THIRD EDITION

INTRODUCTION TO NUTRITION AND METABOLISM

David A Bender

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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 to explain both the conclusions of the many expert committees that 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 what is 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 basic sciences that underlie a proper understanding of health and human sciences and the ways in which human beings and their environment interact. In its turn, the science of nutrition is based on both biochemistry and physiology, on the one hand, and the social and behavioural sciences on the other. This book contains such biochemistry as is essential to an understanding of the science of nutrition.

In a book of this kind, which is an *introduction* to nutrition and metabolism, it is not appropriate to cite the original scientific literature which provides the (sometimes conflicting) evidence for the statements made; in the clinical problems and some of the tables of data I have acknowledged my sources of data as a simple courtesy to my follow scientists, and also to guide readers to the original sources of information. Otherwise, the suggestions for further reading and Internet sites listed under additional resources are intended to provide an entry to the scientific literature.

Two of my colleagues have provided especially helpful comments: Dr Derek Evered, Emeritus Reader in Biochemistry at Chelsea College, University of London, and Professor Keith Frayn (University of Oxford). I would like to thank them for their kind and constructive criticisms of the second edition of this book. I am grateful to those of my students whose perceptive questions have helped me to formulate and clarify my thoughts, and especially those who responded to my enquiry as to what they would like to see (for the benefit of future generations of students) in this new edition.

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 they offer.

David A Bender
December 2001

Additional resources

At the end of each chapter there is a list of the additional resources that are available on the CD that accompanies this book. All of these can be run directly from the CD, or may be copied onto a hard disk or network, for internal use only, in educational institutions – instructions for installation are included in the ReadMe file on the CD. To access the resources listed here you will require an IBM-compatible PC running Windows 95, 98 or higher.

The resources on the CD consist of the following.

PowerPoint presentations to accompany each chapter

If you have Microsoft PowerPoint 2000 installed on your computer then you can view these presentations immediately. If not, the PowerPoint viewer is also on the CD and can be installed by running Ppview32.exe from the folder 'extra files'.

Teachers are welcome to use these PowerPoint presentations, or parts of them, in their lectures, provided that due acknowledgement is made; they are copyright David A Bender 2002 (and some of the figures are copyright Taylor & Francis 2002), and may not be published for profit in any form.

Self-assessment quizzes

For most chapters there is a computer-based self-assessment quiz on the CD. This consists of a series of statements to be marked true or false; you assess your confidence in your answer, and gain marks for being correct, or lose marks for being incorrect, scaled according to your confidence in your answer.

These quizzes are accessed from the program Testme.exe on the CD.

Simulations of laboratory experiments

There are a number of simulations of laboratory experiments on the CD; they are accessed by name – e.g. the Enzyme Assay program (Chapter 2) is accessed from the Enzyme Assay icon.

Problems at the end of chapters

At the end of most chapters there are problems to be considered. These are of various kinds:

- open-ended problems to be thought about;
- defined calculation problems to which there is a correct answer (but the answer is not provided here);
- problems of data interpretation, in which you are guided through sets of data and prompted to draw conclusions (again, deliberately, no answers to these problems are provided);
- clinical problems in which you are given information about a patient and expected to deduce the underlying biochemical basis of the problem, and explain how the defect causes the metabolic disturbances.

Other resources

NUTRITION BOOKS

Bender AE and Bender DA, *Food Tables and Labelling*, Oxford University Press, Oxford, 1998.

Bender DA and Bender AE, *Benders' Dictionary of Nutrition and Food Technology*, Woodhead Publishing, Cambridge, 1999.

Bender DA and Bender AE, *Nutrition: a Reference Handbook*, Oxford University Press, Oxford, 1997.

Garrow JS, James WPT and Ralph A, *Human Nutrition and Dietetics*, 10th edn, Churchill Livingstone, Edinburgh, 2000.

Holland B, Welch AA, Unwin D, Buss DH, Paul AA and Southgate DAT (eds), *McCance & Widdowson's The Composition of Foods*, 5th edn, RSC/HMSO, London, 1991.

BIOCHEMISTRY BOOKS

Campbell PN and Smith AD. *Biochemistry Illustrated*, 4th edn, Churchill Livingstone, Edinburgh, 2000.

Champe PC and Harvey RA. *Lippincott's Illustrated Reviews, Biochemistry*, 2nd edn, Lippincott-Raven, Philadelphia, 1994.

Elliott WH and Elliott DC. *Biochemistry and Molecular Biology*. Oxford University Press, Oxford, 1997.

Frayn KN. *Metabolic Regulation: A Human Perspective*. Portland Press, London, 1996.

Gillham B, Papachristodoulou DK and Thomas JH. *Wills' Biochemical Basis of Medicine*. 3rd edn, Butterworth-Heinemann, Oxford, 1997.

Marks DB, Marks AD and Smith CM. *Basic Medical Biochemistry: A Clinical Approach*. Williams & Wilkins, Baltimore, 1996.
Stryer L. *Biochemistry*, 4th edn, Freeman, New York,1995.
Voet D and Voet JG. *Biochemistry*, 2nd edn, John Wiley, New York, 1995.
Zubay GL, Parson WW and Vance DE. *Principles of Biochemistry*, William C Brown, Dubuque, IA, 1995.

