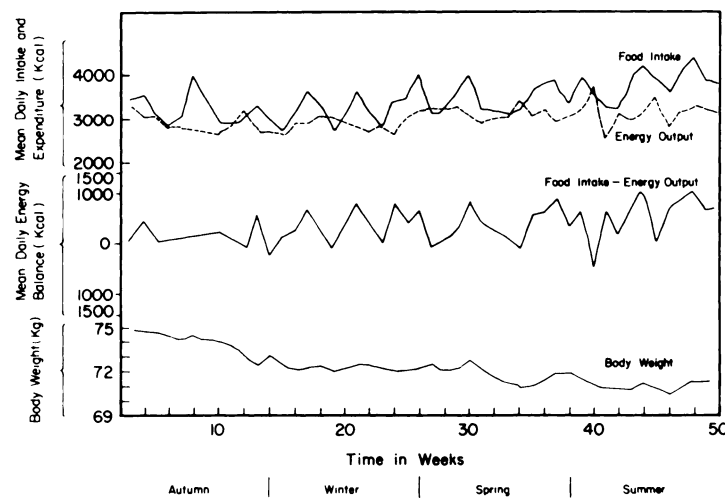

FIG. 1. Food intake, energy expenditure and balance calculated from diary and oxygen consumption and body weight for one subject during ... (8).

Autoregulatory homeostasis

The energy balance study reported by Edholm et al. (6) is limited to 3 noncontinuous wk. It does not, therefore, permit a direct study of autocorrelations and how they evolve over time. However, we believe that since energy balance may well follow the same patterns of regulation as N balance, we can look at our own series on daily N balance as an example of such regulation (1). This shows that on successive days N balance is correlated in a manner represented by the Markoff process. This utilizes two components: a short-term component which arises from the current value of the process at the previous time point, and a long-term component in the form of a random term in model (R) (above) arising from errors of measurement. Autoregressive (AR) models regard the value at time t as regressant on past values at time t-1, t-2 ... with a random residual e_t. The Markoff process is a particular case of AR models in which the current value is most influenced by the value immediately preceding it and the influence of preceding values decreases as the lag increases. This is represented by

$$w_t = \rho w_{t-1} + e_t \ldots (M)$$

where w_t is the balance on the tth day, ρ is the serial correlation of order 1 between w_t and w_{t-1}, and e_t is a random variable distributed around zero with variance σ_e^2. Autoregressive processes are stationary stochastic processes since mean and variance can be shown to be independent of time t. Thus, if it were possible to repeat the circumstances which gave rise to the observed value of balance on any day t, the balance would be distributed around zero within limits which we call homeostasis and which are independent of t. This is represented by

$$\pm \frac{2\sigma_e}{\sqrt{1 - \rho^2}}$$

which is described as stochastic stationary distribution (1). One of the most important functions used in studying AR models is the autocorrelation function. Autocorrelations (or serial correlations) are the correlations between successive observations at different distances apart. In particular, if the first serial correlation is fairly large and gets successively smaller, almost in an exponential manner, it suggests that the underlying model for an observed series is a Markoff process.[4]

The data of Edholm et al. (6) on energy balance must, therefore, be interpreted to mean that although intake may not be equal to expenditure even when averaged over 1 wk, humans are probably in balance every day with varying intervals between peaks and troughs and varying amplitudes in daily balance. For this reason, the data cannot be expected to show the fixed periodicity between intake and output that Edholm et al. (10) and Durnin (11) have been looking for.

This does not mean that the first law of thermodynamics has been violated, as suggested in the statement made by Durnin et al. (7). In living biological systems we must expect a time lag in balancing intake with expenditure. Periods of stress or strain may modify the time lag, but there is always movement towards balance through built-in autoregulatory mechanisms. The fact that the distribution of energy balance is stochastic insures that the expected balance value is zero and the SD is independent of time.

The finding that energy balance is regulated follows from the evidence that humans possess a physiological regulatory mechanism for controlling appetite and energy expenditure. As explained in our earlier article (1), regulation implies adaptation; the magnitude of autocorrelation ρ is an index of the power with which regulation at any given level of intake is controlled. The value of ρ decreases as intake departs from normal. Outside the limits of homeostasis ρ is zero and indicates that the organism is under stress.

