SEVENTH EDITION

HUMAN NUTRITION AND DIETETICS

Sir Stanley Davidson
R. Passmore
J. F. Brock
A. S. Truswell

CHURCHILL LIVINGSTONE

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CHURCHILL LIVINGSTONE
EDINBURGH LONDON AND NEW YORK 1979

CHURCHILL LIVINGSTONE
Medical Division of Longman Group Limited

Distributed in the United States of America by Churchill Livingstone Inc., 1560 Broadway, New York, N.Y. 10036, and by associated companies, branches and representatives throughout the world.

First edition 1959
Second edition 1963
Third edition 1966
Fourth edition 1969
ELBS edition first published 1969
ELBS edition reprinted 1970
ELBS edition reprinted 1971
Fifth edition 1972
ELBS edition of fifth edition 1973
Sixth edition 1975
ELBS edition of sixth edition 1975
Seventh edition 1979
Reprinted 1981
Reprinted 1983

ISBN 0 443 01765 4 (cased)
ISBN 0 443 01764 6 (imp)

British Library Cataloguing in Publication Data
Main entry under title:

Human nutrition and dietetics. — 7th ed.
1. Nutrition
I. Davidson, *Sir* Stanley
641.1 TX353 79-40560

Printed in Hong Kong by
Wilture Enterprises (International) Ltd.

Human Nutrition and Dietetics

SIR STANLEY DAVIDSON
B.A. Cantab., M.D., F.R.C.P. Edin., F.R.C.P. Lond., M.D. (Hon. Oslo), LL.D. Edin. and Aberd.

Extra Physician to Her Majesty The Queen in Scotland:
Regius Professor of Medicine, University of Aberdeen, 1930-1938;
Professor of Medicine and Clinical Medicine, University of Edinburgh, 1938-1959;
Physician-in-Charge, Royal Infirmary, Edinburgh, 1938-1959.

REG PASSMORE
D.M. Oxon., F.R.C.P. Edin.
Reader in Physiology, University of Edinburgh;
Formerly Lieutenant-Colonel, Indian Medical Service.

JOHN F. BROCK
D.M. Oxon., F.R.C.P. Lond., D.Sc. (Hon. Natal), F.A.C.P. (Hon.), F.C.P. (Hon. S.A.).

Emeritus Professor of Medicine, University of Cape Town;
Honorary Consulting Physician, Groote Schuur Hospital.

A. STEWART TRUSWELL
M.D. Cape Town, F.R.C.P. Lond., F.F.C.M.

Boden Professor of Human Nutrition, Sydney University, Australia.
Head of Nutrition Section School of Public Health and Tropical Medicine, Sydney.
Honorary Consultant in Nutrition, Royal Prince Alfred Hospital, Sydney.

Preface to the Seventh Edition

Knowledge of nutrition is of increasing importance in the world today. The number of undernourished and malnourished children and adults in the poorer countries is not diminishing as their populations grow. In the richer countries obesity, diabetes, heart diseases and cancers assume more and more clinical importance, and nutrition has major roles both in their treatment and prevention.

The excellent reception of this book since it was first published in 1959 has convinced us that the policy on which it was based remains sound. This is set out in the preface to the first edition, which is reprinted. For this edition every section has been carefully revised. The seventh edition has been completely revised. It has three new chapters (fuels of the tissues, food processing and consumer protection). The sections on dietary fibre, alcohol, zinc, vitamin D, ascorbic acid, dietary standards, wheat, meat science, infective agents in foods, food toxicity, anorexia nervosa, diseases of the gastrointestinal tract, diseases of the kidneys, community nutrition, food nutrition and cancer, and adult man have been rewritten.

This book is unique in several respects. It covers the whole field of nutrition at a moderately advanced level: nutritional biochemistry; energy metabolism and regulation; foods; deficiency diseases; nutrition in the cause and management of other diseases; public health nutrition; therapeutic dietetics. It is readable and has been regularly revised and kept up to date. Although based in Britain, it is internationally orientated. The authors live in three different countries, and have worked in many more; there is much material and many references from the USA and from numerous developing countries. Indeed there are few countries in the world that are not mentioned somewhere in the book.

The teaching of nutrition is made difficult by the reluctance of many to use the SI units of international science. The calorie and the pound are so much a part of our language that they are only dying slowly as nutrition units. More and more concentrations of nutrients are being expressed in molar units. We are convinced that ultimately these changes make for clarity, although inevitably there continues to be confusion during the change-over period. In most cases we express results in both the old and new units.

