This book is dedicated to Mary Barasi who was an amazing teacher, friend and supporter. Since my undergraduate days, Mary’s belief in my ability to be a researcher and her dedication and encouragement to help me get there resulted in the happy position I am in today at the University of Alberta, in beautiful Canada. It just takes one person to tell you that you are capable and to help you navigate the system, and for me, that was Mary. I am eternally grateful to her and I am honoured to have had the opportunity to be the editor of this book.

I would like to thank from the bottom (to the top) of my heart my wonderful parents who have always supported and encouraged me in all my endeavours and especially in my love of nutrition and research.
# Contents

Acknowledgements viii
How to use your textbook ix
About the companion website xi

## Part I

### Nutrients including carbohydrates, fat, proteins, vitamins, minerals, and alcohol  1

1. Introduction to the nutrients  2
2. The relationship between diet, health and disease  4
3. Energy intake: Food sources  6
4. Energy: Control of food intake  8
5. Energy: Measurement of requirements  10
6. Energy requirements: Components of energy expenditure  12
7. Carbohydrates: Simple and complex carbohydrates  14
8. Carbohydrates: Digestion and utilisation in the body  16
9. Fats: Types of fatty acids  18
10. Fats: Compound lipids (triglycerides, phospholipids, cholesterol, and phytosterols)  20
11. Fats: Digestion and utilisation in the body  22
12. Proteins: Chemistry and digestion  24
13. Proteins: Functions and utilisation in the body  26
15. Dietary supplements  30
16. Micronutrients: Fat-soluble vitamins  32
17. Micronutrients: Water-soluble vitamins  34
18. Micronutrients: Major minerals  36
19. Micronutrients: Trace elements  38
20. Micronutrients: Role in metabolism  40
21. Micronutrients and circulatory system I  42
22. Micronutrients and circulatory system II  44
23. Micronutrients: Protective and defence roles I  46
24. Micronutrients: Protective and defence roles II  48
25. Micronutrients: Structural role in bone I  50
26. Micronutrients: Structural role in bone II  52
27. Alcohol  54
28. Fetal alcohol spectrum disorder  56
29. Fluids in the diet  58

## Part II

### Nutritional epidemiology including assessments, consequences and food choices  61

30. Introduction to nutrition epidemiology: Study designs I  62
31. Introduction to nutrition epidemiology: Study designs II  64
32. Research ethics  66
Part III  Nutrition throughout the life cycle  93
45 Nutrition in pregnancy and lactation  94
46 Nutrition in infants, toddlers and preschool children  96
47 Nutrition in school-age children and adolescents  98
48 Nutritional challenges in infants, children and adolescents  100
49 Nutrition and early origins of adult disease  102
50 Nutrition in older adults  104

Part IV  The role of nutrition in key organs/systems  107
61 Nutrition and the gastrointestinal tract I  108
62 Nutrition and the gastrointestinal tract II  110
63 Nutrition and the brain I  112
64 Nutrition and the brain II  114
65 Nutrition and the eye  116

Part V  Nutrition-related diseases  119
56 Overweight and obesity: Aetiological factors  120
57 Overweight and obesity: Consequences for health and chronic disease  122
58 Overweight and obesity: Insulin resistance and metabolic syndrome  124
59 Overweight and obesity: Prevention and management  126
60 Overweight and obesity: Popular slimming diets  128
61 Underweight and negative energy balance  130
62 Nutrition and cancer I  132
63 Nutrition and cancer II  134
64 Diet and cardiovascular disease: Aetiology  136
65 Diet and cardiovascular disease: Prevention  138
66 Adverse reactions to food and inborn errors of metabolism  140

Part VI  Public health and sports nutrition  143
67 Nutritional genomics  144
68 Nutrition transition  146
69 Promoting nutritional health: A public health perspective I  148
70 Promoting nutritional health: A public health perspective II  150
71 Promoting nutritional health: The role of the dietitian  152
72 Nutrition and sport I  154
73 Nutrition and sport II  156
Part VII  Foods, phytochemicals including functional and genetically modified foods  159