The model shown in equation M above is known as AR model of order 1. It is given here more to illustrate the regulatory homeostatic character of the energy balance than as an exact description of the phenomenon represented by the series analyzed in Table 1. Long-term series under controlled conditions (to permit further refinement of homeostatic models) are unavailable.

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[4] Although Rand et al. (12) claim not to have been able to demonstrate autocorrelations in long-term nitrogen balance experiments, ongoing nitrogen balance experiments in our laboratories continue to demonstrate the phenomenon when subjects are fed adequate protein (13).

Although the series of Edholm et al. (6) on energy balance is too short to work out the correlogram, we can examine it for autocorrelation by computing variance of the mean balance when daily balance is averaged over 2, 3, or more successive days. The results of this exercise are given in **Table 3**. The variance of the mean balance does not vary inversely as the size of the period, but it decreases slowly, thus confirming that successive values are serially correlated. Further, the hypothesis that daily balance is distributed in a stochastic stationary manner of the same Markovian type we observed in nitrogen balance with serial correlation of the first order (equal to 0.4) seems perfectly plausible. Actually, it appears that the variance is stabilized as we increase the number of observations over which the mean is taken. This is also supported by data appearing in Table 2. Apparently, the specialized environment in which an individual is raised interacts with the genetic component to keep the variance constant. We do not know how this happens,

but it appears that some physiological system plays a role in carrying information from the environment and translating it to maintain homeostasis.

Significance of intraindividual variation

The data of Edholm et al. (6) also illustrate that even when the data refer to a week, intraindividual variance accounts for the largest part of the total variance (**Table 4**). The share of intraindividual variation in the total will actually be larger than that shown in this table because when successive observations are correlated, the mean square between individuals is an estimate of

$$3\sigma_b{}^2 + \lambda\sigma_w{}^2$$

where $\sigma_b{}^2$ refers to the true variance between individuals, $\sigma_w{}^2$ to the true variance within individuals, and λ is approximately equal to $\dfrac{1 + \rho}{1 - \rho}$, where ρ now denotes serial correlation of the first order between successive weeks. It will be seen from **Table 5** that even with a value of ρ as low as 0.3, the estimate $\sigma_b{}^2$ comes out to be zero, showing that all the variation in daily energy balance reported by Edholm et al. (6) is intraindividual. The SD is 440 kcal, i.e., 12 to 13% of the mean in the case of depot centers A, B, and C, and 860 kcal/day of 5-day periods, i.e., about 20 to 22% of the mean in the case of depot centers D and E. This result is in line with the finding reported elsewhere using the data of Scrimshaw et al. (14) data on N balance in four individuals at 3-yr intervals on a no-protein diet. It would thus appear that intraindividual

TABLE 3
Variance of an individual's mean energy intake and balance based on p successive days (expressed as proportion of unit variance of p = 1)

Period	Observed values for		Calculated	
	Intake	Balance	r = 0.00	r = 0.30
days				
1	1.00	1.00	1.00	1.00
2	0.62	0.53	0.50	0.63
3	0.44	0.38	0.33	0.49
4	0.45	0.37	0.25	0.39
5	0.37	0.27	0.20	0.32
6	0.31	0.21	0.16	0.27
7	0.31	0.22	0.14	0.24

TABLE 4
Analysis of variance of weekly calorie intake and expenditure per kg of body weight

Source	df	Intake (kg/day)		Expenditure (kg/day)	
		Mean square	Estimated true variance	Mean square	Estimated true variance
Depot centers A, B, and C					
Between subjects within centers	14	93.3	14.2	25.2	4.5
Within subjects	34	50.8	50.8	11.7	11.7
Depot centers D and E					
Between subjects within centers	7	115.7	22.6	15.0	0
Within subjects	18	48.0	48.0	16.0	16.0

TABLE 5
ANOVA of cumulative weekly energy balance (kcal $\times$ 10^{-2})

Source	df	Mean square	Estimates
Depot centers A, B, and C			
Between subjects within centers	14	24.0	$3\sigma_b^2 + \sigma_w^2$*
Between weeks within subjects	34	17.0	σ_w^2*
Depot centers D and E			
Between subjects within centers	7	129.1	$3\sigma_b^2 + \sigma_w^2$†
Between periods within subjects	18	66.0	σ_w^2†

* $\sigma_w^2 = 17.0$; $\sigma_b^2 = 2.3$; $\sigma^2 = 19.3$; $\sigma_w = 410$ kcal; $\sigma = 440$ kcal.