The move of A.S.T. from Queen Elizabeth College, London, to the new Boden Chair of Human Nutrition in Sydney University has made the mechanics of revision more complicated but full cooperation between the authors has been maintained. Sir Stanley Davidson continues to give support and encouragement though poor vision, which happily has not deteriorated, prevents him from taking an active part in revision. The work which J.F.B. could do was limited by a coronary bypass operation which has been successful. The authors have been assisted by Dr Joyce Baird and by Dr Martin Eastwood in the revision of the chapters on diabetes and gastrointestinal diseases. Large parts of the chapter on renal diseases have been rewritten by Dr Mike Bone. The new chapter on fuels of the tissues was written by Dr Philip James, who also contributed much of the material to the chapter on the control of body weight. We are grateful for all this help but, as some of their material has been altered to bring it into line with the rest of the book, we ourselves take full responsibility for the final versions. The diet sheets and glossary prepared for the sixth edition in collaboration with Miss Mary Ellen Collins of the Peter Bent Brigham Hospital and Dr Ruth Kay respectively are substantially unchanged. Their help has, we hope, resolved most of the difficulties that arise from the slightly different uses of the English language on the two sides of the Atlantic. Many others have helped us with advice on sections of the book, and we wish to thank especially Miss Susan Ash, Dr Darnton-Hill, Miss Alison Paul, Miss Cathie Hull, Dr J.A. Loraine, Dr D.B.L. McClelland, Dr D.J. Naismith, Miss Jean Robertson, Miss Marie Sardie, Dr D.A.T. Southgate and Professor A.G. Ward.

Our publishers, Churchill Livingstone, continue to give us kindly assistance and invaluable advice throughout the preparation of this book.

STANLEY DAVIDSON
R. PASSMORE
J.F. BROCK
A.S. TRUSWELL

Edinburgh, 1979

Preface to the First Edition

In 1940 one of us (S.D.), with Dr Ian Anderson, published *A Textbook of Dietetics*. This was based on lectures given to medical students at Aberdeen University and was designed to aid British general practitioners in treating and preventing disease by dietetic measures. Since then, great developments have taken place in the science of human nutrition. The application of this science has spread far beyond the field of clinical practice and is now recognised to be vitally important in many public health problems, as Lord Boyd Orr forecast in his foreword to the first edition of *A Textbook of Dietetics*.

Since many people now realise the importance of good food in adequate amounts for the preservation of health, and the value of suitable diets for the treatment of disease, it seemed to us that a new book on human nutrition and dietetics was needed. Our intention has been to set out the whole wide subject of human nutrition in proper perspective and to bring its many aspects together into one volume.

If asked 'Who is this book for?' we would reply: 'For anyone interested in applying modern scientific knowledge to the practical problems of human nutrition, both in health and disease'. This includes people in many different walks of life.

General practitioners, physicians and surgeons are responsible for seeing that their patients are provided with diets that are most suited for promoting health and aiding recovery from illness. Medical students may find that this book will help them to co-ordinate their knowledge of the physiological, biochemical, clinical and public health aspects of human nutrition. The doctor, in whatever branch of medicine he practises, ought to have a general understanding of the viewpoint of physiologists and food technologists, and *vice versa*. Dietitians and nurses must see that the doctor's dietary prescription is translated into a menu providing meals that are eaten and enjoyed by the patient. For this they need to maintain close and cordial co-operation with the hospital catering officer. Public health doctors and food administrators have the duty to ensure that supplies of food are available, adequate both in quantity and quality, for the needs of the people. Food technologists — chemists, millers, refrigerating engineers and others — must make certain that the methods they use for processing food do not spoil its nutritive value. Farmers and other food producers may well wish to know how the goods which they produce and sell contribute to essential human needs. For people in all of these categories some understanding of the modern science of human nutrition is invaluable.

In recent years nutritional science has advanced in many directions and has sometimes become so highly technical that it is often difficult for an expert in one particular field to view his work clearly in relation to other closely allied developments. There is thus a danger that misunderstandings and misdirected efforts may hinder measures for providing food adequate to sustain the health of mankind.

As doctors we have written this book in the language and style familiar to medicine; nevertheless we hope it will be intelligible to non-medical people professionally concerned with the subject. For this reason we have tried, as far as possible, to avoid obscure technical medical terms. Our aim has been to make most of the text understandable to any interested reader with a background of general scientific education.

The book is divided into six parts.