74  Functional foods  160
75  Phytochemicals  162
76  Genetically modified foods  164
77  Food safety  166

Appendices  168
Appendix A1  Structures of the fat-soluble vitamins A, D, E and K  168
Appendix A2  Structures of the water-soluble vitamins: Thiamin, riboflavin, niacin, vitamin B₆, biotin, pantothenic acid, folic acid, vitamin B₁₂ and vitamin C  170
Appendix A3  Structures of the major classes of phytochemicals  172

Bibliography  174
Index  177
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A special thanks goes to Dr. Gail Andrew, Dr. Shelley Birchard and Dr. Sharon Mitchell for their contributions to Chapter 28 on fetal alcohol spectrum disorder.
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Self-assessment review questions, available on the book’s companion website, help you test yourself after each chapter.
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Don’t forget to visit the companion website for this book:

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• Abbreviations and definitions
• Interactive multiple-choice questions
• References and suggested reading
• Global dietary guidelines and dietary reference intakes (DRIs)

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Nutrients including carbohydrates, fat, proteins, vitamins, minerals, and alcohol

**Chapters**

1. Introduction to the nutrients 2
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22. Micronutrients and circulatory system II 44
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24. Micronutrients: Protective and defence roles II 48
25. Micronutrients: Structural role in bone I 50
26. Micronutrients: Structural role in bone II 52
27. Alcohol 54
28. Fetal alcohol spectrum disorder 56
29. Fluids in the diet 58
Introduction to the nutrients

Aims
1. To show how nutrients are classified and discuss their main roles
2. To describe how nutrients may interact to fulfil similar roles

Food is composed of a large variety of chemical substances, some of which are recognised as nutrients. Over the past century or so, scientists have identified the roles of these nutrients in the body and the consequences of insufficient intakes. Many other substances are present in foods of plant origin that help promote the plant’s growth, protect it against predators or contribute to its appearance or smell to attract animals that will spread its seeds. Although these substances (phytochemicals) are not recognised as nutrients, some may be biologically active in humans and could have either beneficial or harmful effects.

Classification of nutrients
Traditionally, the major nutrients have been classified according to the amounts in which they are required by the body, their chemical nature and their functions. The principal distinction is between macronutrients and micronutrients:
1. Macronutrients are required in relatively large amounts, usually expressed in terms of grams per day.
2. Micronutrients are required in small amounts, usually expressed in terms of milligrams or micrograms per day.

Some classifications also include ultratrace nutrients. These are found in the diet in very small amounts (typically <1 μg/g of dry food). For many of these substances, their roles are, as yet, uncertain.

Water is an essential component of the diet, as an adequate intake of fluid is vital to sustain life.

Macronutrients
This category comprises carbohydrates, fats and proteins:
• Carbohydrates and fats are the major providers of energy, although proteins can also be used to provide energy.
• They all have a structural role in the body, the most important in this respect being proteins.
• All contain carbon, hydrogen and oxygen. In addition, all proteins contain nitrogen, while some amino acids (cysteine and methionine) that are found in proteins contain sulphur.

Carbohydrates
Carbohydrates are the most important source of food energy in the world. Carbohydrates occur in the diet in various degrees of complexity, ranging from simple sugars (mono- and disaccharides) to larger units such as oligosaccharides and polysaccharides. Simple sugars include the monosaccharides glucose, fructose and galactose and the disaccharides sucrose and lactose. Oligosaccharides include maltodextrins and fructo-oligosaccharides. Important polysaccharides include starch and glycogen.

The main function of carbohydrates is to act as a source of energy, in the form of glucose. However, some carbohydrates resist digestion and are termed ‘non-glycaemic’ (see Chapter 8). They comprise the non-starch polysaccharides (NSP), which are part of the category known as ‘dietary fibre’. These carbohydrates play an important role in bowel function.

