Introduction to Human Nutrition

Second Edition

Edited on behalf of The Nutrition Society by

Michael J Gibney

Susan A Lanham-New

Aedin Cassidy

Hester H Vorster

WILEY-BLACKWELL

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Introduction to Human Nutrition

The Nutrition Society Textbook Series

Introduction to Human Nutrition

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Digestion and metabolism of carbohydrates
Nutrition and metabolism of lipids
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Clinical cases
Water and electrolytes

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Contents

Contributors

Professor Arne Astrup
Head, Department of Human Nutrition,
Faculty of Life Sciences,
University of Copenhagen,
Copenhagen, Denmark

Dr David A Bender
Sub-Dean (Education),
University College London Medical School,
London, UK

Professor Kevin D Cashman
Department of Food and Nutritional Sciences,
University College Cork,
Ireland

Dr Stephen C Cunnane
Departments of Medicine, Physiology and Biophysics and Research Center on Aging,
Université de Sherbrooke
Canada

Professor Paul Deurenberg
Associate Professor in Nutrition,
Department of Human Nutrition,
Wageningen University,
The Netherlands
Visiting Professor,
University Tor Vergata, Rome, Italy
Nutrition Consultant, Singapore

Professor Naomi K Fukagawa
Department of Medicine,
University of Vermont,
Burlington, Vermont, USA

Professor Michael J Gibney
Department of Clinical Medicine,
Trinity College, Dublin,
Ireland

Dr Bruce A Griffin
Reader in Nutritional Metabolism,
Nutritional Sciences Division,
Faculty of Health and Medical Sciences,
University of Surrey,
Guildford, UK

Joanne M Holden
Nutrient Data Laboratory,
Beltsville,
Maryland, USA

Una E MacIntyre
Institute for Human Nutrition,
University of Limpopo,
Medunsa,
South Africa

Dr Aideen McKevitt
School of Biomedical Sciences,
University of Ulster,
Northern Ireland

Professor J Alfredo Martínez
Intitute of Nutrition and Food Sciences,
University of Navarra,
Spain

Professor Miguel A Martínez-González
Department of Preventive Medicine and Public Health,
University of Navarra,
Spain

Professor John Mathers
Human Nutrition Research Centre,
Institute for Ageing and Health
University of Newcastle, UK

Dr Judith O'Connor
Food Safety Authority of Ireland,
Dublin, Ireland

Dr Lisa O'Connor
Food Safety Authority of Ireland,
Dublin, Ireland

Alan Reilly
Food Safety Authority of Ireland,
Dublin, Ireland

Professor Hettie C Schönfeldt
School of Agricultural and Food Science
University of Pretoria,
South Africa

Professor JJ (Sean) Strain
Professor of Human Nutrition,
Northern Ireland Centre for Food and Health,
University of Ulster,
Coleraine, Northern Ireland

Christina Tlustos
Food Safety Authority of Ireland,
Dublin, Ireland

Angelo Tremblay
Preventive and Social Medicine,
Laval University,
Ste-Foy, Québec,
Canada

Professor Hester H Vorster
Director of the Centre of Excellence for Nutrition
Faculty of Health Sciences,
North-West University
Potchefstroom, South Africa

Dr Thomas MS Wolever
Department of Nutritional Sciences,
Faculty of Medicine,
University of Toronto,
Canada

Dr Kate M Younger
Lecturer in Human Nutrition,
School of Biological Sciences,
Dublin Institute of Technology,
Ireland

Dr Yong-Ming Yu
Department of Surgery,
Massachusetts General Hospital and Shriners Burns Hospital,
Harvard Medical School,
Boston, Massachusetts, USA

Series Foreword

The early decades of the twentieth century were a period of intense research on constituents of food essential for normal growth and development, and saw the discovery of most of the vitamins, minerals, amino acids and essential fatty acids. In 1941, a group of leading physiologists, biochemists and medical scientists recognized that the emerging discipline of nutrition needed its own learned society and the Nutrition Society was established. Our mission was, and remains, "*to advance the scientific study of nutrition and its application to the maintenance of human and animal health*". The Nutrition Society is the largest learned society for nutrition in Europe and we have over 2000 members worldwide. You can find out more about the Society and how to become a member by visiting our website at www.nutsoc.org.uk

The ongoing revolution in biology initiated by large-scale genome mapping and facilitated by the development of reliable, simple-to-use molecular biological tools makes this a very exciting time to be working in nutrition. We now have the opportunity to obtain a much better understanding of how specific genes interact with nutritional intake and other lifestyle factors to influence gene expression in individual cells and tissues and, ultimately, affect our health. Knowledge of the polymorphisms in key genes carried by a patient will allow the prescription of more effective, and safe, dietary treatments. At the population level, molecular epidemiology is opening up much more incisive approaches to understanding the role of particular dietary patterns in disease causation. This excitement is reflected in the several scientific meetings that the Nutrition Society, often in collaboration with sister learned societies in Europe, organizes each year. We provide travel grants and other assistance to encourage students and young researchers to attend and participate in these meetings.

Throughout its history a primary objective of the Society has been to encourage nutrition research and to disseminate the results of such research. Our first journal, *The Proceedings of the Nutrition Society*, recorded, as it still does, the scientific presentations made to the Society. Shortly afterwards, *The British Journal of Nutrition* was established to provide a medium for the publication of primary research on all aspects of human and animal nutrition by scientists from around the world. Recognizing the needs of students and their teachers for authoritative reviews on topical issues in nutrition, the Society began publishing *Nutrition Research Reviews* in 1988. In 1997, we launched *Public Health Nutrition*, the first international journal dedicated to this important and growing area. All of these journals are available in electronic, as well as in the conventional paper form and we are exploring new opportunities to exploit the web to make the outcomes of nutritional research more quickly and more readily accessible.

