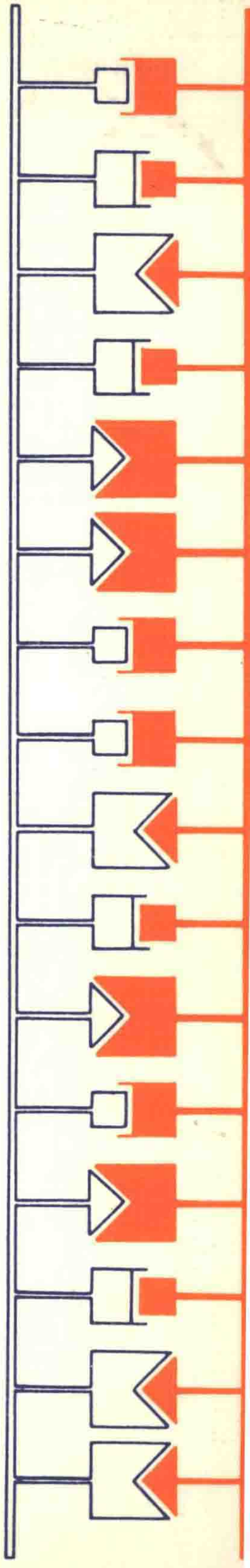
INTRODUCTION TO
Nutrition
AND
Metabolism

David A. Bender



An introduction to nutrition and metabolism

DAVID A. BENDER
University College London

UCL
PRESS

First published in 1993 by UCL Press

UCL Press Limited
University College London
Gower Street
London WC1E 6BT

ISBN:
1-85728-078-4 HB
1-85728-079-2 PB

A CIP catalogue record for this book
is available from the British Library.

An introduction to nutrition and metabolism

PREFACE

The food we eat has a major effect on our physical health and psychological wellbeing. An understanding of the way in which nutrients are metabolized, and hence of the principles of biochemistry, is essential for an understanding of the scientific basis of what we would call a prudent or healthy diet.

My aim in the following pages is both to explain the conclusions of the many expert committees which have deliberated on the problems of nutritional requirements, diet and health over the years, and also the scientific basis on which these experts have reached their conclusions. Much information now presented as "facts" will be proven to be incorrect in years to come. This book is intended to provide a foundation of scientific knowledge and understanding from which to interpret and evaluate future advances in nutrition and health sciences.

Nutrition is one of the sciences which underlie a proper understanding of health and human sciences and the ways in which human beings interact with their environment. In its turn, the science of nutrition is based on both biochemistry and physiology on one hand, and the social and behavioural sciences on the other. This book therefore contains a great deal of biochemistry, which is essential to an understanding of the basic science of nutrition. You do not have to "know" a metabolic pathway in order to be able to follow, and contribute to, a debate about how nutritional and metabolic factors interact with health. What is necessary is the ability to read a metabolic pathway like any other map or flow chart, and to follow the development of biochemical concepts and arguments. Many of the diagrams in this book are, perforce, complex, since they represent complex metabolic pathways. They are included for completeness and reference; the text gives an overview of the relevant and important features of the various pathways discussed.

In a book of this kind, which is an *introduction* to nutrition and metabolism, it is neither possible nor appropriate to cite the original scientific literature which provides the (sometimes conflicting) evidence for the statements made. The bibliography in Appendix IV lists some sources of more detailed information. In turn, these will lead the reader into research review essays, and thence the original research literature.

I am grateful to those of my students whose perceptive questions have helped me to formulate and organize my thoughts. This book is dedicated to those who will use it as a part of their studies, in the hope that they will be able, in their turn, to advance the frontiers of knowledge, and help their clients, patients and students to understand the basis of the advice we offer.

DAVID A. BENDER — London, October 1992

CONTENTS

CHAPTER ONE

Why eat?

An adult eats about a tonne of food a year. This book attempts to answer the question *why?* – by exploring the need for food and the uses to which that food is put in the body. Some discussion of chemistry and biochemistry is obviously essential if we are to investigate the fate of food in the body, and why there is a continuous need for food throughout life. Therefore, in the following chapters, various aspects of biochemistry and metabolism will be discussed. This should provide not only the basis of our present understanding, knowledge and concepts in nutrition, but also – possibly more important – a basis from which to interpret future research findings and evaluate new ideas and hypotheses as they are formulated.

