Nutritional adaptation in man: general introduction and concepts[1,2]

John C Waterlow

ABSTRACT The aim of this paper is to clarify thinking on the subject of nutritional adaptation. A series of concepts and questions are proposed with, as examples, some of the responses that occur to low intakes of energy and protein. The main conclusions are first, that in dealing with human beings value judgments cannot be avoided, but to avoid sterile discussion they must be separated from objective descriptions of adaptive responses. Second, the way ahead lies in examining the shape of the responses of different functions to different degrees and kinds of stress. Objective studies of this kind do not require use of the word adaptation. *Am J Clin Nutr* 1990;51:259-63.

KEY WORDS Adaptation, nutritional, man

Introduction

Nutritional adaptation is a challenging subject from a scientific point of view; it also has very important practical implications in relation to nutrient requirements. The first symposium on this topic that I can recollect was organized nearly 20 years ago by the Pan American Health Organization (1), but it is only in the last few years that it has begun to occupy the center of the stage.

It is always difficult to talk about general concepts in a way that is concrete and useful. By this I mean clarifying rather than confusing and leading, one hopes, to worthwhile observations and experiments. One problem is that people use the word adaptation in many different ways, leading to arguments that cannot be resolved objectively. Should we attempt to define adaptation unambiguously, in a way that distinguishes it from other terms such as homeostasis, accommodation, acclimatization, etc (2)? I believe that this is a forlorn hope; we do not want to spend our time on semantics. I propose, therefore, to present a series of concepts, not necessarily joined together in a logical way, with some examples.

First concept

From the point of view of natural history, all animals and plants are adapted to their environments otherwise they could not survive and reproduce. Mark Twain expressed it very well: "How wonderful nature is, that our legs are always just long enough to reach the ground." However, the word adaptation in this context does more than just state the obvious. It encourages us to look at the characteristics of animals and plants and ask, "What is it that enables this one to withstand drought, that one the extremes of cold, etc?" These are concrete biological and physiological questions. We do not need the word adaptation to formulate them.

Second concept

Adaptation may involve overspecialization and, hence, loss of adaptability. There is no need to stress the obvious point that man is a highly adaptable animal if we allow him the use of artificial aids to survive, taking the word *artificial* in its literal sense, of made by skill. Holliday (3) recently stressed the adaptability that is conferred by the mammalian kidney; it allows adaptation to a wide range of dietary patterns, conserving those nutrients that are in short supply and getting rid of those that are in excess.

Third concept

An adapted state is a sustainable state. This again is obvious but important. For example, it has been suggested that a child with marasmus is adapted whereas a child with kwashiorkor is not (4). If marasmus is defined as a state where the weight is < 60% of expected weight for age (5), I doubt if such a condition is either successful (concept 1) or sustainable.

Fourth concept

Adapted and normal are two sides of the same coin. The Swiss physiologist von Muralt once said that if a textbook of physiology had been written by an Andean Indian, he would have pointed out how remarkable it is that a baby born on the coast can adapt immediately to the transition from the low pO_2 in the uterus to the high Po_2 at sea level, whereas a baby born at high altitude has no such problem. So which is normal, the coast or the mountain, and which is adapted?

[1] From the Division of Clinical Sciences, London School of Hygiene and Tropical Medicine, University of London, London.

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TABLE 1
Energy expenditure over 3 h, which includes walking 5 km at various speeds and zero gradient, by a man weighing 60 kg and carrying a 20-kg load*

	Time		Energy expenditure		
Speed	Walking	Rest	Walking	Rest	Total
km/h	*h*		*kcal*		
1.8	2.8	0.2	330	14	344
2.7	1.85	1.15	280	77	357
3.6	1.4	1.6	273	108	381
4.5	1.1	1.9	282	126	408
5.4	0.9	2.1	301	138	439
6.3	0.8	2.2	325	146	471
7.2	0.7	2.3	352	153	505
9.0	0.55	2.45	411	163	574

* Energy cost of walking calculated from Pimental and Pandolf (6). Rate of energy expenditure in free time taken as 67 kcal/h.

Fifth concept

Every adaptation involves a cost. This is a statement very commonly made. According to concept 1, we naturally think of the process of adaptation as something beneficial without which the organism would be worse off, but it has to pay a price for the benefit. Was it worth it? Here we come into the realm of subjective value judgements, which is rather unsatisfactory. Objectively, maintenance of one function in the face of stress is likely to involve change in some other functions. It might be more appropriate to rephrase the concept: every adaptation involves a choice. (I am indebted to PR Payne for this idea.)

The following is a crude example: Suppose a male person has 3 h in which to walk 5 km and we compute his total energy expenditure over those 3 h, assuming that when he is not walking he is at rest. As shown in **Table 1**, if he walks slowly he saves energy expenditure but has no time left to do anything else. If he walks fast he saves time at the cost of using more energy. Which is the more important to conserve, energy or time? It depends on the circumstances. As someone is reported to have said when told of an athlete who had beaten a record by a few seconds: "Pray what did he do with the time thus saved?"

