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CALORIE BALANCE IN MAN

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Basic physiological factors affecting calorie balance

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To analyse the subject of calorie balance is to enter a dangerous realm where the scientific approach frequently becomes tainted with upsetting emotional complications. For so many adults, an ideal calorie balance is an ideal unattainable except in wishful day-dreaming. Physiology, then, inevitably becomes confounded by psychology. And if our psychological balance is perhaps a little depressed, one might be tempted to wonder just when in our lives calorie balance prevails: not in our infancy, childhood and adolescence; the period of growth necessitates an imbalance of intake and output of calories. If we are fit and active, in our early adult life we may be improving our muscular development further, and again we are not in calorie balance. Our jaded cursory analysis might then allow a fleeting interval when we are still young adults and perhaps truly, though but temporarily, in a perfect state of calorie balance. However, it is rapidly superseded by a return to the usual condition where intake of calories is more than sufficient for our expenditure, a condition occasionally precipitately terminated by its own self-destruction; or, if we reach old age, a condition which may go into reverse and the imbalance becomes a comparative inadequacy of intake to replace expenditure.

Such a presentation obviously somewhat exaggerates the issues, but perhaps serves to accentuate the rather tenuous nature of 'calorie balance in man'. The mechanism whereby our intake is adjusted to meet our energy expenditure would seem to be by no means a fine control. The high incidence of obesity when there are no restraints on the availability of food would alone suggest a control relatively insensitive to precise regulation of calorie balance.

Basal metabolic rate and tabulation of energy expenditure

A consideration of the factors affecting the balance of calories in man requires, initially, some knowledge of the circumstances likely to alter the rate of energy expenditure. The basic premises in the presentation, in simple tabular form, of the precise extent of the variations in rates of energy output occurring in normal life have altered radically, particularly with respect to the importance of the basal metabolic rate (B.M.R.). This alteration in outlook is typified by the two FAO publications on *Calorie Requirements* (FAO: Committee on Calorie Requirements, 1950;

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FAO: Second Committee on Calorie Requirements, 1957). Although the 1950 Committee made some reservations, they mainly derived the requirements of their reference man using the hitherto accepted standard of the B.M.R. The B.M.R. is supposed to be the minimum metabolism required to maintain life, and the total energy output of a man was estimated, by this Committee, by first of all multiplying the B.M.R. by a factor of 1·2 to give a figure of 'resting metabolism', which is assumed to operate over the 24 h. An allowance of 10% was made for the specific dynamic action of the food, and the required energy for physical activity was calculated as two components, one of them related and the other unrelated to body size.

This method of constructing a total value for daily energy expenditure is, in essence, similar to that used by Orr & Leitch (1937–8), Lehmann, Müller & Spitzer (1950), and many others. However, in recent years both the concept and the practical value of basal metabolism have been much criticized; it is doubtful if, in normal life, anyone is in a truly basal condition for more than a few hours during part of the period of sleep. The measurement itself is also open to many objections, both statistical and because of the practical difficulty in reproducing exactly similar conditions. For the most part it is unnecessary to consider the B.M.R. when actual measurements of total energy output are done; a measurement by indirect calorimetry of a man working or sitting is always initially a gross value and it seems superfluous, and indeed perhaps misleading, to deduct a predicted estimate for basal metabolism in order to convert this gross figure to a net value. In human studies related to energy expenditure, the only real use attached to derived values for the B.M.R. would seem to be in the assessment of the energy expended in sleep, and also possibly to compare people of different age and build when engaged in the same type of physical activity. This is the concept of 'relative metabolic rate', which is a measure of the total energy expended in a piece of work related to the basal metabolism of the subject, and has apparently been of practical use to Japanese investigators in assessing the heaviness of work (Katsuki, 1960).

A more satisfactory plan for tabulating some of the factors which vary the daily energy expenditure is shown in Table 1.