We eat because we are hungry. Why have we evolved complex physiological and psychological mechanisms to control not only hunger but also our appetite for different types of food? Why are meals such an important part of our life?

The need for energy

We can see an obvious need for energy in order to perform measurable physical work. Work has to be done to lift a load against the force of gravity, and we require a source of energy to perform that work. As discussed in Chapter 6, we can measure the energy used in various activities, and we can measure the metabolic energy yield of the foods which are the fuel for that work. This means that we can calculate the balance between the intake of energy, as metabolic fuels, and the body's energy expenditure. Obviously, energy intake has to be adequate to meet energy expenditure; as discussed in Chapters 6, 7 and 8, neither deficit nor excess intake is desirable.

Quite apart from this visible work output, the body has a considerable requirement for energy, even at rest. Only about one-third of the average person's energy expenditure is for obvious work. The remainder is required for maintenance of the body's functions, homeostasis of the internal environment and metabolic integrity. We can measure this energy requirement by the production of heat when the subject is completely at rest, in an environment at a temperature where the body is neither gaining nor losing heat. The result is called the **basal metabolic rate** (abbreviated to BMR) – the energy requirement for maintenance of body functions and metabolic integrity.

Part of this basal energy requirement is obvious: the heart beats to circulate the blood; respiration continues; there is considerable electrical activity in nerves and muscles, whether they are "working" or not; and the kidneys use a great deal of energy during the filtration of waste products from the bloodstream. All of these processes require a metabolic energy source. Less obviously, there is also a requirement for energy for the wide variety of biochemical reactions going on all the time in the body: laying down reserves in the form of fat and carbohydrate; a continuous turnover of tissue proteins and other compounds; transport of substrates into, and products out of, cells; and the production and secretion of hormones and neurotransmitters.

Units of energy

We measure energy expenditure by the production of heat (see p. 157). The unit of heat used in the early studies was the **calorie**: the amount of heat required to raise the temperature of 1 gram of water by 1 °C. The calorie is sometimes still used, although because of the relatively large amounts of energy involved in human metabolism we talk in **kilocalories** (kcal, sometimes written as Calories with a capital C). One kcal is 1,000 calories (10^3 cal), and hence the amount of heat required to raise 1 kg of water through 1 °C.

Correctly, we use the **joule** as the unit of energy. The Joule is an SI unit, named after James Prescott Joule, who first showed the equivalence of heat, mechanical work and other forms of energy. One joule is a very small amount of energy, and in biological systems we talk in **kilojoules** ($1\ kJ = 10^3\ J = 1{,}000$ joules) and **megajoules** ($1\ MJ = 10^6\ J = 1{,}000{,}000\ J$).

To convert between calories and joules:

$$1\ kcal = 4.186\ kJ$$
$$1\ kJ = 0.239\ kcal.$$

As discussed in Chapter 6, the average energy expenditure of adults is 7.5–10MJ/day for women and 8–12MJ/day for men.

Metabolic fuels

The dietary sources of metabolic energy (the metabolic fuels) are carbohydrates, fats, protein and alcohol. The metabolism of these fuels in the body results in the production of carbon dioxide and water (and also urea in the case of proteins, see p. 203). We can convert them to these same end-products chemically, by burning them in air. Although the process of metabolism in the body is more complex, it is a basic law of chemistry that, if the starting material and end-products are the same, the energy yield is the same, regardless of the route taken. Therefore we can determine the energy yield of foodstuffs by measuring the heat produced when they are burnt in air, making allowance for the extent to which they are digested and absorbed from foods. The energy yields of the metabolic fuels are shown in Table 1.1.

Table 1.1 The energy yield of metabolic fuels.

	kJ/g
Carbohydrate	17
Protein	16
Fat	37
Alcohol	29

1 kcal = 4.186 kJ or 1 kJ = 0.239 kcal

The need for carbohydrate, fat and protein Although we have a requirement for energy sources in the diet, it does not matter unduly how that requirement is met. There is no requirement for a dietary source of carbohydrate; as discussed on p. 153, the body can make as much carbohydrate as it requires from proteins. Similarly, there is no requirement for a dietary source of fat, apart from the essential fatty acids (see p. 81). There is certainly no requirement for a dietary source of alcohol!