Sixth concept

For most variables or functions there is a range of acceptable or sustainable states. The purpose of an adaptation is to keep the function within the acceptable range.

The problem, of course, is the definition of acceptable. This approach brings us close to the classical concept of homeostasis, which literally means a like or similar condition but has more and more come to acquire the connotation of constancy. In fact, there is no such thing as constancy. The normal pH range of extracellular fluid, from 7.35 to 7.45, looks very narrow in those units but in fact represents a range of ±12.5% in hydrogen ion concentration, which is not negligible.

I suggest that the differences between homeostasis and adaptation are basically ones of timing and degree. I think of homeostatic mechanisms as working away all the time to maintain those relative constancies on which our life depends. I think of adaptation as a longer-term process: a response to environmental change or stress which, once made, is maintained. Obvious examples would be the increase in red cell mass on acclimatization to altitute or the increase in plasma volume on acclimatizing to heat stress.

Seventh concept

This is not so much a concept as an approach to the definition of acceptable range. The real questions are: What is the relationship of defined function Y to defined stress X? Is there a threshold? Where is it?

Different variables that are of interest in nutrition behave in different ways. Some are more closely fixed than others. For example, in a study of normal serum values for biochemical screening, the coefficients of variation in healthy young adult males varied from 5% for calcium to 23% for urea (7). Other variables seem to have a maximum beyond which they cannot be further changed. Garby and Killander (8) pointed out that if a group of people is given all necessary hemopoietic substances, their hemoglobin reaches an upper level that is characteristic for each person. I suspect that the same applies to plasma albumin: irrespective of how much protein is fed, I know of no record of it rising above ~50 g/L. Henry et al (9) produced an interesting example of the relationship of liver protein mass to protein intake in the rat. The increase was exponential, with each successive increment of protein intake having less and less of an effect on liver protein mass. It is unlikely that the DNA content was changing with protein intake, so what seems to be regulated, as regards its upper limit, is the amount of protein per unit DNA in liver cells.

It would be very valuable if we had input-output curves of this kind for other functions and variables. They would probably not all be the same shape (**Fig 1**). The exponential curve, like that for liver protein, provides an upper limit but no natural lower limit. A sigmoid curve would define a level of input below which a dramatic decrease occurred. In other cases again the relationship could be continuous with no threshold as has been said to be the case for the relationship between salt intake and blood pressure (10).

I end with some examples that illustrate the application of these concepts. First example: consider the adult exposed to a low level of energy intake. The inevitable and obvious response is a decrease in body weight, but because many components of energy expenditure are related to body weight, provided that the energy intake is not too low, the person should come into energy balance again at a lower weight. The Food and Agriculture Organization (11) has called this a costless biological adaptation, but how low can we go and at which point is there a cost? Three of us participating in this symposium have recently tried to examine this question (12). If weight is expressed as body mass index (BMI), the average in healthy people in industrialized countries is ~24, in third world countries 20–21; from what we could find in the literature, the lower limit of acceptable BMI would be ~18. **Figure 2** shows results of a study in Bangladesh. These data illustrate the kind of studies that need to be made to relate functional response to degree of stress; in this example, function deteriorated continuously although not linearly as BMI decreased. The lower (?) point at which we can say that the adaptation in body weight is costless represents a

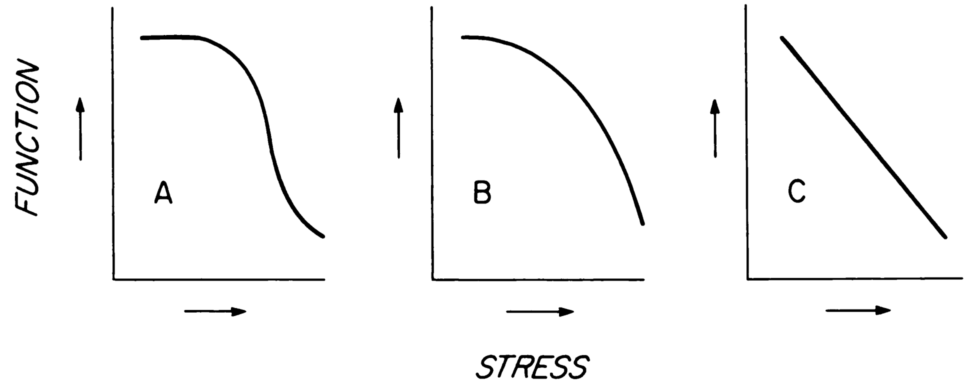

FIG 1. Hypothetical relationships between increasing stress and decreasing function. A, sigmoid; B, exponential; C, linear.

value judgment and cannot be defined in an objective, scientific way.