The normal day is divided into 8 h of sleep, 8 h of work and 8 h recreation. Three levels of physical activity at work have been allowed for and the 8 h of recreation have

Table 1. *Energy expenditure (kcal) of the reference man (age 25, weight 65 kg)*

(A)	8 h in bed at basal metabolic rate		= 500	
(B)	8 h off-work and recreations			
	1 h personal necessities at 3 kcal/min	=180		
	1½ h walking at 3·5 miles/h at 4·6 kcal/min	=420		
	4 h sitting and standing activities at 2·0 kcal/min	=480		
	1½ h active recreation and domestic work at 4·7 kcal/min	=420		
			=1500	
(C)	8 h sedentary occupation (minimum overall rate) at 1·65 kcal/min		= 800	
	Grand total			2800
(C)	8 h light occupation (overall rate) at 2·5 kcal/min		=1200	
	Grand total			3200
(C)	8 h heavy occupation (maximum overall rate) at 5·0 kcal/min		=2400	
	Grand total			4400

been subdivided. Some of the activities, such as walking or active recreation, might not reach their respective allocations in a normal working day, but the extra time spent in these activities at weekends increases the daily average over the week. The daily mean over the whole week would also have to be adjusted, depending upon the number of days worked.

Factors affecting energy output and balance

From such a tabulation it can clearly be seen that a most important factor in varying expenditure of energy is the amount of physical activity. Division of the day into periods of sleep, work and recreation also facilitates the discussion of other factors which may exert an effect, such as body size, age, sex, climate, high or low resting metabolism and others. These probably affect different components of the day differently. For instance, it is likely that the energy expended when at work is little affected by low or high resting metabolic rate or by age. The older man usually has to keep up with his mates—or find an easier job. However, if he is tired, an older man can rest at home. He is less likely than young people to engage in energetic physical recreation. Similarly, climate may have different effects on the three components of the day's activities, which may differ from the effect on the basal metabolic rates.

Many factors then clearly affect our energy expenditure. But how many of them, if any at all, affect our calorie balance? Age, as I have briefly mentioned, may do so—growth in the young and frequently an increasing tendency to a mild degree of emaciation in the old. Climate has been postulated as disturbing the calorie balance in that fat may be deposited in the body under conditions of extreme cold. Some data, for instance those of Johnson & Kark (1947) and Lewis & Masterton (1958), showing the very high food intakes of men living in the Arctic, seem to give support for this possibility. But there are so many complicating factors, such as boredom and lack of activity during the long winter days indoors, good insulation from the effects of the weather, and so on, that we just have not sufficient evidence to give an answer.

The factor of exercise, or lack of it, is also a difficult problem in relation to calorie balance. Mayer (1955) has suggested that, at very low levels of physical activity, it may be difficult, and it will often be unsatisfying, to restrict the intake of food so that it just balances the energy expended. This may be at least part of the reason why obesity is so common in our very sedentary civilization. Most of us eat more than we need—our needs are so small. And a small excess of intake over our output of energy, operating over a period, produces obesity. The same reasoning surely provides a possible answer to the frequent criticism of the efficacy of exercise in restoring an ideal calorie balance. Much emotionalism distorts this subject and experimental observations of a properly controlled nature are very restricted in quantity. The 'obvious uselessness' of exercise is usually illustrated by saying something like 'to lose 1 lb of fat, it is necessary to walk continuously for 10 h'. This may be quite true, but the exercise need not necessarily be taken all at once. The same amount of exercise could well be spread over 20 days, by walking half an hour per day, and the effect, at least theoretically, could be the same.

Regulation of appetite

Much of the problem in discussing factors affecting calorie balance, derives from the fact that, although our intake of calories should usually balance our expenditure, frequently in practice it does not seem to be so. Our appetite control is a peculiar mechanism. The nature of the control is difficult to contemplate. Is it a control of calories, or do other nutrients become important in certain circumstances? The latter is true in some animals, at least. But even restricting the control to calories is sufficiently complicating. This problem will presumably be dealt with at some length by subsequent speakers, but I should just like to refer here to some data from a recent publication (Durnin, 1961*a*). In that paper I have attempted to analyse the relationship between the daily intake and the expenditure of calories in sixty-nine individuals. Although one would expect the intake to equal the output, in only ten of the subjects was there any significant relationship between the calorie intake and output, and in only four out of these ten was the relationship the proper, positive one.