To protect the public and to enhance the career prospects of nutritionists, the Nutrition Society is committed to ensuring that those who practice as nutritionists are properly trained and qualified. This is recognized by placing the names of suitably qualified individuals on our professional registers and by the award of the qualifications Registered Public Health Nutritionist (RPHNutr) and Registered Nutritionist (RNutr). Graduates with appropriate degrees but who do not yet have sufficient postgraduate experience can join our Associate Nutritionist registers. We undertake accreditation of university degree programs in public health nutrition and are developing accreditation processes for other nutrition degree programs.

Just as in research, having the best possible tools is an enormous advantage in teaching and learning. This is the reasoning behind the initiative to launch this series of human nutrition textbooks designed for use worldwide. This was achieved by successfully launching the first series in multiple languages including Spanish, Portuguese and Greek. The Society is deeply indebted to Professor Mike Gibney and his team of editors for their tireless work in the last 10 years to bring the first edition of this series of textbooks to its successful fruition worldwide. We look forward to this new edition under the stewardship of Dr Susan Lanham-New in equal measure. Read, learn and enjoy.

Professor Ian McDonald
President of the Nutrition Society

Preface

The Nutrition Society Textbook Series started ten years ago as an ambitious project to provide undergraduate and graduate students with a comprehensive suite of textbooks to meet their needs in terms of reference material for their studies. By all accounts the project has been successful and the Nutrition Society Textbook Series have been adapted by all of the best academic nutrition units across the globe. The series has been translated into Spanish and Portuguese.

This second edition of *Introduction to Human Nutrition* is an update of the very basic foundations for the study of human nutrition. Although little has changed, all authors have made whatever updates are necessary and we have made some re-arrangements of some chapters. The study of human nutrition at universities across the globe is rapidly expanding as the role of diet in health becomes more evident. Indeed, the sequencing of the human genome has highlighted the narrower range of genes controlling human biology, emphasising the critically important role of the environment including diet in human health. Moreover, we now recognize the important role that diet plays in interacting with our genome both *in utero* and in the immediate period of post natal development.

The study of human nutrition needs a solid base in the physiology and biochemistry of human metabolism and that is the basis of the textbook *Nutrition and Metabolism*. The present textbook is designed to serve two needs. Firstly, many will use this book as an introduction to human nutrition and go no further. Students in pharmacy, food science, agriculture and the like may take introductory modules to human nutrition and leave the subject there but be well informed in the area. Those who will go on to study human nutrition will find within this textbook an introduction to the many areas of diet and health that they will go on to study in greater depths using the remaining textbooks in the Nutrition Society series. Besides the basic biology, students will be introduced to the concept of food policy and to the dual challenges to the global food supply, both over and under nutrition.

As I write, I am handing over the leadership of the Nutrition Society Textbook Series to Dr Susan Lanham-New at the University of Surrey who has agreed to take on this important task for the Society. I would like to thank all those with whom I have worked with on this project and to wish Sue and her new team all the very best.

Michael J Gibney

The Nutrition Society Textbook Series Editors

Acknowledgments

With grateful appreciation to all those who have served on the International Scientific Committee and the Textbook Editors, without whom this task would be insurmountable and to all the authors who gave time to make this edition possible. Very special thanks must go to Mike Gibney and Julie Dowsett, for their effort and dedication in seeing this textbook of the second edition through to publication.

1

Introduction to Human Nutrition: A Global Perspective on Food and Nutrition

Hester H Vorster

Key messages

- Human nutrition is a complex, multifaceted scientific domain indicating how substances in foods provide essential nourishment for the maintenance of life.
- To understand, study, research, and practice nutrition, a holistic integrated approach from molecular to societal level is needed.
- Optimal, balanced nutrition is a major determinant of health. It can be used to promote health and well-being, to prevent ill-health and to treat disease.
- The study of the structure, chemical and physical characteristics, and physiological and biochemical effects of the more than 50 nutrients found in foods underpins the understanding of nutrition.
- The hundreds of millions of food- and nutrition-insecure people globally, the coexistence of undernutrition and overnutrition, and inappropriate nutritional behaviors are challenges that face the nutritionist of today.
- Nutrition practice has a firm and well-developed research and knowledge base. There are, however, many areas where more information is needed to solve global, regional, communal and individual nutrition problems.
- The development of ethical norms, standards, and values in nutrition research and practice is needed.

1.1 Orientation to human nutrition

The major purpose of this series of four textbooks on nutrition is to guide the nutrition student through the exciting journey of discovery of nutrition as a science. As apprentices in nutrition science and practice students will learn how to collect, systemize, and classify knowledge by reading, experimentation, observation, and reasoning. The road for this journey was mapped out millennia ago. The knowledge that nutrition – what we choose to eat and drink – influences our health, well-being, and quality of life is as old as human history. For millions of years the quest for food has helped to shape human development, the organization of society and history itself. It has influenced wars, population growth, urban expansion, economic and political theory, religion, science, medicine, and technological development.

It was only in the second half of the eighteenth century that nutrition started to experience its first renaissance with the observation by scientists that intakes of certain foods, later called nutrients, and eventually other substances not yet classified as nutrients, influence the function of the body, protect against disease, restore health, and determine people's response to changes in the environment. During this period, nutrition was studied from a medical model or paradigm by defining the chemical structures and characteristics of nutrients found in foods, their physiological functions, biochemical reactions and human requirements to prevent, first, deficiency diseases and, later, also chronic noncommunicable diseases.

Since the late 1980s nutrition has experienced a second renaissance with the growing perception that the knowledge gained did not equip mankind to solve the global problems of food insecurity and malnutrition. The emphasis shifted from the medical or pathological paradigm to a more psychosocial, behavioral one in which nutrition is defined as a basic human right, not only essential for human development but also as an outcome of development.