Although there is no requirement for fat in the diet, fats do have nutritional importance:

(a) It is difficult to eat enough of a very low-fat diet to meet energy requirements. As shown in Table 1.1, the energy yield of 1g of fat is more than twice that of 1g of carbohydrate or protein. It would be necessary to eat a considerably larger amount of a very low-fat diet to meet energy needs from carbohydrate and protein alone. However, as discussed in Chapter 2, the problem in Western countries is generally a high intake of fat from the diet, contributing to the development of both obesity and the so-called diseases of affluence.

(b) Four of the vitamins - A, D, E and K (see Ch. 11) - are fat-soluble, and are found in fatty and oily foods. More importantly, their absorption from the gut requires an adequate amount of fat in the diet, since they are absorbed dissolved in fats. On a very low-fat diet the absorption of these vitamins will be much reduced.

(c) There is a requirement for small amounts of the essential fatty acids. These are constituents of fats which are required for specific functions and which cannot be formed in the body, so that they must be provided in the diet (see p. 81).

(d) In many foods a great deal of the flavour (and hence the pleasure of eating, see below) is carried in the fat.

(e) Fats lubricate food, and make chewing and swallowing easier.

The need for protein

Unlike fats and carbohydrates, there is a requirement for protein in the diet. In a growing child this need is obvious. As the child grows, and the size of its body increases, so there is an increase in the total amount of protein in the body.

Adults also require protein in the diet. There is a continuous small loss of protein from the body, for example in hair, shed skin cells, enzymes and other proteins secreted into the gut and not completely digested, etc. More importantly, there is turnover of body proteins. Tissue proteins are continuously being broken down and replaced. Although there is no change in the total amount of protein in the body, an adult with an inadequate intake of protein will be unable to replace this loss, and will lose tissue protein. Protein turnover and requirements are discussed in Chapter 9.

Minerals and vitamins

In addition to metabolic fuels and protein, the body has a requirement for a variety of **mineral salts**, in very much smaller amounts. Obviously, if a metal or ion has a function in the body, it must be provided by the diet, since the different chemical elements cannot be interconverted. Again, the need is obvious for a growing child; as the body grows in size, so the total amount of the various minerals in the body will increase. In adults there is a turnover of minerals in the body, with losses that must be replaced from the diet.

There is a requirement for a different group of nutrients, also in very small amounts: the **vitamins**. These are relatively complex organic compounds that have essential functions in metabolic processes. They cannot be synthesized in the body, and so must be provided by the diet. There is turnover of the vitamins, so there must be replacement of the losses. Vitamins and minerals are discussed in Chapter 11.

Hunger and appetite

Human beings have evolved a complex system of physiological and psychological mechanisms to ensure that the body's needs for metabolic fuels and nutrients are met.

There are hunger and satiety centres in the hypothalamus, which stimulate us to begin eating (the **hunger centres**) or to stop eating when we have satisfied our needs (the **satiety centres**). We are beginning to understand the rôle of these brain centres in controlling food intake, and there are drugs which modify responses to hunger and satiety. Such drugs can be used to reduce appetite in the treatment of obesity, or to stimulate it in people with anorexia (see p. 181).

These hypothalamic appetite centres control food intake very precisely. Most people can regulate their food intake, quite unconsciously, to match their energy expenditure very closely; they neither waste away from lack of metabolic fuels for physical activity nor lay down excessively large reserves of fat. Indeed, even people who have excessive reserves of body fat, and can be considered to be so overweight or obese as to be putting their health at risk, balance their energy intake and expenditure relatively well. We are talking about an intake of a tonne of food a year, while the record obese people weigh about 250 kg (compared with average weights between 55 and 80 kg), and it takes many years to achieve such a weight.

In addition to hunger and satiety, which are basic physiological responses, we have to consider **appetite**, which is related not only to physiological need but also to the pleasure of eating: flavour and texture, and a host of social and psychological factors.