Again, if the control depends on calories, there may be calorie balance at approximately the ideal weight but a concomitant condition of malnutrition may be present —the calories are adequate but there is an inadequate intake of, perhaps, protein, or of a mineral such as calcium or iron, or of one of the vitamins. Possibly this situation is unusual except in regions where it is difficult to obtain a balanced diet, or perhaps by reason of poverty.

Weight balance of the body

The question of calorie balance is intimately associated with that of the weight balance of the body and I should like to make brief reference now to it. When we measure the calorie intake or expenditure over a limited period of say a week or a little longer, there is no way of ensuring, in practice, that the subject of the study is maintaining the normal routine of his or her daily life. He may be eating more, or less, than usual or expending more, or less, energy. I feel that alteration in energy expenditure is less likely than in food intake, but theoretically, at any rate, an alteration should be apparent by weighing the subject and finding whether there is a change in weight during the course of the measurements. And a frequent question addressed to us in connexion with our studies is 'Did you weigh the subjects at the beginning and at the end of your survey?' It sounds an eminently sensible question. A difference of say 1 lb in the weight of the subject should mean something for which we can make an allowance in our calculations to balance calorie intake and expenditure; 2 lb ought to be even more significant. One would think so: 2 lb, in the form of fat deposited in the body or lost from the body, represents approximately 7000 kcal. In the space of a week this would account for a difference between intake and expenditure of 1000 kcal daily. If only we could easily measure such a weight difference! There is no technical difficulty; balances are easily capable of fine accurate weighing. But the meaning of this weight change, with respect to calories, is incomprehensible.

We have measured, in a group of forty-four men living under very controlled conditions, changes in their weight from day to day of up to 1 kg—more than 2 lb.

A few typical measurements are shown in Table 2. These weighings were done under highly standardized conditions—the men were naked, and the measurements were done immediately on their rising from bed in the morning, before any food or drink

Table 2. *Daily body-weights (kg) of young men weighed under standardized conditions*

Subject	25 Aug.	26 Aug.	27 Aug.	28 Aug.	29 Aug.	30 Aug.
A	78·3	78·2	77·4	78·2	78·4	77·1
J	66·0	66·6	66·7	67·0	67·1	66·1
P	86·7	87·2	88·3	88·1	88·0	87·9
S	64·4	65·0	64·8	65·0	64·3	64·1
T	65·1	66·4	65·7	65·9	65·1	65·1
W	69·4	69·5	69·3	69·6	69·4	69·0

had been taken, and after the urinary bladder had been emptied—conditions difficult to emulate in experiments in the field. The obvious conclusion is that the fluid content of the body can vary within quite wide limits; and a measurement of fluid content is too difficult to make routine in the field, and open also to inaccuracies which would make it relatively useless for such purposes as these.

Dr O. G. Edholm, I know, has similar findings on his subjects. As an illustration of the confusion which may arise because of the variability of the body-weight, I well remember a field study of a new army ration, conducted by Dr Edholm and his colleagues and in which I took part, the purpose of which was to test out a light-weight diet which, it was known, would not provide a sufficiency of calories over the 4- or 5-day trial period. The men taking part in the experiment were weighed, before the study, daily for 4 days. Unfortunately, as I remember it, results could have been obtained showing (a) that they had an insufficient intake, (b) an adequate intake, and (c) even possibly an excessive intake, depending upon which of these 4 days was chosen as the base-line.

Relative calorie losses in urine and faeces

Another factor which may be important in maintaining calorie balance is the relative efficiency of the body in dealing with the available energy presented to it in the form of food, that is to say, the comparative losses in the faeces and urine with regard to intake. This might, superficially, seem to be of insignificant importance. We lose such a small percentage of our intake that the effect of a variation in it would be minimal. At present, one can only theorize on this problem. Very little experimental work of the requisite high accuracy has been published since the original studies at the beginning of this century, from which our modern assumptions about the net calorific value of foods have been derived. These original studies were done on so few subjects that we have little information on the range of the percentage loss of calories, both among subjects eating the same sort of food and those eating different kinds of food.