Fats
Fats are a diverse group of lipid-soluble substances, the majority of which are triacylglycerols (TAGs). Other lipid-soluble substances including phospholipids and sterols (e.g. cholesterol) are also included in this group.

TAGs are broken down to yield energy and are the body’s richest source of energy, having over twice the caloric content of carbohydrates and proteins. They are also the body’s major energy reserve, stored in the adipose tissue. Specific fatty acids found in TAGs (called essential fatty acids) are important for cell membrane structure and function. Since the body lacks the ability to manufacture essential fatty acids, they must be supplied in the diet.

Proteins
Proteins consist of chains of amino acids. Food proteins typically contain 20 different amino acids, but because these can be arranged in countless ways, there is enormous diversity between different proteins in the diet in terms of their amino acid sequences. On digestion, individual amino acids are used for the synthesis of other amino acids and proteins required by the body. This process involves considerable recycling of the components.

There are eight essential amino acids (more in children), which must be supplied by the diet. Certain other amino acids may become conditionally essential in situations of physiological stress. Only when there is no further need for amino acids are they broken down and used as a source of energy. During that process, the nitrogen part of the amino acid is excreted via the urine as urea.

Micronutrients
The micronutrients consist of the vitamins and minerals (see Table 1.1).

Table 1.1 Classification of micronutrients by chemical properties.

<table>
<thead>
<tr>
<th>Name</th>
<th>Main members of the group</th>
<th>Role(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat-soluble vitamins</td>
<td>Vitamins A, D, E, K</td>
<td>Structural role, cell integrity, homeostasis, antioxidant, nerve impulses</td>
</tr>
<tr>
<td>Water-soluble vitamins</td>
<td>B vitamins, vitamin C</td>
<td>Metabolism, cell division, antioxidant, cofactors for enzymes, synthesis of neurotransmitters</td>
</tr>
<tr>
<td>Minerals</td>
<td>Calcium, phosphorus, sodium, chloride, potassium, magnesium, iron, zinc, copper, manganese, iodine, selenium</td>
<td>Structural role, cofactors for enzymes, acid–base balance</td>
</tr>
</tbody>
</table>
**Vitamins**

Vitamins are organic substances that are required by the body in very small amounts for its normal functioning. They are classified into the fat-soluble vitamins (A, D, E and K) and the water-soluble vitamins (B-group vitamins and vitamin C).

The body does have the capacity to synthesise some vitamins. For example, vitamin D is synthesised in the skin by the action of ultraviolet light on a precursor molecule, 7-dehydrocholesterol. Vitamin B₃ (niacin) can also be made in the body, from the amino acid tryptophan, which means that a separate supply of niacin may not be needed if protein intake is adequate. However, in the case of both of these vitamins, there are situations where synthesis is insufficient, and so a dietary need remains.

**Minerals**

Minerals are inorganic substances required by the body in small amounts, generally to function as part of the structure of other molecules (e.g. calcium in the bone or iron in haemoglobin) or to act as essential cofactors for the activity of enzymes (e.g. selenium in glutathione peroxidase).

For some minerals (e.g. iron), uptake from the diet must be carefully regulated as there is only a very limited capacity for excretion, and potential toxicity may result if large amounts accumulate in storage organs.

In addition, some minerals compete with each other for absorption, so excessive intakes of one may hinder the uptake of another (e.g. zinc and iron, or iron and calcium).

**Water**

Water provides the basic medium in which all the body’s reactions occur. Inadequate fluid intakes will quickly compromise the metabolic functions of the body and disturb the homeostatic mechanisms that normally operate.

**Alcohol**

Alcohol is not considered a nutrient, but when ingested, it is broken down to provide energy. Some alcoholic beverages (e.g. beer) provide additional nutrients such as B vitamins, albeit in small amounts.