Part I gives an account of the physiology of nutrition. It is somewhat longer and more complete than the accounts found in most standard textbooks of physiology.

Part II gives a general description of the foods most commonly eaten by man. Their chemical and nutritive properties are described, as are the effects of food processing — milling, preserving and cooking. A short account is given of the various forms of food poisoning.

Part III describes in detail those diseases that are known to be primarily due to faulty nutrition.

Part IV deals with the role of defective diets in contributing to the onset of general diseases which are not primarily nutritional in origin. An account is given of the dietetic treatment of the principal diseases in which diet is of undoubted therapeutic value.

Part V is concerned with nutrition in relation to public health. The various measures available (especially in times of crisis) for ensuring an adequate supply of food are discussed. This part includes an account of the work of the Food and Agriculture Organization of the United Nations (FAO) and of other international bodies concerned with human nutrition. A chapter on the population problem is included.

Part VI deals briefly with the modifications necessary in normal diets to meet the special circumstances of pregnancy, lactation, childhood, athletic training and climatic extremes. Rations for expeditions and emergencies (such as shipwreck) are also discussed.

Numerous tables showing the nutritive values of different foods will be found in Parts I and II, while twenty diets recommended for the treatment of various diseases, and a table of suitable dietary exchanges, have been inserted at appropriate points in the text of Parts III and IV.

In presenting this book our hope is that we have been able to show that the business of feeding people now rests on a sound scientific basis, and that the study of human nutrition deserves recognition as a proper academic discipline.

STANLEY DAVIDSON
A. P. MEIKLEJOHN
R. PASSMORE

January, 1959

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1. Historical and Geographical Perspectives

Nutrition as a science can be said to have been founded by Lavoisier towards the end of the eighteenth century, but dietetics is a much older subject. Hippocrates frequently gave his patients advice about what foods they should eat and, since the days of ancient Greece, doctors in all countries have used dietetics as an important part of their treatment. Nutrition is an art and also a science, based on increasingly secure foundations. Only in the twentieth century did governments begin to assume responsibility for seeing that the poorer and underprivileged sections of society receive enough of the right types of food; to carry out this responsibility knowledge of the science of nutrition becomes of great practical importance.

From a nutritional point of view mankind can be divided into four types: (1) primitive hunter-gatherers, (2) peasant agriculturists and pastoralists, (3) urban slum dwellers, and (4) the affluent. There are not many primitive hunter-gatherers in the world today, but the major part of the human race are still peasant agriculturists, although increasing numbers are either joining the urban slum dwellers or becoming affluent. In no country is there only one type of community. Britain and the United States of America are affluent, but contain many urban slum dwellers and in each there are still a few peasant agriculturists. India has all four types of communities. She is still predominantly a country of peasants, but the rapidly growing towns have increasing numbers of poor urban slum dwellers and a sizeable affluent society; in the jungles a few primitive hunter-gatherers live their lives outside any civilisation.

In this book the problems of therapeutic dietetics and community nutrition are not sharply separated. Each depends on the same fundamental biochemical and physiological science. Before starting an account of this science, a brief description is given of the main nutritional problems in the four types of society.

HUNTER-GATHERERS

Homo sapiens and his predecessors *Homo erectus* and *Australopithecus* were primarily vegetarians but they have done some hunting for up to a million years. Hunting slowly developed as man moved away from the other primates; he became omnivorous (whereas other primates are largely vegetarian) skilled in toolmaking and developed social groups, such as large families and hunting bands. All these changes probably arose more or less simultaneously.

It was only 10000 years ago that the next stage, the technical development of agriculture, began. Thus for at least 99 per cent of the time that man has been evolving from his primate precursors, he has been a hunter-gatherer so that our bodies have presumably evolved well adapted for doing what hunter-gatherers do and eating what they eat.

It is a common misconception that our forebears lived in the cold and ate nothing but meat. The archaeological evidence indicates that man originated in the sunny parts of the world. Loomis (1967) has suggested that man's original skin colour was brown, giving protection from the sun, and that white men evolved after settlement in northern Europe where dark-skinned people would suffer more readily from rickets (p. 276). However, there must have been many differences in diets from place to place and from time to time. For example, Eskimos and Lapps obtain ample vitamin D from marine sources; in some coastal sites the relative amounts of shells in the middens compared with the numbers of bones indicate that shellfish provided the major part of the animal protein intake. Until recently the vegetable part of early man's diet was ignored. Remains of vegetable food in archaeological sites are far less spectacular and much more difficult to identify than the animal bones.