† $\sigma_w^2 = 66.0$; $\sigma_b^2 = 21.0$; $\sigma^2 = 87.0$; $\sigma_w = 810$ kcal; $\sigma = 930$ kcal.

variation constitutes the most fundamental variation in both energy and N balance in man. This means that we cannot know the balance of intake over expenditure for any period, but that the expected value of the balance in individual subjects is zero. Another way of saying the same thing is that the observed differences in weekly intake reported by Widdowson (3) and others among adults maintaining body weight and engaged in similar activities were not due to differences between individuals. Rather, they were due to differences in the same individual and are a reflection of the fact that energy is used with variable efficiency in an attempt to regulate body stores. The value of 0.3, which we have assumed for serial correlation between weeks, may be questioned. If an autoregressive series of order 1 were an exact description of the daily balance, the question would be in order, but as we have said, it is not. Intraindividual variation is a fundamental source of variation even when the data are averaged over a week (Table 4). A good example of this variation is reported by Paranjpe (15) and is illustrated in **Figure 2**. Observing daily intake on herself and her husband at home, she found that weekly average intakes are serially correlated, with $\rho = 0.5$ for herself and $\rho = 0.6$ for her husband. These are perhaps the longest series ever reported in the literature and body weights varied over the period of observation, but never more than ± 1 kg.

When intraindividual variation in energy balance is the fundamental source of variation and the successive values can be generated by an autoregressive process such as the Markoff process, it also means that there is no absolute energy requirement for any day or period. The individual is in homeostasis and his/her requirement is controlled by a regulated system, the nature of which we do not presently understand. Viewed this way, intraindividual variation would appear to reflect the capacity to adapt (or regulate) intake and expenditure in such a way that the expected value of daily energy balance is zero and the *variance* between daily energy balance k days apart is constant over time. It is unlikely that there is some mechanism, involving a kind of thermostat, which operates to measure energy intake of food consumed and then tells the individual to stop eating. The reason for this is that balance, as we have seen, is maintained in a probabilistic and not absolute sense. On the other hand, the metabolic pathways which lead to variation in energy utilization *are* known, and it seems more likely that the body regulates its energy balance by varying the efficiency of energy utilization. Miller (16) comes very close to reaching the same conclusions, but does not explicitly refer to metabolic pathways.

The important concept to remember when discussing variable efficiency of energy utilization is that when the body needs energy for any of its functions, it takes it from that part of the energy consumed which is mediated through ATP or other high-energy bonds, and not directly from the energy in food
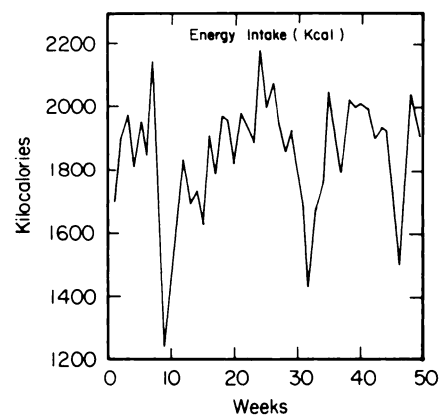

FIG. 2. Energy intake: series of weekly averages in one subject (15).

consumed. In this process, like all systems which convert energy from one type to another, the human body dissipates heat. That is to say, it is less than 100% efficient. Thus, the metabolic pathways for glucose and fat show that the maximum amount of energy they contain which can be mediated through ATP is uncertain, but is approximately 50 to 55% (17). The rest is wasted heat. These values represent the theoretical maximum, and it is uncertain whether this amount of energy can ever be fully converted to "useful" work since opportunities exist for inefficient utilization of ATP in virtually all metabolic processes. Thus, because a man eats only intermittently, he is forced to store much of the energy in adipose tissue to insure that a continuous supply is available to the body. It is estimated that in the process of converting glucose to triglycerides and mobilizing the latter when needed, there is a loss of about 10 to 15% of potential energy.