**Grouping of nutrients by functional role**

Many nutrients interact in carrying out their functional roles in the body, and this may also be used as a basis for classification:

- At the genetic level, nutrients are involved in regulating the transcription of genes, thus affecting the synthesis of proteins, including enzymes.
- At the cellular level, nutrients are involved as cofactors in controlling and regulating metabolic reactions and the release of energy. They are regulated by hormones and other chemical messengers, such as cytokines, which are also influenced by the nutrient environment.
- Immune and defence mechanisms function through the release of highly reactive molecules called free radicals, which must then be quenched by antioxidants, again supplied directly by the diet or indirectly as enzymes activated by dietary factors.

**Interactions**

When food is eaten, interactions may occur between nutrients and non-nutritional constituents at all stages of the processing and metabolism of the food. It is therefore unwise to study nutrients in isolation without considering some of the other factors that may influence their activity and how they may interact in whole body functioning.

**Key characteristics of nutrients**

In studying the nutrients, it is important to pay attention to:

- Their structure and chemical characteristics
- Which foods are major sources
- How they are digested, absorbed, transported and stored
- In what form they are used, what determines their use, how and in what circumstances they are mobilised and how surplus or metabolic end products are excreted
- What the physiological requirement for the nutrient is and how this can be translated into a recommended level of intake
- How the body responds to overconsumption and under-consumption
- How long it takes to develop a deficiency or a toxicity and what are the characteristic features
- Interaction between nutrients
- Which members of a population are vulnerable to deficiency
- Whether there are any therapeutic applications of the nutrient
- What are the gaps in knowledge requiring further study
The relationship between diet, health and disease

Aim

1 To gain an insight into the associations between diet, health and disease and to recognise the complexity of these relationships

Scientific approaches, such as nutritional epidemiology, can provide evidence on which dietary advice and public health policies can be based.

Historical perspective

Early studies in nutrition originated from observations of nutrient deficiencies, for which cures with a single nutrient were discovered. This led the way to the identification of many micronutrients (see Table 2.1). For example:

- **Scurvy** had been a significant cause of death among sailors on long sea voyages since the fifteenth century. In the eighteenth century, it was discovered that it could be treated by consuming citrus fruits. However, it was not identified as being due specifically to vitamin C deficiency until the early twentieth century, when the guinea pig was found to be susceptible to the disease and could thus be used as an experimental model.
- **Beriberi**, the disease caused by vitamin B1 deficiency, was reported in Java, Indonesia, during the late nineteenth century among humans and birds fed refined rice. It could be cured by feeding rice bran, which was eventually shown to be rich in the vitamin.
- The association between low levels of iodine in food and drinking water and the swelling of the thyroid gland, known as goitre, was described in the early nineteenth century. The key role of iodine in the formation of thyroid hormones was not established until the early part of the twentieth century.
- Iron, folate and vitamin B12 deficiencies are associated with anaemias that have distinct cytological profiles. Although the common feature was anaemia, differential diagnosis and treatments were required to ensure the correct treatment.
- **Rickets** is due to vitamin D deficiency. Vitamin D can be obtained in the diet, but for most people, synthesis in the skin on exposure to sunlight is the most important source. Thus, exposure to ‘country air’, away from smoky cities, was initially believed to be the cure. It is now understood that exposure to sunlight results in hydroxylation of vitamin D occurs in the liver and kidney, producing the active form. Therefore, renal and hepatic dysfunction may also be a cause of rickets. Additional roles for vitamin D in cellular metabolism have also been described.

Toxicity can result from overconsumption of dietary factors. Classic examples include:

- Vitamin A toxicity was recorded among northern polar explorers consuming livers from polar bears. Excessive intake of vitamin A has been shown to cause fetal malformations in early pregnancy.
- In the early 1950s, infants given excessive amounts of formula milk and cod liver oil supplements containing large amounts of vitamin D developed hypercalcaemia.

Once the link between a nutrient and a particular disease was established, public health measures were introduced to prevent or treat the disease, for example, prescribing folic acid to pregnant women for prevention of neural tube defects (NTD).