But what were the women doing while their menfolk went out hunting? In rock paintings in southern Africa man the hunter is shown stalking antelopes and shooting at animals with bow and arrow. But the women, with their secondary sex characteristics overemphasised, often have short sticks in their hands, which may be weighted with a stone towards the lower end. These are not weapons. They are sticks used for digging out roots and tubers to eat, the Stone Age forerunners of spade and plough. Thus archaeology gives some understanding of our early ancestors' way of life.

We can also study the hunter-gatherers who are living in the world today. There are only a few groups left and in another generation there may be even fewer. It is not that the people themselves are dying out but their technology is too limited and subtle to stand up to competition from industrial technology. At a symposium on contemporary hunter-gatherers Lee (1967) showed that most of them, except in the Arctic, obtain more food from gathering vegetables than from hunting animals. Lee and De Vore of Harvard made a study of Kung Bushmen in north-west Botswana. These Bushmen are isolated from the outside world of technology by a waterless belt around them, 80 miles wide. This area appears as a blank on the map, except for Mount Aha which when you get there is not a mountain at all. The strategy of the Harvard study was that two or three social anthropologists lived in their own camp near a Bushman camp for a year or more at a time. They learnt the click language, made friends with and observed the Bushmen while disturbing their way of life as little as possible.

One of us (A.S.T.) made three visits to assess their medical and nutritional states at different seasons (Truswell and Hansen, 1976). Our main conclusions were as follows. First, the Bushmen do not become obese, except for the few who live with Bantu primitive pastoralists in the neighbourhood. At the end of the dry season the Bushmen tend to become somewhat undernourished and energy deficient, and this may contribute to their short adult stature.

Secondly, they showed no malnutrition unless something had gone wrong, e.g. an illness or an injury. There were no clinical or biochemical signs of deficiency of any vitamin.

Thirdly, high blood pressure was not found, and both systolic and diastolic pressures fall with increasing age in male Bushmen. This is in striking contrast to the picture in affluent communities, in which mean systolic and diastolic pressures rise with age in both men and women. The explanation could be that the Bushmen do not eat salt (Truswell *et al.*, 1972). There is no archaeological evidence that palaeolithic or mesolithic man undertook salt extraction or had any interest in salt deposits. This seems to have started in neolithic times, presumably when there were food surpluses, which had to be preserved and stored.

Fourthly, the Bushmen's plasma cholesterol concentration averaged 3.0 mmol/l (120 mg/100 ml), a figure among the lowest in the world. Much higher figures are found in most populations who eat meat, as the high proportion of saturated fatty acids in the fat of domestic animals tends to raise cholesterol concentration. But the meat of wild buck has no fat round it and the small amount of fat in the muscle of wild bovids contains mostly polyunsaturated fatty acids (Crawford, 1968). The Bushmen do not eat only meat; they obtain more than half their energy from vegetable foods. The largest single item in their diet is the mongongo nut, *Ricinodendron rautanenii*, which is a good source of protein and whose oil is rich in linoleic acid. The essential characteristic of the hunter-gatherer's diet is that it is mixed. The men go out hunting but the supply of meat is intermittent and more of it comes from hares and other small animals, than from the larger antelopes. The women, meanwhile, collect vegetable food. This often involves walking long distances carrying heavy loads of nuts, etc. on their backs, and sometimes a baby as well. The old women stay behind in camp and do the chores like breaking up nuts and fetching water in ostrich egg shells from the well a mile away.

Fifthly, the Bushmen do not have carious teeth though their teeth get worn down by the hard food as they get older. They occasionally enjoy wild honey but have no other concentrated sugar.

Sixthly, their numbers are few and appear to be stationary; One reason for the wide spacing of births could be the delayed resumption of ovulation as breast feeding is continued for about three years. If they do not die from infections or accidents, they live to a good old age. The proportion over 65 years, approximately 7 per cent, is the same as that in Scotland in 1901.

These observations on the Bushmen and other studies on contemporary hunter-gatherers give some insights into nutritional and other aspects of early man, but care is needed in extrapolating because present-day hunter-gatherers may be regressive societies.

Some people would like to go back to the hunter-gatherer's way of life, but this is impossible; there are too many of us and hunter-gatherers need a lot of space.

PEASANT AGRICULTURISTS AND PASTORALISTS

How to grow crops and to domesticate animals was discovered independently in several widely separated centres from about 8000 or 9000 BC, first around Mesopotamia. It was then possible for people to stay in one place, to build homes and cities, and to store treasure. Distribution became uneven, societies became structured and jobs specialised. The population increased greatly. Wars and human epidemics became part of the pattern of life. Great civilisations like the Egyptian, the Mayan and the classical Greek were based on primitive agriculture.