Changes in enzyme levels similarly contribute to inefficiencies in the overall utilization of the energy available. Because of this wastage, a healthy individual varies his or her intake, increasing it when the wastage is larger and decreasing it when it is lower. This is done without altering body weight and level of physical activity, thus maintaining homeostasis within certain limits. Outside of these limits, the individual may adapt at a different level, or may not be able to adapt at all. For example, in our own laboratory experiments on postprandial metabolism in healthy subjects whose energy balance was regulated, we saw that the thermic effect lasts for several hours and can account for as much as a 20% increase in resting metabolic rate (RMR) depending on the quantity and composition of the meal. This thermic effect of food was not potentiated by exercise; an increase was observed with exercise, but the increase was the same as that observed in the resting state. This finding conflicts with Miller (18) who claims a potentiation of the thermic effect of food by exercise. By calculating RMR every hour to estimate daily expenditure, we found that the cost of maintenance cannot be constant as assumed in the literature, but that it is regulated. The work of Apfelbaum et al. (19) also confirms that within the range of intraindividual variation, RMR increases as intake increases and vice versa without changing body weight or physical activity. It is apparently the autoregulatory mechanism in daily expenditure which enables individuals to adapt requirements without affecting net energy needed for maintenance and physical activity. All this confirms that the energy requirement of man or the efficiency with which he uses energy consumed varies greatly over the range of intraindividual variation as illustrated in **Figure 3.**

Therefore, a model can easily be suggested. At the lower threshold value of 1900 kcal, an individual functions with maximum efficiency (50%); at 2550 kcal, which is the "average requirement" for adult males, the efficiency of utilization is 37% and at 3200 kcal it drops to 30%. This means that of the energy released from a given amount of food, only about 35% is available for essential anabolic processes and physical activity. The rest is lost as heat. Eventually, even the energy used
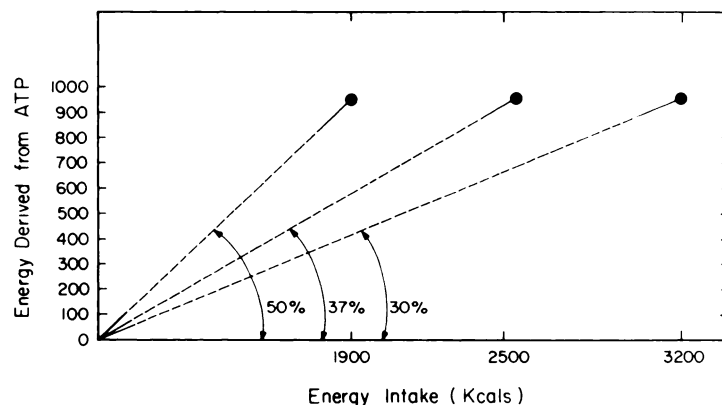

FIG. 3. Efficiency of energy consumption.

in essential processes appears as heat because no energy can be lost without some trace. Probably the greatest support for this hypothesis comes from acute overfeeding experiments (20, 21).

Obviously, this will need further testing in human metabolic experiments on energy and N balance. The implications of the hypothesis are so enormous for formulation of nutritional policy that experiments designed to test it must be carried out under strictly controlled but differing ecological conditions.

The meaning of requirement and its implications for assessment

The significance of intraindividual variation described above has important implications for defining requirements. As we have stated, "requirement" is a dynamic (not static) concept because in a healthy, active individual engaged in specific tasks, balance will vary as a matter of course around zero. In statistical jargon, energy balance will vary with stationary variance without implying under- or overnutrition. A person must be considered in balance whenever his intake falls within homeostatic limits determined by the stationary distribution for balance. It is only when the balance exceeds the homeostatic mechanism that he is under stress from inadequate or excessive intake.