Several dietary factors implicated in disease

In some diseases, the role of individual dietary components is difficult to identify because people eat a range of foods that include many nutrients, some that may themselves interact with each other. While ongoing research adds to our understanding of the conditions, it also raises more questions. This is true for cardiovascular disease and cancer.

Other factors affecting susceptibility to disease

Dietary factors may not operate in isolation. Rather, their effects can be modified or amplified by fixed or changeable factors, including:

- Genetic susceptibility: nutrient–gene interactions
- Aspects of early life in the uterine environment
- Environmental factors
- Lifestyle

Even for a condition, such as being overweight, that has an apparently simple cause (excessive energy intake in relation to energy expenditure), the exact mechanisms involved and the ways to intervene for any one individual are not easy to find. They may include many other factors seemingly unrelated to energy intake, for example, psychological factors. Further, it should be recognised that in the diet–health–disease relationship, different factors may be involved in the initiation, progression and treatment and/or prevention of the disease. This complexity may make it especially difficult to identify precisely the role of dietary components in disease and to formulate policies intended to affect change.

Introduction to nutritional epidemiology

Nutritional epidemiology is the scientific study of the relationship between exposure to particular dietary factors and diseases (the outcome). Nutritional epidemiology can investigate the strength of such relationships and may establish causation.

---

Table 2.1 Examples of nutrition-related diseases predominately associated with single dietary factors.

<table>
<thead>
<tr>
<th>Disease/abnormality</th>
<th>Dietary factor responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deficiency</td>
<td></td>
</tr>
<tr>
<td>Scurvy</td>
<td>Vitamin C</td>
</tr>
<tr>
<td>Beriberi</td>
<td>Vitamin B1</td>
</tr>
<tr>
<td>Goitre</td>
<td>Iodine</td>
</tr>
<tr>
<td>Rickets</td>
<td>Vitamin D</td>
</tr>
<tr>
<td>Anaemias</td>
<td>Iron/folate/vitamin B12</td>
</tr>
<tr>
<td>Overconsumption</td>
<td></td>
</tr>
<tr>
<td>Fetal abnormalities</td>
<td>Vitamin A</td>
</tr>
<tr>
<td>Infant hypercalcaemia</td>
<td>Vitamin D</td>
</tr>
</tbody>
</table>

A number of standards must be fulfilled before any conclusions about causality can be drawn. The absence of any one of these standards does not necessarily preclude a relationship between exposure and outcome, but may imply that further information is needed.

Epidemiological evidence is usually collected when it is impossible or impractical to collect experimental evidence. However, once a potential causal relationship has been identified, experimental studies that can determine causality may be developed.

Summary

The relationship between diet and disease may be simple, involving single nutrient deficiencies that are readily treated. However, the majority of nutrition-related diseases have complex relationships with diet. In addition, variations in individual susceptibility are increasingly being recognised.
Aim

To describe how energy intake from food is quantified.

Energy is needed for all the functions performed by the body. These include:

- Metabolic activity at the cellular, tissue and organ level, which is largely outside of our conscious awareness and continues throughout life.
- Voluntary actions performed as part of physical activity.
- Tissue repair and replenishment of stores after physical activity.
- Growth, during the early years of life, in adolescence and during pregnancy.

Energy from food

The energy required by the body must be supplied by food. Macronutrients (carbohydrates, fats and proteins), together with alcohol, provide energy as they are broken down. Minerals and vitamins do not provide energy, but some are essential as cofactors in the biochemical pathways that release energy.

Methods for measuring food energy

The potential or gross energy content of a food can be measured using a bomb calorimeter. This is an apparatus in which a small sample of the food is combusted in the presence of pure oxygen under high pressure. The energy (heat) released from the food is absorbed by water, causing a small but measurable rise in temperature in the water from which, by a simple calculation, the gross energy content can be determined.

The breakdown of food in the body is not as efficient as when it is combusted in a bomb calorimeter. For example, cellulose and other forms of fibre will combust completely in a bomb calorimeter but are indigestible in humans. Therefore, the energy available to the body is less than the gross energy content. This lower value is known as the metabolisable energy content.