Taste and flavour

Five basic tastes can be distinguished by the tongue: salt, sweetness, bitterness, sourness and savouriness. Two of these, salt and sweetness, are pleasurable sensations, while bitterness and sourness are instinctively perceived as unpleasant, and presumably evolved as a means of protection. The sensation of **savouriness** is distinct from that of saltiness, and is sometimes called "*umami*" (Japanese for savory). It is largely due to the presence of free amino acids (and especially glutamate) in foods. Stimulation of the *umami* receptors of the tongue is the basis of flavour enhancers such as **monosodium glutamate**, which is an important constituent of traditional oriental condiments and is widely used in manufactured foods.

Salt (correctly the mineral sodium chloride) is essential to life, and wild animals will travel great distances to a salt lick. Like other animals, we have evolved a pleasurable response to salty flavours; this ensures that we meet our physiological need for salt. However, there is no shortage of salt in developed countries, and we can now indulge this pleasure to excess. As discussed on p. 25, average intakes of salt are considerably greater than requirements, and may be high enough to pose a hazard to health.

The other instinctively pleasurable taste is **sweetness**. The evolutionary reason for this is less easy to work out, but we can argue that ripe fruits are sweet – indeed the process of fruit ripening is largely one of converting starches to sugars – and, in general, ripe fruits are better sources of vitamins and minerals than unripe fruits.

Sourness and **bitterness** are instinctively unpleasant sensations. We can learn to enjoy some sour and bitter foods, but this is a process of learning or acquiring tastes, not an innate or instinctive response. We can hypothesize that the instinctive aversion to bitter flavours evolved as a protection against poisonous compounds found in some plants, many of which are bitter. The aversion to sourness is presumably the converse of the pleasurable reaction to sweetness: if we wait until the fruit is ripe it will not have the sour flavour, and will have a greater nutritional value.

In addition to the basic taste sensations provided by the taste-buds on the tongue, we can distinguish a great many flavours by the sense of smell. Again some flavours and aromas (fruity flavours, fresh coffee and, at least to a non-vegetarian, the smell of roasting meat) are pleasurable. They tempt us to eat and, if we can smell the food but not yet eat it, they stimulate our appetite. Other flavours and aromas are repulsive and tell us not to eat the food. In many cases this again can be seen as a warning of possible danger: the smell of decaying meat or fish tells us that it is not safe to eat.

Like the acquisition of a taste for bitter or sour foods, we can acquire a taste for foods with what would seem at first to be an unpleasant aroma or flavour. Here, things become more complex; a smell pleasant to one person may be repulsive to another. Some enjoy the smell of cooked cabbage and sprouts, while others can hardly bear to be in the same room.

The durian fruit is a highly prized delicacy in Southeast Asia, yet to the uninitiated it smells of sewage or faeces – hardly an appetizing aroma.

Why do people eat what they do?

People have different responses to the same taste or flavour. Sometimes we can explain this in terms of childhood memories, pleasurable or otherwise. An aversion to the smell of a food may protect someone who has a specific allergy or intolerance (although sometimes people have a craving for the foods to which they are intolerant). Most often we simply cannot explain why some people dislike foods that others eat with great relish.

Factors influencing the choice of particular foods include:

The availability of food In developed countries the simple availability of food is not likely to be a constraint on choice. We have a wide variety of foods available. When fruits and vegetables are out of season at home they are imported; frozen, canned or dried foods are widespread. By contrast, in developing countries the availability of food is a major constraint on what people choose. Little food is imported, and what is available will depend on the local soil and climate. Even in normal times the choice of foods may be very limited, while in times of drought there may be little or no food available at all, and what little is available will be very much more expensive than most people can afford.

The cost of food Even in developed countries the cost of foods may limit the choices available to some people. Among the most disadvantaged members of the community, poverty may impose severe constraints on the choice of foods. In developing countries, cost is the major problem. Indeed, even in times of famine, food may be available, but it is so expensive that few people have the money to buy it.

Habit and tradition Foods which are commonly eaten in one area may be little eaten elsewhere, even though they are available, simply because people have not been used to eating them. To a very great extent, our eating habits as adults continue the habits we learned as children.

Haggis and oat cakes are rarely eaten outside Scotland, except as specialty items; black pudding is a staple of northern British breakfasts, but is rarely seen in the southeast of England. Until the 1960s, yoghurt was almost unknown by people in Britain, apart from a few health food "cranks" and immigrants from eastern Europe; many British children believe that fish comes only as rectangular "fish fingers", while children in inland Spain may eat fish and other sea-food three or four times a week. The French mock the British habit of eating lamb with mint sauce, and the average British reaction to such French delicacies as frogs' legs and snails in garlic sauce is one of horror. The British eat their cabbage well boiled; the Germans and Dutch ferment it to produce sauerkraut.