In this first, introductory text, the focus is on principles and essentials of human nutrition, with the main purpose of helping the nutrition student to develop a holistic and integrated understanding of this complex, multifaceted scientific domain.

1.2 An integrated approach

Human nutrition describes the processes whereby cellular organelles, cells, tissues, organs, systems, and the body as a whole obtain and use necessary substances obtained from foods (nutrients) to maintain structural and functional integrity. For an understanding of how humans obtain and utilize foods and nutrients from a molecular to a societal level, and of the factors determining and influencing these processes, the study and practice of human nutrition involve a spectrum of other basic and applied scientific disciplines. These include molecular biology, genetics, biochemistry, chemistry, physics, food science, microbiology, physiology, pathology, immunology, psychology, sociology, political science, anthropology, agriculture, pharmacology, communications, and economics. Nutrition departments are, therefore, often found in Medical (Health) or Social Science, or Pharmacy, or Agriculture Faculties at tertiary training institutions. The multidisciplinary nature of the science of nutrition, lying in both the natural (biological) and social scientific fields, demands that students of nutrition should have a basic understanding of many branches of science and that they should be able to integrate different concepts from these different disciplines. It implies that students should choose their accompanying subjects (electives) carefully and that they should read widely in these different areas.

1.3 A conceptional framework for the study of nutrition

In the journey of discovery into nutrition science it will often be necessary to put new knowledge, or new applications of old knowledge, into the perspective of the holistic picture. For this, a conceptual framework of the multidisciplinary nature of nutrition science and practice may be of value. Such a conceptual framework, illustrating the complex interactions between internal or constitutional factors and external environmental factors which determine nutritional status and health, is given in Figure 1.1.

On a genetic level it is now accepted that nutrients dictate phenotypic expression of an individual's genotype by influencing the processes of transcription, translation, or post-translational reactions. In other words, nutrients can directly influence genetic (DNA) expression, determining the type of RNA formed (transcription) and also the proteins synthesized (translation). For example, glucose, a carbohydrate macronutrient, increases transcription for the synthesis of glucokinase, the micronutrient iron increases translation for the synthesis of ferritin, while vitamin K increases post-translational carboxylation of glutamic acid residues for the synthesis of prothrombin. Nutrients, therefore, influence the synthesis of structural and functional proteins, by influencing gene expression within cells.

Nutrients also act as substrates and cofactors in all of the metabolic reactions in cells necessary for the growth and maintenance of structure and function. Cells take up nutrients (through complex mechanisms across cell membranes) from their immediate environment, also known as the body's internal environment. The composition of this environment is carefully regulated to ensure optimal function and survival of cells, a process known as homeostasis, which gave birth to a systems approach in the study of nutrition.

Nutrients and oxygen are provided to the internal environment by the circulating blood, which also removes metabolic end-products and harmful substances from this environment for excretion through the skin, the kidneys, and the large bowel.

The concerted function of different organs and systems of the body ensures that nutrients and oxygen are extracted or taken up from the external environment and transferred to the blood for transport and delivery to the internal environment and cells. The digestive system, for example, is responsible for the ingestion of food and beverages, the breakdown (digestion and fermentation) of these for extraction of nutrients, and the absorption of the nutrients into the circulation, while the respiratory system extracts oxygen from the air. These functions are coordinated and regulated by the endocrine and central nervous

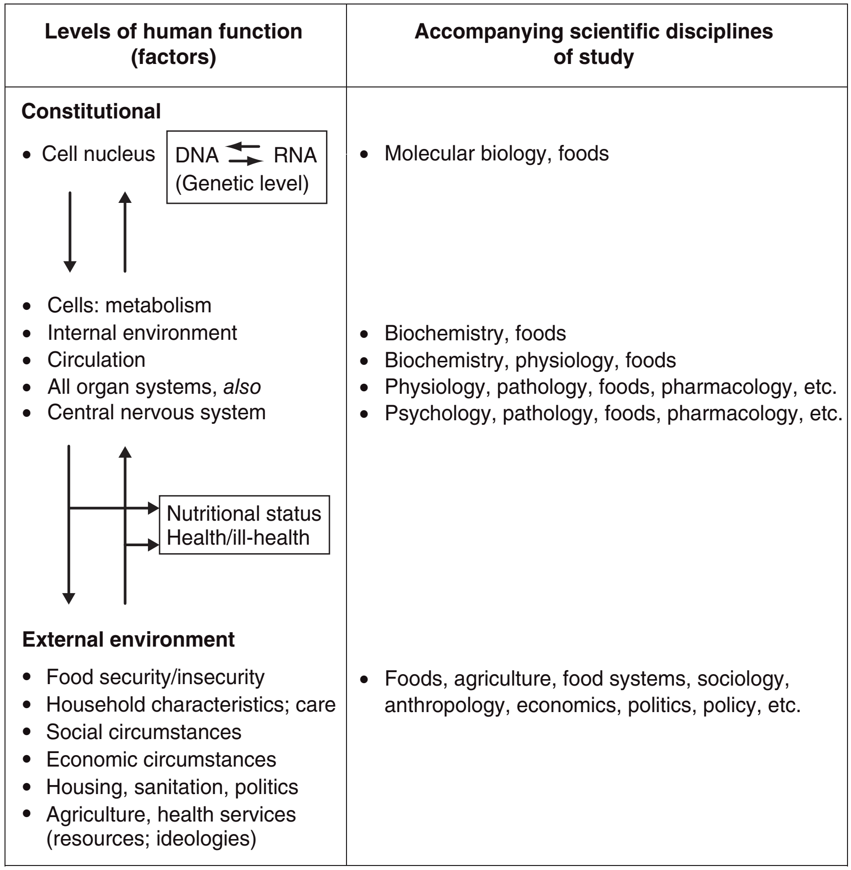

Figure 1.1 Conceptual framework for a holistic, integrated understanding of human nutrition.

systems in response to the chemical and physical composition of the blood and internal environment, and to cellular needs.