The amount of metabolisable energy available from each macronutrient and from alcohol is known (Table 3.1). These energy conversion factors can be used to calculate the energy content of a food once its composition is known, and it is these values, rather than the gross energy content, that are found in food composition tables.

In calculating the energy content of foods and in diet planning, it is important to remember that assumptions made about the efficiency of digestion and absorption under normal circumstances may not be true in cases of illness involving diarrhoea or malabsorption syndromes or when laxatives are used.

Units used for measuring energy in nutrition

Traditionally, energy has been expressed in kilocalories (kcal), reflecting the observed generation of heat by metabolic reactions. More recently, the kilojoule (kJ), the SI unit for measurement of energy, has become the preferred unit among nutritionists. However, both units are still used, and members of the public generally recognise kilocalories better than kilojoules. It is therefore essential to know the conversion factor between the two units:

- 1 Kcal = 4.18 KJ
- Larger amounts of energy may be expressed in terms of megajoules (MJ), where 1 MJ = 1000 kJ.

Energy conversion factors

The energy conversion factors for macronutrients and alcohol are:

- Carbohydrates (as monosaccharides): 3.75 kcal/g (=16 kJ/g)
- Fat: 9 kcal/g (=37 kJ/g)
- Protein: 4 kcal/g (=17 kJ/g)
- Alcohol: 7 kcal/g (=29 kJ/g)

Calculating the contribution of macronutrients to total energy intake

On the basis of the calculations illustrated in Table 3.1, it is also possible to calculate what percentage of the energy in a food is provided by which macronutrient.

So, taking white bread (which has a total energy content of 219 kcal/100 g) as an example,

- (172.9/219) × 100 = 79% of the energy comes from CHO
- (31.6/219) × 100 = 14.4% of the energy comes from protein
- (14.4/219) × 100 = 6.6% of the energy comes from fat

This type of calculation can also be applied to a whole meal, to a day’s food intake for an individual, or to determine the major foods contributing to energy intake for an entire population.

Table 3.1 Example of use of energy conversion factors in calculating the total energy content of foods.

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<th>Protein (g/100 g)</th>
<th>Energy from protein/100 g (C)</th>
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</thead>
<tbody>
<tr>
<td>White bread</td>
<td>46.1</td>
<td>172.9</td>
<td></td>
<td>1.6</td>
<td>14.4</td>
<td></td>
<td>7.9</td>
<td>31.6</td>
<td></td>
<td>219</td>
</tr>
<tr>
<td>Milk, semi-skimmed</td>
<td>4.7</td>
<td>17.6</td>
<td></td>
<td>1.7</td>
<td>15.3</td>
<td></td>
<td>3.4</td>
<td>13.6</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>Baked beans</td>
<td>15.3</td>
<td>57.4</td>
<td></td>
<td>0.6</td>
<td>5.4</td>
<td></td>
<td>5.2</td>
<td>20.8</td>
<td></td>
<td>84</td>
</tr>
</tbody>
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<th>Energy from protein/100 g (C)</th>
<th>Factor used: 4 kcal/g</th>
<th>Total energy/100 g of food (A + B + C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White bread</td>
<td>46.1</td>
<td>172.9</td>
<td></td>
<td>1.6</td>
<td>14.4</td>
<td></td>
<td>7.9</td>
<td>31.6</td>
<td></td>
<td>219</td>
</tr>
<tr>
<td>Milk, semi-skimmed</td>
<td>4.7</td>
<td>17.6</td>
<td></td>
<td>1.7</td>
<td>15.3</td>
<td></td>
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<td>13.6</td>
<td></td>
<td>46</td>
</tr>
<tr>
<td>Baked beans</td>
<td>15.3</td>
<td>57.4</td>
<td></td>
<td>0.6</td>
<td>5.4</td>
<td></td>
<td>5.2</td>
<td>20.8</td>
<td></td>
<td>84</td>
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