Review journals

Nutrition Research Reviews, published biannually by CABI Publishing, Wallington, Oxford, for the Nutrition Society.
Nutrition Reviews, published monthly by the International Life Sciences Institute, Washington, DC.
Annual Reviews of Biochemistry and *Annual Reviews of Nutrition*, published annually by Annuals Reviews Inc.

If you have problems with some of the chemistry in this book, try the following:

Wood EJ and Myers A, *Essential Chemistry for Biochemistry*, 2nd edn, The Biochemical Society/Portland Press, London, 1991.

Internet links

Professional organizations and learned societies

American Council on Science and Health: http://www.acsh.org/
American Society for Nutritional Sciences: http://www.nutrition.org
Association for the Study of Obesity: http://www.aso.org.uk
Biochemical Society: http://www.biochemsoc.org.uk/default.htm
British Association for the Advancement of Science: http://www.britassoc.org.uk/info/scan5.html
British Dietetic Association: http://www.bda.uk.com
British Nutrition Foundation: http://ww.nutrition.org.uk
COPUS (Committee on Public Understanding of Science): http://www.royalsoc.ac.uk/st_cop01.htm
International Society for the Study of Obesity: http://www.iaso.org/home.html
International Union of Nutritional Sciences home page: http://www.monash.edu.au/IUNS/
Learning and Teaching Support Network, bioscience: http://ltsn.ac.uk/NV/bioframes.htm
National Sports Medicine Institute: http://nsmi.org.uk/
North American Association for the Study of Obesity: http://www.naaso.org
Nutrition Society: http://www.nutsoc.org

Information about nutrition and food

Arbor Nutrition Guide: http://arborcom.com/
Eat Well, Live Well Research and Information Centre, Monash University: http://www.healthyeating.org
Food and Nutrition Information Center, US Department of Agriculture: http://www.nal.usda.gov/fnic/
International Food Information Service: http://www.ifis.org/
Martindale's Virtual Nutrition Center: http://www.sci.lib.uci.edu/HSG/Nutrition.html
Nutrition web sites reviewed from Tufts University: http://navigator.tufts.edu

General research tools and information

Cornell Cooperative Extension – a useful source of information on nutrition and agriculture: http://www.cce.cornell.edu/
Enzyme database: http://www.expasy.ch/enzyme/
Glossary of biochemistry and molecular biology online: http://db.portlandpress.com/db.htm
ILSI (International Life Sciences Institute) – publishers of *Nutrition Reviews*: http://www.ilsi.org
MedBioWorld – links to nutrition-related journals available on-line: http://www.sciencekomm.at/journals/food.html
Medline: http://www.nlm.nih.gov/PubMed/
MedWeb Biomedical Internet Resources from Emory University: http://www.cc.emory.edu/WHSCL/medweb.html
OMNI (Organising Medical Networked Information): http://www.omni.ac.uk
On-Line Mendelian Inheritance in Man (OMIM): http://www3.ncbi.nih.gov.Omim/

Government and international sites

Department of Environment, Food and Rural Affairs, UK: http://www.maff.gov.uk/defra/default.htm
Department of Health, UK: http://www.open.gov.uk/doh/dhhome.htm
FAO Food and Agriculture Organization of the UN: http://www.fao.org
FDA Consumer – the consumer bulletin of the US Food and Drug Administration: http://www.fda.gov/fdac/796_toc.html
Food and Nutrition Information Center: http://www.nal.usda.gov/fnic/
Food Standards Agency (UK): http://www.foodstandards.gov.uk
Health Canada Nutrition: http://www.hc-sc.gc.ca/hppb/nutrition
IUNS (International Union of Nutritional Sciences): http://www.monash.edu.au/
NHS Direct Online – UK government site providing advice and information about illnesses: http://www.nhsdirect.nhs.uk
United Nations and other international organizations:http://www.undcp.org/unlinks.html

US Food and Drug Administration: http://www.fda.gov.default.htm
WHO World Health Organization: http://www.who.int/home-page/

Just for fun

David Bender's home page: http://www.biochem.ucl.ac.uk/~dab/dab.html

Contents

CHAPTER 1

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 in order 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, more importantly, 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 do meals form such an important part of our life?

Objectives

After reading this chapter you should be able to:

- describe the need for metabolic fuels and, in outline, the relationship between food intake, energy expenditure and body weight;
- describe in outline the importance of an appropriate intake of dietary fat;
- describe the mechanisms involved in short-term and long-term control of food intake;
- describe in outline the mechanisms involved in the sense of taste;
- explain the various factors that influence people's choices of foods.

1.1 *The need for energy*

There is an obvious need for energy to perform physical work. Work has to be done to lift a load against the force of gravity, and there must be a source of energy to perform that work. As discussed in section 5.1, the energy used in various activities can readily be measured, as can the metabolic energy yield of the foods that are the fuel for that work (see Table 1.1). This means that it is possible to calculate a balance between the intake of energy, as metabolic fuels, and the body's energy expenditure. Obviously, energy intake has to be appropriate for the level of energy expenditure; as discussed in Chapters 6, and 8 neither excess intake nor a deficiency is desirable.