The health or disease state of the different organs and systems will determine the nutrient requirements of the body as a whole.

The central nervous system is also the site or "headquarters" of the higher, mental functions related to conscious or cognitive, spiritual, religious, and cultural behaviors, which will determine, in response to the internal and external environments, what and how much will be eaten. What and how much is eaten will further depend on what is available, influenced by a host of factors determining food security. All of these factors, on an individual, household, community, national, or international level, shape the external environment.

During the first renaissance of nutrition, emphasis was placed on the study of nutrients and their functions. A medical, natural science or biological model underpinned the study of the relationships between nutrition and health or ill-health. During the second renaissance, these aspects are not neglected, but expanded to include the study of all other external environmental factors that determine what and how much food and nutrients are available on a global level. These studies are underpinned by social, behavioral, economic, agricultural, and political sciences. The study of human nutrition therefore seeks to understand the complexities of both social and biological factors on how individuals and populations maintain optimal function and health, how the quality, quantity and balance of the food supply are influenced, what happens to food after it is eaten, and the way that diet affects health and well-being. This integrated approach has led to a better understanding of the causes and consequences of malnutrition, and of the relationship between nutrition and health.

1.4 Relationship between nutrition and health

Figure 1.2 shows that individuals can be broadly categorized into having optimal nutritional status or being undernourished, overnourished, or malnourished. The major causes and consequences of these nutritional states are indicated. It is important to realize that many other lifestyle and environmental factors, in addition to nutrition, influence health and well-being, but nutrition is a major, modifiable, and powerful factor in promoting health, preventing and treating disease, and improving quality of life.

1.5 Nutrients: the basics

People eat food, not nutrients; however, it is the combination and amounts of nutrients in consumed foods that determine health. To read one must know the letters of the alphabet; to do sums one must be able to count, add, subtract, multiply, and divide. To understand nutrition, one must know about nutrients. The study of nutrients, the ABC and numeric calculations of nutrition, will form a major part of the student's nutrition journey, and should include:

- the chemical and physical structure and characteristics of the nutrient
- the food sources of the nutrient, including food composition, the way in which foods are grown, harvested, stored, processed and prepared, and the effects of these on nutrient composition and nutritional value
- the digestion, absorption, circulatory transport, and cellular uptake of the nutrient, as well as regulation of all these processes
- the metabolism of the nutrient, its functions, storage, and excretion
- physiological needs (demands or requirements) for the nutrient in health and disease, and during special circumstances (pregnancy, lactation, sport events), as well as individual variability
- interactions with other nutrients, nonnutrients (phytochemicals), antinutrients, and drugs

Nutritional situation		Health consequences, outcomes
Optimum nutrition Food-secure individuals with adequate, balanced and prudent diets	→	Health, well-being, normal development, high quality of life
Undernutrition: hunger Food-insecure individuals living in poverty, ignorance, politically unstable environments, disrupted societies, war	→	• Decreased physical and mental development • Compromised immune systems • Increased infectious diseases • Vicious circle of undernutrition, underdevelopment, poverty
Overnutrition Overconsumption of food, especially macronutrients, plus: • low physical activity • smoking, stress, alcohol abuse	→	Obesity, metabolic syndrome, cardiovascular disease, type 2 diabetes mellitus, certain cancers: chronic NCDs, often characterized by overnutrition of macronutrients and undernutrition of micronutrients
Malnutrition Nutrition transition: Individuals and communities previously food insecure → confronted with abundance of palatable foods → some undernourished, others too many macronutrients and too few micronutrients	→	Double burden of infectious diseases plus NCDs, often characterized by overnutrition of macronutrients and undernutrition of micronutrients

Figure 1.2 Relationship between nutrition and health. NCD, noncommunicable disease.

- the consequences of underconsumption and overconsumption of nutrients
- the therapeutic uses of the nutrient
- factors influencing food and nutrition security and food safety.

There are more than 50 known nutrients (including amino acids and fatty acids) and many more chemicals in food thought to influence human function and health (Box 1.1). Nutrients do not exist in isolation, except for water and others in some pharmaceutical preparations. In foods, in the gut during digestion, fermentation and absorption, in the blood during transport, and in cells during metabolism, nutrients interact with each other. Therefore, a particular nutrient should not be studied in isolation, but integrated with other nutrients and seen in the context of total body function. The study of nutrition also includes how to determine nutrient requirements to make recommendations for intakes and how nutritional status is monitored by measuring intakes, anthropometry, body composition, biochemical markers reflecting nutritional status, and the clinical signs of malnutrition.

This knowledge of nutrients and their functions will enable the nutritionist to advise individuals what and how much to eat. However, this knowledge is not sufficient to understand and address the global problem of malnutrition facing mankind today. This perception has resulted in the cultivation of social science disciplines to support knowledge from the biological sciences to address global malnutrition.

1.6 Global malnutrition

It is a major tragedy that millions of people currently live with hunger, and fear starvation. This is despite the fact that food security or "access for all at all times, to a sustainable supply of nutritionally adequate and safe food for normal physical and mental development and healthy, productive lives" is a basic human right embedded in the constitution of most developing countries. It is also despite the fact that sufficient food is produced on a global level (see Box 1.2). Food

Box 1.2

Food insecurity: when people live with hunger, and fear starvation.
Food security: access for all, at all times, to a sustainable, affordable supply of nutritionally adequate and safe food for normal physical and mental development and healthy, productive lives.