In large areas of rural Africa, South America, Asia and Oceania the people are still at this stage of technical development and obtain their food from subsistence farming. Nutrition in this setting has five striking differences from that of hunter-gatherers.

First, with harvests once a year, food has to be stored. Hunter-gatherers do not store food; they share it.

Secondly, some of the wealthy overeat and become obese. Hunter-gatherers feast now and again after a successful hunt but not regularly.

Thirdly, alcohol is available, made from the ready supply of carbohydrate in cereals. Hunter-gatherers do not have this solace. Perhaps in smaller social groups they have less need for it.

Fourthly, the most dangerous nutritional effects have come from concentrating on a single crop that yields the most energy (calories per acre or joules per hectare). If this crop fails from drought or blight there is famine. The Irish potato famine of 1845–46 was the most terrible example in Europe (p. 500). The Irish peasants at that time had become completely dependent on potatoes. When the crop became infected by epidemic potato blight the effect was devastating. If a crop becomes contaminated with a toxin many people are likely to be poisoned. Ergotism and lathyrism are examples.

Fifthly, there is the liability to develop specific deficiency diseases, when a large proportion of the dietary energy comes from a single staple food, e.g. a cereal or starchy root. Children are more likely than adults to suffer from such a disease, because of their extra need of nutrients for growth and because the common infections of childhood increase rates of utilisation. The two most important of such specific deficiency diseases are kwashiorkor, principally due to lack of protein, and keratomalacia, where lack of vitamin A may lead to permanent blindness. Diets based on large quantities of a cereal from which most of the vitamin B_1 has been removed by milling may lead to beriberi, a disease once common amongst rice-eaters in the East. Pellagra is still an important disease amongst maize-eaters in Africa and elsewhere. It is due to a lack of nicotinic acid and its precursor, the amino acid tryptophan.

Most of the healthy and virile populations of the world have been peasant agriculturists. The Highlands of Scotland and Nepal have for generations produced famous battalions of fighting men, feared and respected by their adversaries throughout the world. Peasant agriculturists are healthy and feed well, as long as they have enough good land and favourable weather; but in Asia and Latin America and to a lesser extent in Africa increases in population, due to decline in mortality from infectious disease, have caused fragmentation of the holdings. It is difficult for a man to provide a good mixed diet for his family on less than 10 acres (4 hectares) of land.

Pastoralists

Pastoralists are at the same technical level as subsistence agriculturists but have a different way of life and are less numerous. In arid grasslands they follow their grazing animals with the seasons, travelling light and living in tents. The life of Lapps is based on reindeer, of Iranian nomads on sheep and goats, and of Tibetan nomads on yaks; in Africa the Tuareg depend on their camels, and the Fulani and Masai on their cattle. Pastoral tribes once had a military advantage with their horses over their sedentary neighbours. (Sedentary is used here in the anthropological sense to mean settled on an area of land, not inactive.) However, now the two groups usually coexist peacefully in a symbiotic relationship, trading animal for agricultural products. Pastoralists have fallen behind since sedentary groups, in tidy constituencies, have more voting power, more schooling and get on better with administrators.

Pastoral tribesmen do not show the usual relation between income and the quality of the diet (p. 460). Although they are poor in money yet they may eat a diet rich in animal protein. Some consume large quantities of sour milk even as adults; their intestinal lactase persists, as in northern Europeans. They may not eat this rich animal diet all the year round. Nutritionists know far less about the day-to-day way of life of these people than they do about sedentary groups, which are more comfortable to study. Pastoralists deserve sympathetic understanding by officials: there should be a place for them in the ecosystem.

URBAN SLUM DWELLERS

The industrial revolution produced multitudes of a new urban proletariat who were uprooted from their rural origins and packed round the factories in bad housing. Such conditions, so vividly described by Dickens and other novelists, are being repeated today in many countries. But the problems are bigger because the twentieth-century slum and shanty town dwellers have fewer resources and are more numerous. In the industrial countries the growing cities of 100 years ago, for all their grime and misery, had a solid basis of economic life. But, as Barbara Ward (1969) has described, the new migrant multitudes are pouring 'into an urban wilderness where opportunities grow less as the millions pile on top of one another and the farms do not feed them or the industries employ them'.