It is with this in mind that we must judge the validity of the procedures used in the literature for evaluating the nutritional status of individuals. While it may be valid to compare the average intake of a population with a reference standard such as described by FAO/WHO, individual intakes must be known to determine whether a person is undernourished or not. Although dietary recommendations usually contain a caution that they are meant to be applied to groups of persons, in practice they are misused and are applied to individual nutritional status. A glaring example of such misuse is shown in **Figure 4**, redrawn from the World Bank study on the dimensions of malnutrition and poverty (22). Another example is contained in the study by Dandekar and Rath (23). As can be seen from Figure 4, the authors of the World Bank study estimate that 44% of the population in Brazil is malnourished because this population, consisting of 5.1% from the
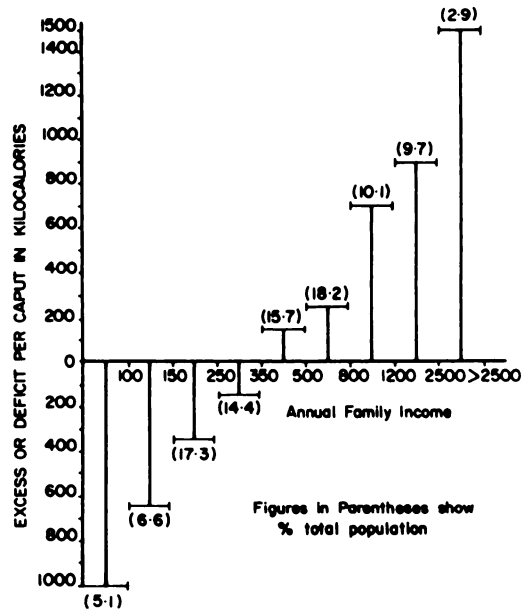

FIG. 4. Per caput excess of deficit in energy consumption by income class in Brazil.

lowest income group, 6.6% from the next income group, and 17.3 and 14.4% from the remaining groups, has an income less than what corresponds to the FAO/WHO requirement for their country. Surely, if 44% of the people below the average are to be classified as malnourished, then the 56% above the poverty line must be considered as overnourished and at risk of obesity. If the dividing line between under- and overnutrition is the average level of national requirement, as claimed in Dandekar and Rath (23), one must conclude that the more serious problem for Brazil, as for India, is overnutrition. Simple as the logic is, it has been ignored in describing the nutrition situation in developing countries.

During the early years of FAO, this method was used to conclude that two-thirds of the world was under- and malnourished (24). Still earlier, Bowley (25) used the same method to suggest that half the British population was undernourished because they had intakes below the average requirement of Great Britain. However, this was 40 yr ago when the concept of energy requirement had hardly developed to a point where we could grasp its full implications. To adopt the same method today for comparing intake with requirement, something which was discarded

by Great Britain decades ago, is to ignore the knowledge that has been gained in understanding the concept of physiological requirement. FAO (2) has revised its earlier estimates of undernutrition to bring them in line with the methodology discussed in this paper. It is now time that the World Bank do the same. That such assessments are misleading can also be seen from the findings of Ferro-Luzzi et al. (26) as well as our own investigations in India. Thus, a nutritional survey of 1000 children in New Guinea has shown that a high proportion of nutritionally inadequate diets assessed using FAO standards do not match with physiological or clinical signs and symptoms of malnutrition. Not even 3% of the total children examined were clinically malnourished, as contrasted with the estimate that 50% should be malnourished if one compared intakes with requirements as suggested by the World Bank. If we persist in such exaggerations, we will merely allow the benefits of nutrition programs to be seized by those who need them least while the really poor and undernourished will continue to suffer.

None of this should detract from the serious deprivation which can occur when an individual's requirements exceed the limits of homeostasis because of his/her work or ecological setting. Those people most clearly at risk are laborers, landless peasants, urban slum dwellers, and the children of these individuals. For those living at the lower borderline of homeostasis, acute ecological changes, such as drought and other losses of food production capacity and/or income, can rapidly precipitate severe malnutrition. Conditions such as these are also prevalent in the developing world among individuals in the lower economic classes who have already made the maximum adaptation to deprivation and cannot adjust further. History shows that emergency feeding programs usually fail because disasters strike so rapidly that even with the best intentions, interventions are rarely quick enough to be helpful. Furthermore, the interventions are often subverted to external forces. Among these are the black market, charging for food, even further decrease in income, all of which prevent food from reaching the people.

In view of the above, we believe that food policies must be reoriented to deal more effectively with potential disasters by generat-

ing social and economic programs which provide greater income, develop self-sufficiency, and promote long-range food availability. By anticipating the crises and planning effectively, much needless suffering can be avoided. As a result of our analyses, we know that the actual prevalence of malnutrition is much lower than previously estimated. Although poverty and malnutrition *are* closely correlated, everyone below the poverty line is *not* malnourished. The claim that the developing countries do not have the resources to cope with the problem of malnutrition is *not* true. Virtually every developing country can solve the problem of malnutrition once it is realized that the magnitude of the problem is not as great as had previously been suggested, based on an improper analysis of the problem.

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