Box 1.1 Classes of nutrients for human nutrition

Class/category	Subclass/category	Nutrient examples
Carbohydrates (macronutrients)	Monosaccharides Disaccharides Polysaccharides	Glucose, fructose, galactose Sucrose, maltose, lactose Starch and dietary fiber
Proteins (macronutrients)	Plant and animal source proteins	Amino acids ($n = 20$): aliphatic, aromatic, sulfur-containing, acidic, basic
Fats and oils (lipids) (macronutrients)	Saturated fatty acids Monounsaturated fatty acids Polyunsaturated fatty acids (n-3, n-6, n-9)	Palmitic and stearic acid Oleic (*cis*) and elaidic (*trans*) fatty acids Linoleic, α-linolenic, arachidonic, eicosapentaenoic, docosahexaenoic acid
Minerals (micronutrients)	Minerals and electrolytes Trace elements	Calcium, sodium, phosphate, potassium, iron, zinc, selenium, copper, manganese, molybdenum, fluoride, chromium
Vitamins (micronutrients)	Fat soluble	Retinol (A), calciferols (D), tocopherols (E), vitamin K
	Water soluble	Ascorbic acid (C), thiamine (B_1), riboflavin (B_2), niacin (B_3), pyridoxine (B_6), folate, cobalamin (B_{12})
Water	Water	Water

insecurity is an obstacle to human rights, quality of life, and human dignity. It was estimated that, during the last decade of the twentieth century, 826 million people were undernourished: 792 million in developing countries and 34 million in developed countries. In developing countries, more than 199 million children under the age of 5 years suffer from acute or chronic protein and energy deficiencies. An estimated 3.5–5 billion people are iron deficient, 2.2 billion iodine deficient, and 140–250 million vitamin A deficient. This has led to several global initiatives and commitments, spearheaded by a number of United Nations organizations, to reduce global undernutrition, food insecurity, hunger, starvation, and micronutrient deficiencies. Some progress has been made in reducing these numbers, but the problems are far from solved. Some of the initiatives are:

- the 1990 United Nations Children's (Emergency) Fund (UNICEF)-supported World Summit for Children, with a call to reduce severe and moderate malnutrition among children under 5 years of age by half the 1990 rate by the year 2000, including goals for the elimination of micronutrient malnutrition
- the 1992 World Health Organization/Food and Agriculture Organization (WHO/FAO) International Conference on Nutrition that reinforced earlier goals and extended them to the elimination of death from famine
- the 1996 FAO-supported World Food Summit during which 186 heads of state and governments pledged their political will and commitment to a plan of action to reduce the number of undernourished people to half their 1996 number by 2015
- the establishment in 1997 of the Food Insecurity and Vulnerability Information and Mapping System (FIVIMS) and their Interagency Working Group (IAWG), which consists of 26 international organizations and agencies with a shared commitment to reduce food insecurity and vulnerability and its multidimensional causes rooted in poverty; information about these initiatives can be accessed at: http://www.fao.org/
- Millennium Development Goals: the United Nations articulated eight goals, ranging from halving extreme poverty and hunger, halting the spread of the human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS) and providing universal primary education, to be reached by the target date of 2015; the blueprint of these goals was agreed to by all the world's countries and leading development institutions.

A 2001 report from the FAO indicated that in 1997–1999 there were 815 million undernourished people in the world, of whom 777 million were in developing countries, 27 million in transitional countries and 11 million in the industrialized countries. The annual decrease in undernourished people from the 1990–1992 period was 6 million. To reach the World Food Summit's goal of halving the number of undernourished in developing countries by 2015, it is estimated that the annual decrease required is 22 million.

Clearly, this is a huge challenge for food and nutrition scientists and practitioners. It would need a holistic approach and understanding of the complex, interacting factors that contribute to malnutrition on different levels. These include immediate, intermediate, underlying, and basic causes:

- individual level or immediate causes: food and nutrient intake, physical activity, health status, social structures, care, taboos, growth, personal choice
- household level or intermediate causes: family size and composition, gender equity, rules of distribution of food within the household, income, availability of food, access to food
- national level or underlying causes: health, education, sanitation, agriculture and food security, war, political instability, urbanization, population growth, distribution and conflicts, war, natural disasters, decreased resources
- international level or basic causes: social, economic and political structures, trade agreements, population size, population growth distribution, environmental degradation.

To address these causes of undernutrition food-insecure and hungry communities and individuals must be empowered to be their own agents of food security and livelihood development. Complicating the task of fighting food insecurity and hunger are natural disasters such as droughts, floods, cyclones and extreme temperatures, ongoing wars and regional conflicts, as well as the devastating impact of HIV and AIDS, especially in sub-Saharan Africa.

In many developing countries, indigenous people have changed their diets and physical activity patterns to those followed in industrialized countries. Supplementary feeding programs in these countries have often been associated with increasing trends towards obesity, insulin resistance, and the emergence of chronic diseases of lifestyle in some segments of these populations, while other segments are still undernourished.

The coexistence of undernutrition and overnutrition, leading to a double burden of infectious and chronic, noncommunicable diseases, and the multifactorial causes of malnutrition, call for innovative approaches to tackle both undernutrition and overnutrition in integrated nutrition and health-promoting programs, focusing on optimal nutrition for all.

1.7 Relationship between nutrition science and practice

The journey through the scientific domain of nutrition will, at a specialized stage, fork into different roads. These roads will lead to the different scopes or branches of nutrition science that are covered in the second, third, and fourth texts of this series. These different branches of nutrition science could lead to the training of nutrition specialists for specific practice areas.