An increasing number of the world's population is crowding in and around the cities of Asia, Africa and Latin America. They tend to have the worst of both worlds. Traditions are lost but not replaced by education. Families are broken up, mothers go out to work and leave their babies inadequately cared for. The food which they buy is likely to be poor value for money and contaminated by pathogens. The problems are often compounded by alcoholism and violence.

In many towns in Africa, Asia and Latin America the infant mortality (defined on p. 473) is over 100, whereas in prosperous countries with good health services it is below 15. In 1900 infant mortality rates were over 100 in many towns in Europe and North America. A combination of poor hygiene and bad nutrition was and is responsible. In a slum, conditions are ideal for the spread of infections, notably gastroenteritis and respiratory infections. These illnesses diminish food intake and increase the need for nutrients, and so readily precipitate marasmus, a severe and often fatal state of undernutrition in children. Infants prematurely weaned are particularly susceptible. While the infant mortality in a poor community may be 10 times that in a prosperous one, in the 1 to 4 year age-group the mortality may be 50 times higher. Again infectious diseases may precipitate severe undernutrition in toddlers on a poor diet with little or no milk. Measles and whooping cough are ubiquitous. Nowadays in Britain these illnesses are usually mild and a death is exceptional. Yet 70 years ago large numbers of young children in Britain died of measles and whooping cough, as they still do in many countries.

In slum conditions adolescents and adults are much less susceptible to deficiency diseases than are children, but such diseases may follow severe infections. In adults a more important cause is drug dependence. Alcohol was the drug most commonly responsible in the past and still is in many places, but nowadays other psychotropic drugs may contribute. Persons dependent on drugs may become malnourished for four reasons: (1) they may spend so much money on the drug that they cannot afford a proper diet, (2) a drug may depress their appetites, (3) a drug habit may upset incentives to healthy living, and (4) a drug may interfere with metabolism in the tissues and organs, notably in the liver. Poor nutrition is but one aspect of urban poverty, albeit a very important one. It sets up a vicious circle, making its victim physically and mentally unfit for work and so driving him and his family deeper into poverty. All contemporary experience shows that programmes for better housing, for clean water, for the control of infectious diseases, for more and better food, and for education in health and nutrition, or the provision of better wages and more jobs, do not alone solve the problems of poverty. A coordinated attack simultaneously along these fronts is needed. Nutritionists cannot work effectively on their own. They require to be in a team with other health and social workers.

AFFLUENT SOCIETIES

Affluent societies, as in Britain today, present nutritionists with a new set of challenges. The whole picture is different. In place of undernutrition we are now more worried by overnutrition. The most malnourished segment of the community is no longer the babies, who tend to be obese, but some of the elderly, especially those who are lonely, depressed and failing physically or mentally. Some new varieties of malnutrition are appearing in patients whose lives have been saved by the miracles of modern medicine or surgery.

We are free of fear of crop failure and can eat our favourite dishes all the year round. Modern food industry uses foods imported from many parts of the world and preserves them mainly by refrigeration and canning. We are now worried about our foods being too refined—without sufficient fibre—or adulterated by fertilisers, insecticides and food additives. Instead of food taking much time and effort to prepare and being eaten formally with all the family, we have instant and convenience foods. The housewife may not be sure what is in them. The family tends to eat in a hurry in different places, and the mother may not know what her children are eating.

A feature of affluent societies is that they consume enormous quantities of pharmaceuticals. Many of these increase the needs for specific nutrients and interfere with nutrition in other ways. Patients receiving such drugs are at increased risk of nutritional disorders. Examples can be found by looking up the items under 'drugs' in the Index.

In Britain in the 1970s about 42 per cent of our energy came from fat and 20 per cent from sugar. There is a strong suspicion that diet has at least something to do with several of the chronic and degenerative diseases of later life. The relationship between diet and dental disease is fairly clear (p. 391) though what is to be done is not. Coronary heart disease, diabetes, gallstones, diverticulosis and some cancers may each be partly determined by diet.

Instead of lack of basic education and no nutritional advice, we find ourselves in a Tower of Babel of nutritional breakthroughs and threats. From newspapers, women's magazines, television, radio advertisements and supermarket shelves we are bombarded with information from competing interests in the food industry, from journalists and from some medical men. One can hardly blame the man or woman in the street if they conclude that all the advice and advertisements cancel each other out. 'It can't matter much what you eat, so I'll eat what I enjoy.'