Because of the scarcity of fundamental knowledge on the calorie factors to be applied when calculating the net calorific value of foods, we have been engaged in studying the percentage losses in the urine and faeces of subjects of both sexes and of two age ranges (about 20 and about 70 years) when eating diets containing small and moderate amounts of roughage (Durnin, 1961*b*; Southgate, 1961). Completed results are, thus far, only to hand on the young men and women, but Table 3 shows the mean values and the ranges for these twelve men and fourteen women.

Table 3. *Coefficient of available energy on two 'normal' diets of young men and women*

	Diet 1		Diet 2	
	Mean	Range	Mean	Range
Men	93·2	94·2–92·1	91·1	92·9–89·7
Women	92·4	93·7–91·4	90·8	92·2–89·7

Diet 1 contained small amounts of unavailable carbohydrate.
Diet 2 contained moderate amounts of unavailable carbohydrate.

Again the difference looks small but it may be of some significance. There was very little scatter, and the total range in both groups on both types of diet was of the order of 2–3%. This represents a difference of something like 70–100 kcal for the men (2–3% of the total daily intake of about 3500 kcal) and 50–70 kcal for the women. Although over a period of 1 day this is a negligible quantity, it is perhaps one of the fallacies of many theories in connexion with calorie balance in general and obesity in particular that we tend to consider the effects of various factors from this short-term viewpoint. Exercise, as has been already mentioned, also falls into this category. Though the effect of the variation in calorie losses during 1 day is negligible, over a period of days it may become significant, and a difference of 50–100 kcal/day, in the course of a month, represents the equivalent of ½ to 1 lb of body fat.

The same order of difference, i.e. about 2%, is seen when we compare the percentage calorie losses on the two different diets, the diet containing the moderately high quantity of roughage resulting in a comparative decrease in the available energy of the food of about 2% relative to the diet with little roughage.

The effects of these factors on the calorie balance of the body in physiological conditions can only be a subject for speculation with the knowledge at present available. But, as we have seen from Table 2, the regulation of intake might appear to be such a haphazard process from day to day that the long-term resultant might easily assume importance in causing upset of the rather fickle control of body composition.

I have not mentioned, in this cursory summary, any reference to the excellent work on lower animals and on monkeys. Fortunately, the title of the Symposium makes it unnecessary but nevertheless, for myself, I have doubts about the direct application of these results to man, in a subject so complex as calorie balance.

Inevitably, one seems to end a consideration of these and similar problems by repeating that, though man is a difficult and awkward experimental animal, much rewarding information can be obtained from him by well-conducted experiments. These are sadly lacking in the field which we have been discussing.

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The central nervous regulation of calorie balance

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Over short periods of a few days calorie balance does not appear to be regulated in any way we can analyse. A day-to-day record of the fluctuations in food intake and energy expenditure—the two components of calorie balance—usually yields a series of uncorrelated and apparently random numbers. It does not mean there is no relation between intake and output—there must be, or no long-term stability of body-weight would be possible—but it means that the relation is usually obscured by environmental variables. Under controlled conditions in the laboratory, one can detect regular rhythms of body-weight, appetite and activity in animals (Brobeck, Wheatland & Strominger, 1947), but they merely emphasize that calorie balance tends to 'hunt' or fluctuate around a mean value rather than to be rigidly preserved at all times. It is often suggested that, since eating is a periodic phenomenon rather than a continuous process, the study of energy balance should begin with the individual meal—that is with the mechanism of appetite and satiety. To do so, I believe, would be to risk missing the wood among the trees. We must start with the long-term behaviour of the animal. I say animal advisedly, because for obvious reasons central regulations are more easily studied in animals than in man, but I shall try to relate animal to human experiments as I go along.

Let me begin with two propositions which are common sense rather than physiology. First, I will repeat that there must be a long-term regulation of energy balance. Secondly, there is no *a priori* reason why this balance should be maintained by control of appetite alone, since it depends as much on calorie expenditure as on calorie intake. If you starve a laboratory rat for a few days and then restore its food, it will quickly recover its previous weight—one of the best possible proofs that energy balance is actively regulated. If you choose an elderly rat, it will put back the lost weight by overeating. But if the rat is a young one, it eats no more than it did before being starved—it reduces its energy expenditure and recovers its weight just as quickly (Adolph, 1947; Kennedy, 1950).

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