The *second example* relates to adaptation to low-protein intakes, about which Young will no doubt tell us much more. As everyone knows, the first line of defense is a decrease in urea excretion, brought about by a whole range of enzyme changes: reduction in the activities and amounts of the urea cycle enzymes and of the enzymes that help transfer nitrogen into the cycle, such as the dehydrogenases and aminotransferases (13, 14). This adjustment, until the subject comes into nitrogen balance again, takes a few days and involves a very small loss of total body nitrogen, of the order of 1% (**Fig 3,** line X). It seems unlikely that this small loss can have any functional significance. Thus, within the range of this first line of defense, which maintains nitrogen balance, there are no functional deficits and all points represent equally acceptable levels of adaptation.

If this line of defense fails, there will be a negative balance and loss of body nitrogen. However, provided that the nitrogen intake is greater than the obligatory nitrogen loss, the subject should come into balance again at a lower level of lean body mass (point Y in Fig 3). How far can this process go without functional deficit? We do not know. There are, however, some interesting pointers if we accept that a decrease in plasma albumin concentration is, at least, a crude indicator of the extent to which body protein mass is reduced. In this connection it is interesting that more than half a century ago Weech et al (15) in balance studies on dogs showed that loss in total body nitrogen was ~30 times the loss in circulating plasma albumin nitrogen. Thus, even a small degree of hypoalbuminaemia may represent a significant loss of body protein. The results, therefore, of Barac-Nieto et al (16), shown in **Figure 4,** are very interesting. I suggest that the subjects described as moderately malnourished could be regarded as protein deficient, because although their BMIs were within what we regard as the acceptable range, they had substantial reductions in circulating albumin and muscle mass. In the severely malnourished group there was a large further decrease in albumin, muscle mass, and $\dot{V}O_2$max as a measure of functional capacity. It would be difficult to define any cutoff point in these relationships that would represent the lower limit of adaptation.

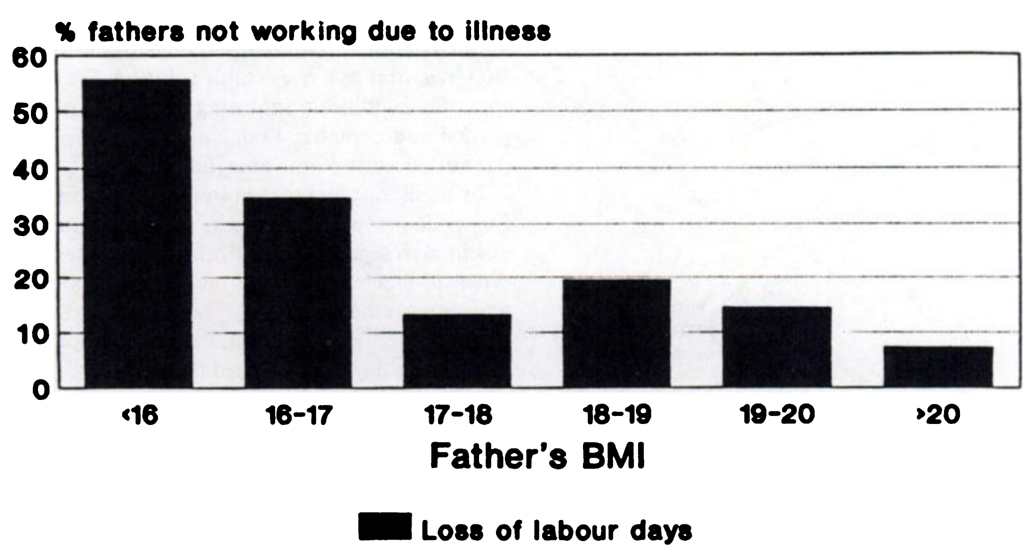

FIG 2. Relation between body mass index [BMI = wt(kg)/ht^2 (m^2)] and percentage of men (n = 199) taking time off work through illness in the month before the survey. Data of J Pryer from Bangladesh (unpublished observations, 1989). Reproduced by permission.