For professional nutritionists there are two kinds of job to be done. First, we have to continue scientific research, and the biggest challenge is to try and work out the place of nutrition among the multiple and interacting causes of the chronic disease where we have epidemiological clues. Because little progress is being made in the prevention of chronic disease, life expectancy in men has now stopped lengthening in Western countries (Burch, 1972). The science of nutrition has achieved much in relating gross nutritional deficiency to certain acute diseases. But we have a long way to go in relating subtle nutritional imbalances to the increased risk of a chronic disease many years later. This is not a field in which quick results can be guaranteed and the situation is made difficult because of inadequate financial investment in this type of research.

The second big task is to discover how to give the people in an affluent society a better understanding of what they should aim to eat. And since an increasing proportion of our food is prepared by manufacturers, there is a responsibility to advise them on long-term planning of their products. The trouble is that to give any general advice at all one has to make a judgment on insufficient evidence, then simplify it and put it in a form that appeals to people. Professional nutritionists should have their arguments in professional societies and journals, not on the air or in newspapers. We should try a bit harder to reach a consensus for the benefit of the people as a whole.

School children, young adults and the elderly each require different nutritional advice. Food habits are acquired early in life and it is very difficult to change them. Nutrition education is considered on page 477.

This account of historical and geographical perspectives attempts to lay a basis for the application of nutritional science to the needs of a varied and evolving world population. The scientific principles are broadly the same whatever cultural group is being considered. The application through nutrition education is vastly different. If this universal science is to bring the best results for the world as a whole we must learn to apply it to all groups, using language and educational techniques which are adapted to regional cultures.

2. Composition of the Body

What are little boys made of?
What are little boys made of?
Slugs and snails and puppy-dogs' tails;
That's what little boys are made of.

What are little girls made of?
What are little girls made of?
Sugar and spice and all things nice;
That's what little girls are made of.

Many carcasses of small animals have been analysed chemically, but the results do not necessarily apply to man. A complete chemical analysis of the human cadaver is a formidable task which has been carried out on a number of occasions, but not sufficiently often to give the range of variations in people of different age and sex (Widdowson *et al.*, 1951). Nevertheless, enough is known to state that the data in Table 2.1 are representative of a normal man.

Table 2.1 A normal chemical composition for a man weighing 65 kg

	kg	Per cent
Protein	11	17.0
Fat	9	13.8
Carbohydrate	1	1.5
Water	40	61.6
Minerals	4	6.1

Most of the material listed in Table 2.1 is part of the essential structure of the body, but a portion represents reserves or stores. Of the 9 kg of fat not more than about 1 kg is essential; the remainder represents a store which can be drawn upon in times of need. In obese people this store may be very much larger and form up to 70 per cent of the body weight. Most of the protein is an essential component of the cells, but probably about 2 kg can be lost without serious results. By contrast, the body can be depleted at most by 200 g of carbohydrate. During starvation the store of carbohydrate is continually replenished by synthesis from the larger reserves of protein and fat. The body can lose up to 10 per cent of its total water and at least a third of the mineral content of the skeleton without serious risk to life. The size of the stores and the factors that determine deposits and withdrawals are important nutritional considerations, amplified in succeeding chapters.

COMPARTMENTS OF THE BODY

At a meeting of the New York Academy of Sciences in 1963 the Professor of Surgery at Harvard, Dr Francis D. Moore, went to the blackboard and wrote the following equation:

$$\text{MAN}=\text{CM}+\text{EST}+\text{FAT}$$

This is interpreted as follows. A man can be divided into three compartments. CM is the cell mass which is the active tissue, carrying out all the work of the body. EST is the extracellular supporting tissue which supports the cell mass. This again can be subdivided into two parts: the extracellular fluid, and minerals and protein fibres in the skeleton and other supporting tissue. The extracellular fluid comprises the blood plasma and lymph and the fluid which bathes the cells. The living skeleton is, however, very different from the dead specimens familiar in anatomy museums. It is a cellular organ in which the supporting mineral deposits are laid down. FAT is the energy reserve held in adipose tissue beneath the skin and around the internal organs.

In a healthy body the cell mass may contribute about 55 per cent of the total weight, the extracellular supporting tissue about 30 per cent and the fat reserve about 15 per cent. These proportions may be greatly altered by disease. Thus in starvation arising from lack of food or in the emaciation that results from any wasting disease, the cell mass is reduced and the fat reserve may be almost completely utilised. The extracellular supporting tissue is little altered in absolute size and so becomes relatively bigger and may comprise 50 per cent or more of the body weight. In obesity the fat reserve is greatly increased.