The main aim of nutrition professionals is to apply nutrition principles to promote health and well-being, to prevent disease, and/or to restore health (treat disease) in individuals, families, communities and the population. To help individuals or groups of people to eat a balanced diet, in which food supply meets nutrient needs, involves application of nutrition principles from a very broad field to almost every facet of human life. It is therefore not surprising that these different branches or specialties of nutrition have evolved and are developing. They include clinical nutrition, community nutrition, public health, and public nutrition. It can be expected that there will be overlap in the practice areas of these specialties.

- The clinical nutritionist will counsel individuals from a biomedical–disease–behavioral paradigm to promote health, prevent disease, or treat disease. The clinical nutritionist will mostly work within the health service (facility-based settings such as hospitals, clinics, private practice).
- The community nutritionist, with additional skills from the psychosocial behavioral sciences, should be aware of the dynamics within particular communities responsible for nutritional problems. These would include household food security, socioeconomic background, education levels, childcare practices, sanitation, water, energy sources, healthcare services, and other quality-of-life indicators. The community nutritionist will design, implement, and monitor appropriate, community-participatory programs to address these problems.
- The public health or public nutritionist covers the health and care practice areas but will also be concerned with food security (agricultural) and environmental issues on a public level. The public health or public nutritionist will, for example, be responsible for nutrition surveillance, and the design, implementation, and monitoring of dietary guidelines that address relevant public health problems. A background knowledge in economics, agriculture, political science, and policy design is essential for the formulation and application of nutrition policy in a country.

Many developing countries will not have the capacity or the financial resources to train and employ professionals for different specialties. However, future specialized training and employment of different professionals could result in a capacity to address nutritional problems more effectively.

1.8 Nutrition milestones: the development of nutrition as a science

Ancient beliefs

Throughout human existence people have attributed special powers to certain foods and developed beliefs and taboos regarding foods. These were often based on climatic, economic, political, or religious circumstances and principles, but also on observations regarding the relationship between the consumption of certain foods and health.

Recorded examples are ancient Chinese and Indian philosophers who advised on the use of warming and cooling foods and spices for certain conditions and for "uplifting the soul," the Mosaic laws documented in the Old Testament which distinguished between clean and unclean foods, the fasting and halal practices of Islam, and the Benedictine monks from Salerno who preached the use of hot and moist versus cold and dry foods for various purposes. Hippocrates, the father of modern medicine, who lived from 460 to about 377 BC, and later Moses Maimonides, who lived in the twelfth century, urged people to practice abstemiousness and a prudent lifestyle. They, and others, advised that, for a long and healthy life, one should avoid too much fat in the diet, eat more fruit, get ample sleep, and be physically active – advice that is still incorporated in the modern, science-based dietary guidelines of the twenty-first century!

Cultural beliefs

The perception that food represents more than its constituent parts is still true. Eating together is an accepted form of social interaction. It is a way in which cultural habits and customs, social status, kinship, love, respect, sharing, and hospitality are expressed. Scientists and nutrition professionals realize that, when formulating dietary guidelines for traditional living people, cultural beliefs and taboos should be taken into account and incorporated. There are numerous examples of traditional food habits and diets, often based on what was available. Today, with the world becoming a global village, cultures have learned from each other, and dietary patterns associated with good health, such as the Mediterranean diet, are becoming popular among many cultures.

The first renaissance: development of an evidence base

The knowledge of the specific health effects of particular diets, foods, and nutrients is now firmly based on the results of rigid scientific experimentation. Nutrition developed gradually as a science, but advanced with rapid strides during the twentieth century. There are numerous meticulously recorded examples of how initial (often ancient and primitive) observations about diet and health relationships led to the discovery, elucidation of function, isolation, and synthesis of the different nutrients. Perhaps the most often quoted example is James Lind's description in 1772 of how citrus fruit could cure and prevent scurvy in seamen on long voyages. The anti-scurvy factor (ascorbic acid or vitamin C) was only isolated in 1921, characterized in 1932, and chemically synthesized in 1933. Other examples of nutritional milestones are the induction of beriberi in domestic fowl by Eijkman in 1897, the observation of Takaki in 1906 that beriberi in Japanese sailors could be prevented by supplementing their polished rice diets with wheat bread, and, eventually, the isolation of the responsible factor, thiamine or vitamin B_1, by Funk in 1911. Others are the Nobel Prize-winning discovery by Minot and Murphy in 1926 that pernicious anemia is a nutritional disorder due to a lack of vitamin B_{12} in the diet, the description of kwashiorkor as a protein-deficiency state by Cecily Williams in 1935, and the discovery of resistant starch and importance of colonic fermentation for humans by nutritionists of the Dunn Clinical Nutrition Centre in the 1980s.

The history of modern nutrition as practiced today is an exciting one to read, and students are encouraged to spend some time on it. It is often characterized by heartbreaking courage and surprising insights. An example of the former is the carefully documented clinical, metabolic, and pathological consequences of hunger and starvation by a group of Jewish doctors in 1940 in the Warsaw ghetto: doctors who themselves were dying of hunger. An example of the latter is the studies by Price, an American dentist, who tried to identify the dietary factors responsible for good dental and overall health in people living traditional lifestyles. He unwittingly used a fortigenic paradigm in his research, examining the strengths and factors that keep people healthy, long before the term was defined or its value recognized.

At present, thousands of nutrition scientists examine many aspects of nutrition in laboratories and field studies all over the world and publish in more than 100 international scientific nutrition journals. This means that nutrition science generates new knowledge based on well-established research methodologies. The many types of experiments, varying from molecular experimentation in the laboratory, through placebo-controlled, double-blinded clinical interventions, to observational epidemiological surveys, and experiments based on a health (fortigenic) or a disease (pathogenic) paradigm, will be addressed in this volume (Chapter 13). The peer-review process of published results has helped in the development of guidelines to judge how possible, probable, convincing, and applicable results from these studies are. New knowledge of nutrients, foods, and diet relationships with health and disease is, therefore, generated through a process in which many scientists examine different pieces of the puzzle all over the world in controlled scientific experiments. Therefore, nutrition practice today has a firm research base that enables nutritional professionals to practice evidence-based nutrition.