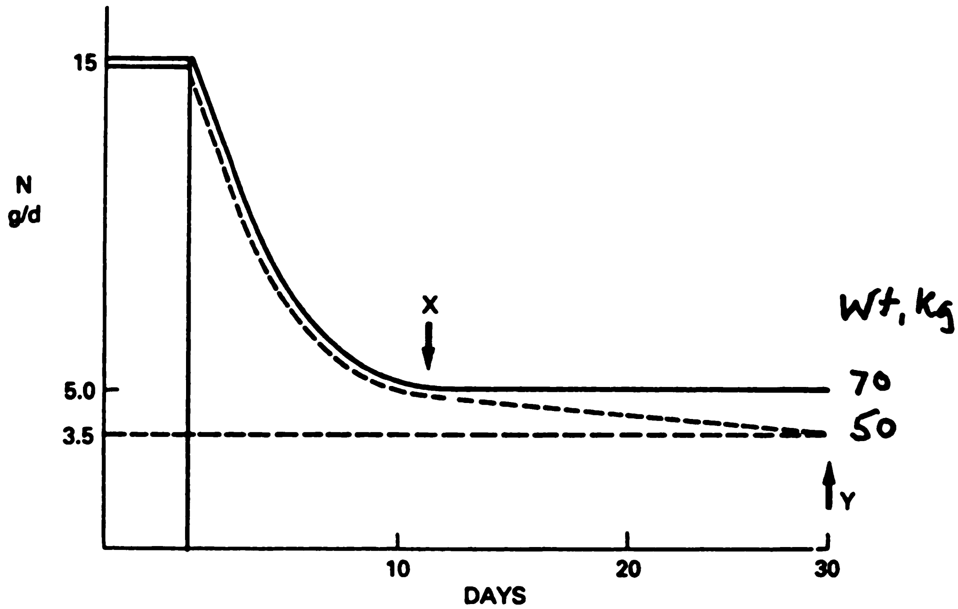

FIG 3. Schematic representation of two stages of nitrogen loss. Rate of nitrogen output (g/d) in relation to time. Conditions as follows: body weight 70 kg, body nitrogen 30 g/kg, obligatory nitrogen loss 70 mg/kg, fractional loss 0.0023/d, initial intake 15 g N/d. *1*) Intake reduced to 5 g N/d; loss 4.9 g N/d; balance achieved at X by enzyme adaptation within a few days, with minimal body nitrogen loss. *2*) Intake further reduced to 3.5 g N/d. Loss continues at the same fractional rate. In theory, total body nitrogen is lost exponentially until a new balance is achieved at body weight 50 kg (Y). With the values chosen it would take 2.5 y to approach within 5% of that weight. After 1 y weight would be 58.5 kg with a loss of 16% of initial body nitrogen. Reproduced with permission from reference 2.

Eighth concept (or question)

Can we get away from value judgments? It would be dereliction of duty for a nutritionist to end without some reference to the challenging question of stunting in linear growth in Third World children. There are some who regard this as an adaptation in that a small child is more likely to survive when food is in short supply. Others, for example Gopalan (17), say that we cannot have one standard for the rich and another for the poor. It is true that there are some handicaps in being small and having a low-absolute capacity for physical work (eg, 18), but taking the world as a whole it would be hard to show that small people do worse than big people. The conflict here is about values, not about science. An example may help to explain what I mean. Homer Smith (*see* 3) showed that the lungfish, when the rivers run dry, encapsulates itself in the mud and puts up a tube so that it can breathe and survive. No one cares that during this time the fish cannot do anything except survive. In the case of the fish it would be absurd to say that it should not be forced to adapt in this way. However, human beings are different. We should not accept a status quo that requires children to become stunted in order to survive and then, by labeling it as an adaptation, regard it as a respectable solution. We have a right to say that the conditions imposing the adaptation cannot be regarded as acceptable. I conclude that in dealing with man we cannot get away from value judgments.

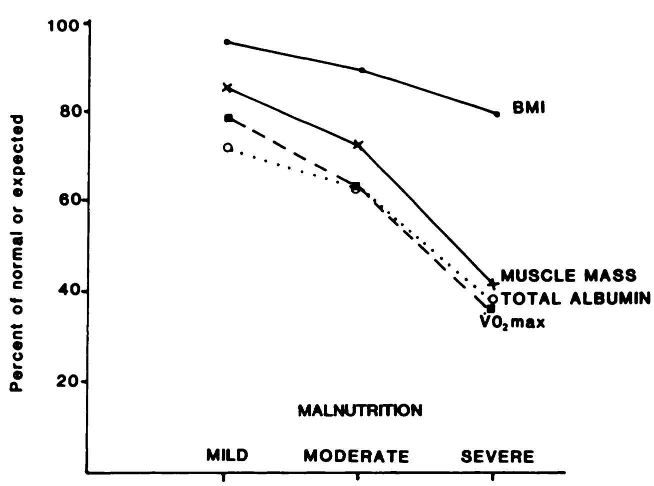

FIG 4. Body mass index (BMI), muscle mass, circulating albumin mass, and $\dot{V}O_2$max in Colombian men with different grades of severity of malnutrition. Results expressed as percent of control or expected values. (Recalculated from data in reference 16).

In many discussions about adaptation in man, value judgments do creep in and it is in order that they should, but it is essential to separate them from objective descriptions of physiological, biochemical, and metabolic responses to nutritional and environmental stress. These responses can be described perfectly well without using the word adaptation. So my final question is, do we really need the word? ■

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