ELECTROLYTES

An important difference exists between the chemical constitution of the fluid within the cells and that of the extracellular fluid which surrounds them. Cell fluid is primarily a solution of potassium ions and extracellular fluid a solution of sodium chloride. The anions within the cell are provided mainly by phosphates, proteins and organic acids in varying proportions. Table 2.2 shows approximate concentrations of these and other ions in the two fluids. The difference between the concentration of the ions inside and outside the cells is only maintained by the expenditure of energy which is provided by the metabolic processes within the cells. Much of the energy expenditure of the resting body is used to maintain this electrolyte equilibrium. Cellular activity either in muscle, nerve or secretory cell is associated with local disturbances of ionic equilibrium at the cell wall and chemical energy is needed to restore resting conditions.

Table 2.2 A normal distribution of ions in intracellular and extracellular fluids

	Intracellular (mEq/l)	Extracellular (mEq/l)
Cations:		
Na^+	10	145
K^+	150	5
Ca^{2+}	2	2
Mg^{2+}	15	2
	177	154
Anions:		
Cl^-	10	100
HCO_3^-	10	27
SO_4^{2-}	15	1
Organic acids		5
PO_4^{3-}	142	2
Proteins		19
	177	154

CHEMICAL DISSECTION OF THE BODY

It is possible by chemical methods to determine the size of the chief compartments of the human body. The methods are of necessity indirect. Many of them are too complex and time-consuming to be of practical value in routine clinical medicine. They are, however, mostly within the competence of even a small research laboratory. The results obtained, using the methods now to be described, have had a profound effect on our understanding of the changes that take place in the body as a result of nutritional diseases. They make possible quantitative measurements of these changes. A fuller account of the chemical anatomy of the human body is given by Passmore and Draper (1970).

The dilution principle

It is possible to determine the volume (V) of a fluid in an irregular container by adding to it a measured quantity (Q) of a substance which diffuses freely and evenly throughout the fluid. After an interval to allow even distribution of the test substance, its concentration (C) in the fluid is determined. Then the volume can be calculated from the formula

$$V = \frac{Q}{C}$$

This principle has wide applications in human biology.

Total body water

In living man or any intact animal it is possible to estimate the total body water in the following way. A known weight of a substance which is freely diffusible in all the body fluids is given to the subject, either by mouth or by intravenous injection. After sufficient time has been allowed for the substance to diffuse throughout all the tissues, a sample of blood is withdrawn and the concentration of the substance in the plasma determined. The total body water can then be calculated as described above. Corrections have to be made for any excretion or metabolism of the substance during the period of diffusion. Many freely diffusible substances, e.g. urea, antipyrine and ethanol, have been used for this purpose. Today the isotopes deuterium and tritium are usually employed. Consistent results with each have been obtained by experienced workers. As there is the dual assumption not only that the test substance is freely diffusible into all cells of the body, but also that proper corrections have been made for any losses, the prudent sometimes express their results in terms of the size of the 'tritium space' or the 'antipyrine space'. A normal value for the total body water is 40 litres and varies from 50 to 65 per cent of the body weight, or even more widely according to the degree of fatness of the subject.

Extracellular water

A number of substances — sucrose, inulin (a carbohydrate derived from a plant root), sodium thiocyanate, sodium thiosulphate and the bromide ion, which can be labelled isotopically — when injected into the body appear to occupy a 'space' which is much smaller than the total body water and which is probably the same as the extracellular fluid. The 'thiocyanate space' can be measured conveniently in any laboratory without special equipment, and provides a useful measure of the extracellular fluid. (Thiocyanate enters the red blood corpuscles and a correction has to be made in calculating the extracellular fluid from the thiocyanate space.) The extracellular fluid normally comprises 18 to 24 per cent of the body weight. In patients with oedema from starvation or other cause, it may be increased to 50 per cent of the body weight. In dehydration it is markedly reduced.

Cell water and cell mass

If the total body water and extracellular water are measured as described above, the difference between the two can be taken as the cell water. Thus the reference man whose chemical composition is given in Table 2.1 has a total body water of 40 l. If the extracellular water is 15 l then

$$\text{Cell water} = 40 - 15 = 25 \text{ litres}$$

Cells vary in their water content. Muscle cells are about 75 per cent water. Red blood corpuscles, brain cells and cells in tendons and connective tissue contain much less water. It is a reasonable approximation to say that 70 per cent of the whole cell mass is water. Hence in our reference man