The second renaissance: solving global malnutrition

There is little doubt that improved nutrition has contributed to the improved health and survival times experienced by modern humans. However, global figures on the prevalence of both undernutrition and overnutrition show that millions of people do not have enough to eat, while the millions who eat too much suffer from the consequences of obesity. It is tempting to equate this situation to the gap between the poor and the rich or between developing and developed countries, but the situation is much more complex. Obesity, a consequence of overnutrition, is now a public health problem not only in rich, developed, food-secure countries but also in developing, food-insecure countries, especially among women. Undernutrition, the major impediment to national development, is the biggest single contributor to childhood death rates, and to impaired physical growth and mental development of children in both developing and developed countries. Moreover, a combination of undernutrition and overnutrition in the same communities, in single households, and even in the same individual is often reported. Examples are obese mothers with undernourished children and obese women with certain micronutrient deficiencies. The perception that these global problems of malnutrition will be solved only in innovative, multidisciplinary, and multisectorial ways has led to the second, very recent renaissance in nutrition research and practice.

1.9 Future challenges for nutrition research and practice

Basic, molecular nutrition

The tremendous development in recent years of molecular biology and the availability of sophisticated new techniques are opening up a field in which nutrient–gene interactions and dietary manipulation of genetic expression will receive increasing attention (see Chapter 15). The effects of more than 12 000 different substances in plant foods, not yet classified as nutrients, will also be examined. These substances are produced by plants for hormonal, attractant, and chemoprotective purposes, and there is evidence that many of them offer protection against a wide range of human conditions. It is possible that new functions of known nutrients, and even new nutrients, may be discovered, described, and applied in the future.

Clinical and community nutrition

Today, the focus has moved from simple experiments with clear-cut answers to studies in which sophisticated statistics have to be used to dissect out the role of specific nutrients, foods, and diets in multifactorial diseases. Nutrition epidemiology is now established as the discipline in which these questions can be addressed. A number of pressing problems will have to be researched and the results applied, for example:

- the biological and sociological causes of childhood obesity, which is emerging as a global public health problem
- the nutrient requirements of the elderly: in the year 2000, more than 800 million of the Earth's inhabitants were older than 60 years; to ensure a high-quality life in the growing elderly population, much more needs to be known about their nutrient requirements
- the relationships between nutrition and immune function and how improved nutrition can help to defend against invading microorganisms; in the light of the increasing HIV/AIDS pandemic, more information in this area is urgently needed
- dietary recommendations: despite sufficient, convincing evidence about the effects of nutrients and foods on health, nutritionists have generally not been very successful in motivating the public to change their diets to more healthy ones. We need to know more about why people make certain food choices in order to design culturally sensitive and practical dietary guidelines that will impact positively on dietary choices. The food-based dietary guidelines that are now being developed in many countries are a first step in this direction.

Public health nutrition

The single most important challenge facing mankind in the future is probably to provide adequate safe food and clean water for all in an environmentally safe way that will not compromise the ability of future generations to meet their needs. In addition to the hundreds of millions not eating enough food to meet their needs for a healthy, active life, an additional 80 million people have to be fed each year. The challenge to feed mankind in the future calls for improved agriculture in drought-stricken areas such as sub-Saharan Africa, the application of biotechnology in a responsible way, interdisciplinary and intersectorial cooperation of all involved, and a better distribution of the food supply so that affordable food is accessible by all. The need for sustained economic growth in poor countries is evident.

Nutritionists have an important part to play in ensuring food security for all, a basic human right, in the future. One of their main functions would be to educate and inform populations not to rely too heavily on animal products in their diet, the production of which places a much heavier burden on the environment than plant foods. A major challenge would be to convince political leaders and governments that addressing undernutrition (the major obstacle in national development) in sustainable programs should be the top priority in developing and poor communities. Another challenge is to develop models based on the dynamics within communities and, using a human rights approach, to alleviate undernutrition without creating a problem of overnutrition. There are examples where such models, incorporated into community development programs, have been very successful (e.g., in Thailand).

Functional foods: a new development

Functional foods are new or novel foods, developed to have specific health benefits, in addition to their usual functions. Examples are spreads with added phytosterols, to lower serum low-density lipoprotein cholesterol and the risk of coronary heart disease, and the development of starchy products with resistant starch and lower glycemic indices, to help control blood glucose levels. The development and testing of functional foods is an exciting new area. These foods may help to improve or restore nutritional status in many people. However, much more should be known about suitable biomarkers to test their efficacy, variability in human response to specific food products, safety, consumer understanding, and how their health messages must be formulated, labeled, and communicated.

Food safety

The continued provision of safe food, free from microorganisms, toxins, and other hazardous substances that cause disease, remains a huge challenge. Recent experiences with animals suffering from bovine spongiform encephalopathy (BSE or mad cow disease) or from foot-and-mouth disease, or birds infected with the influenza A virus (bird flu), have shown how quickly a national problem can become an international one because of global marketing of products. The list of possible hazardous substances in foods emphasizes the need for continuous monitoring of the food supply by health officials (Figure 1.3).