Figure 1.1 shows the relationship between food intake, physical work and changes in body reserves of metabolic fuels, as shown by changes in body weight. This study was carried out in Germany at the end of the Second World War, when there was a great deal of rubble from bomb damaged buildings to be cleared, and a large number of people to be fed and found employment. Increasing food intake resulted in an increase in work output – initially with an increase in body weight, indicating that the food supply was greater than required to meet the (increased) work output. When a financial reward was offered as well, the work output increased to such an extent that people now drew on their (sparse) reserves of metabolic fuel, and there was a loss of body weight.

Quite apart from obvious 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 voluntary work (section 5.1.3). Two-thirds is required for maintenance of the body's functions, homeostasis of the internal environment and metabolic integrity.

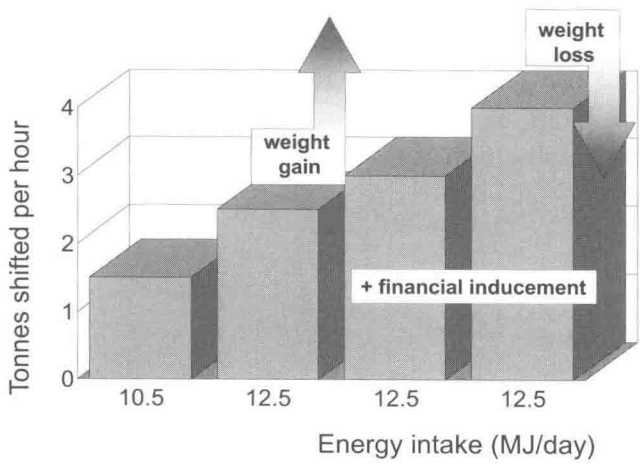

FIGURE 1.1 *The relationship between food intake, work output and body weight (Wuppertal data). From data reported by Widdowson EM, MRC Special Report series no. 275, HMSO, 1951.*

As shown in Figure 1.2, about 20% of total energy expenditure is required to maintain the electrical activity of the brain and nervous system. This energy requirement, the basal metabolic rate (BMR; section 5.1.3.1) can be measured by the output of heat, or the consumption of oxygen, when the subject is completely at rest.

Part of this basal energy requirement is obvious – the heart beats to circulate the blood; respiration continues; and there is considerable electrical activity in nerves and muscles, whether they are 'working' or not. These processes require a metabolic energy source. Less obviously, there is also a requirement for energy for the wide variety of biochemical reactions occurring all the time in the body: laying down reserves of fat and carbohydrate (section 5.6); turnover of tissue proteins (section 9.2.3.3); transport of substrates into, and products out of, cells (section 3.2.2); and the production and secretion of hormones and neurotransmitters.

1.1.1 Units of energy

Energy expenditure is measured by the output of heat from the body (section 5.1). 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 degree Celsius. The calorie is still used to some extent in nutrition; in biological systems the kilocalorie, kcal (sometimes written as Calorie with a capital C) is used. One kilocalorie is 1000 calories (10^3 cal), and hence the amount of heat required to raise the temperature of 1 kg of water through 1 degree Celsius.

Correctly, the joule is used as the unit of energy. The joule is an SI unit, named after James Prescott Joule (1818–89), who first showed the equivalence of heat, mechanical work and other forms of energy. In biological systems, the kilojoule (kJ = 10^3 J = 1000 J) and megajoule (1 MJ = 10^6 J = 1,000,000 J) are used.

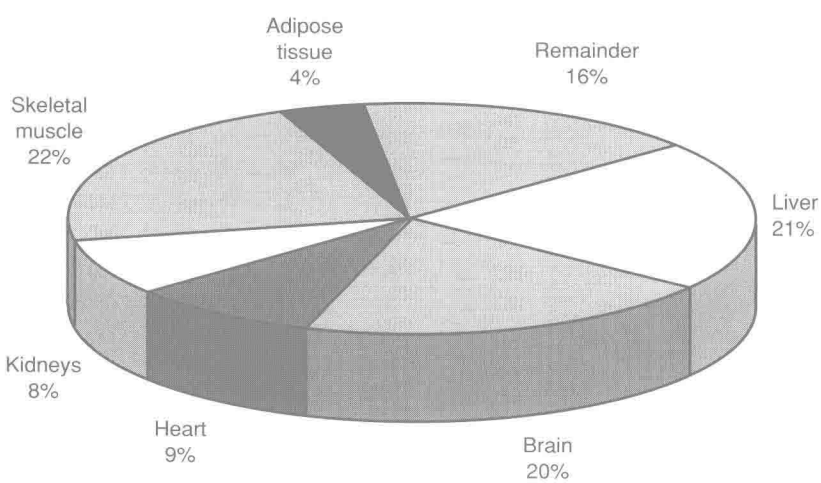

FIGURE 1.2 *Percentage of total energy expenditure by different organs of the body.*