This regional and cultural diversity of foods provides one of the pleasures of travel. As people travel more frequently, and become (perhaps grudgingly) more adventurous in their choice of foods, so they create a demand for different foods at home, and there is an increasing variety of foods available in shops and restaurants.

A further factor which has increased the range of foods available has been the migration of people from a variety of different backgrounds, all of whom have, as they have become established, introduced their traditional foods to their new homes. It is difficult to appreciate that in the 1960s there was only a handful of Tandoori restaurants in the whole of Britain, or that pizza was something you saw only in southern Italy or a few specialist restaurants.

Some people are naturally adventurous, and will try a new food just because they have never eaten it before. Others are more conservative, and will try a new food only when they see someone else eating it safely and with enjoyment. Others are yet more conservative in their food choices; the most conservative eaters "know" that they do not like a new food because they have never eaten it before.

Luxury status of scarce and expensive foods Foods that are scarce or expensive have a certain appeal of fashion or style; they are (rightly) regarded as luxuries for special occasions rather than everyday meals. Conversely, foods that are widespread and cheap have less appeal. In the 19th century, salmon and oysters (which are now relatively expensive luxury foods) were so cheap that the Articles of apprentices in London specified that they should not be given salmon more than three times a week, while oysters were eaten by the poor. Conversely, chicken and trout, which were expensive luxury foods in the 1950s, are now widely available, as a result of changes in farming practice, and they form the basis of inexpensive meals. As farming practices change, so salmon is again becoming an inexpensive meal, and venison is no longer the exclusive preserve of the wealthy landed gentry or poachers.

The social functions of food Human beings are essentially social animals, and meals are important social functions. People eating in a group are likely to eat better, or at least to have a wider variety of foods and a more lavish and luxurious meal, than people eating alone. We may well use the excuse of entertaining guests to eat foods which we "know" to be nutritionally undesirable, and we eat more at a "feast" than we really need. Indeed, the greater the variety of courses and dishes offered, the more we are likely to eat. As we reach satiety with one food, so another, different, flavour is offered to tempt appetite. Studies have shown that, faced with only one food, people tend to reach satiety sooner than when a variety of different foods is on offer. Here again we see the difference between hunger and appetite. Even when we are satiated, we can still "find room" to try something different.

Conversely, and more importantly, many lonely single people (and especially the bereaved elderly) have little stimulus to prepare meals. While poverty may be a factor in limiting their choice of foods, apathy (and frequently, in the case of widowed men, ignorance) is more important in limiting the range of foods eaten, and may result in undernutrition. There is often little or no incentive to prepare a meal, and no stimulus to appetite. When these problems are added to those of infirmity, ill-fitting dentures (which make eating painful) and arthritis (which makes handling many foods difficult), and the difficulty of carrying food home from the shops, it is not surprising that we include the elderly among those vulnerable groups of the population who are at risk of undernutrition.

The attractiveness (or otherwise) of food In hospitals and other institutions, we face a further problem. In hospitals we are dealing with people who are unwell, whose physical energy expenditure is low, but who have higher than normal requirements for energy, protein and other nutrients, as a part of the process of replacing tissue in convalescence, or as a result of fever or the metabolic effects of cancer (see p. 184). At the same time, illness impairs appetite, and a side-effect of many drugs is to distort the sense of taste, depress appetite or cause nausea. It is difficult to provide a range of exciting and attractive foods under institutional conditions, yet this is what is needed to tempt the patient's appetite.

Summary

Food serves many purposes. At the basic level it provides a metabolic fuel and meets a physiological need. However, it also serves social and psychological functions, and good food can be a source of pleasure.

We have to consider whether the foods that tempt us are nutritionally desirable, and whether our choice of foods may affect our general health. In order to understand the rôle of diet in health, and the rôle of modifications of diet in treating or controlling diseases, we have to understand the functions of the nutrients in the body, and hence the way in which the body maintains its functions and metabolic integrity.