Microbial contamination Bacteria and mold (fungi) producing toxins and aflatoxins Toxins cause "food poisoning" and aflatoxins are carcinogenic	
Natural toxins Such as cyanide in cassava, solanine in potatoes; can be produced by abnormal circumstances, could be enzyme inhibitors or antivitamins	**Agricultural residues** Pesticides such as DDT or hormones used to promote growth such as bovine somatotrophin
Environmental contamination Heavy metals and minerals Criminal adulteration, industrial pollution Substances from packaging materials Changes during cooking and processing of foods	**Intentional additives** Artificial sweeteners Preservatives Phytochemicals Modified carbohydrates (for functional foods)

Figure 1.3 Potential hazardous substances in food. DDT, dichloro-diphenyl-trichloroethane.

1.10 Perspectives on the future

Nutrition research and practice, although it has been around for many years, is in its infancy as a basic and applied scientific discipline. The present and future nutrition student will take part in this very exciting second renaissance of nutrition and see its maturation. However, to influence effectively the nutrition and health of individuals and populations, the nutritionist will have to forge links and partnerships with other health professionals and policy-makers, and will have to develop lateral thinking processes. The magnitude and complexity of nutritional problems facing mankind today demand concerted multidisciplinary and multisectorial efforts from all involved to solve them. Therefore, the principal message to take on a nutrition science journey is that teamwork is essential: one cannot travel this road on one's own; partners from different disciplines are needed. Another essential need is the continuous development of leadership in nutrition. Leaders on every level of research and practice are necessary to respond to the existing challenges of global malnutrition and to face future challenges.

The modern advances in molecular biology and biotechnology on the one hand, and the persistence of global malnutrition on the other, increasingly demand a re-evaluation of ethical norms, standards, and values for nutrition science and practice. Direction from responsible leaders is needed (Box 1.3). There is an urgent need for ethical guidelines and a code of conduct for partnerships between food industries, UN agencies, governments, and academics. These partnerships are necessary for addressing global malnutrition in sustainable programs.

Box 1.3 Future challenges that require exceptional leadership

- Basic molecular nutrition
  - Nutrient–gene interactions
  - Role of phytochemicals in health
  - New nutrients? New functions?
- Community and public health nutrition
  - Childhood obesity
  - Requirements of the elderly
  - Dietary recommendations
  - Nutrition of patients with human immunodeficiency virus/acquired immunodeficiency syndrome
- Public nutrition
  - To feed mankind
  - Food security
- Functional foods
  - To ensure that novel foods are effective and safe
- Food safety
  - Continuous monitoring
- Partnerships with other disciplines
- Leadership

The student in nutrition, at the beginning of this journey of discovery of nutrition as a science, must make use of the many opportunities to develop leadership qualities. May this be a happy, fruitful, and lifelong journey with many lessons that can be applied in the research and practice of nutrition to make a difference in the life of all.

Further reading

Websites

http://whq.libdoc.who.int/trs/who_trs_916
http://www.who.int/nutrition/en
http://www.ifpri.org
http://fao.org/ag/agn/nutrition/profiles_en.stm

2
Body Composition

Paul Deurenberg

Key messages

- Body composition data are used to evaluate nutritional status, growth and development, water homeostasis, and specific disease states.
- Human body composition is studied at atomic, molecular, cellular, tissue, and whole body levels. The levels are interrelated.
- A "normal weight" human body consists of approximately 98% oxygen, carbon, hydrogen, nitrogen, and calcium; of 60–70% water, 10–35% fat (depending on gender), 10–15% protein, and 3–5% minerals.
- The variation in body composition between individuals is large, mainly because of variations in fat mass. Variations in fat-free mass are smaller.
- Several direct, indirect, and doubly indirect techniques are available to measure body composition, each with its own distinct advantages and disadvantages.
- The choice of method will be influenced by the availability of instrumentation, invasiveness, and radiation danger to subjects, price, accuracy required, and application objectives.
- Interpretation and application of data from body composition measurements should be carried out with care and should take into account the limitations of the method used, age, gender, and ethnic group.

2.1 Introduction

Mankind has long been fascinated with the composition of the human body. Centuries ago, the Greeks dissected human cadavers to obtain an insight into the structure and build of the human body, and drawings from the Middle Ages of gross muscle structures grace the walls of many famous art galleries. They are prized not only for their artistic merit, but also for what they reveal of the work of the dissectionists of that era. With progress in the development of analytical chemical methods in the twentieth century, these studies of body composition were applied to body tissues, fetuses, and cadavers of newborns. Scientists such as Mitchell, Widdowson, and Forbes performed the most important work of chemical analyses in adult cadavers during the 1940s and 1950s. Today, neutron activation analysis allows the chemical composition of the human body to be studied *in vivo*. These early chemical analyses of the body gave insights into the changes occurring during growth and development. They also form the basis for a number of methods now widely used to assess body composition *in vivo*.

Today, it is known that many diseases and disorders are related to abnormal body composition or to changes in body composition. The most common of these conditions is obesity, in which the amount of body fat is excessively high, leading to abnormalities in lipid and carbohydrate metabolism, high blood pressure, and adult-onset diabetes. At the other end of the nutritional spectrum, energy and protein malnutrition results in a decrease in the amount of fat and protein stores in the body, and many diseases are related to abnormalities in total body water or to the distribution of body water across the intracellular and extracellular spaces.

Because of the high variability between subjects in chemical body composition, mainly due to the high variation in body fat stores, the concept of fat-free mass (FFM) was introduced at the end of the nineteenth century. If body composition data are expressed as a proportion of the FFM, data become much more consistent between individuals. For example, the fraction of water in the FFM (0.73 ± 0.02) is very consistent across individuals, whereas the between-subject variation is two to three times higher if expressed per kilogram of body weight. This high variability in body components led to the definition of a "reference man," an imaginary person with a given body composition.

In this chapter a (global) description of the composition of the healthy human body is given and discussed at the following levels:

- atomic
- molecular
- cellular
- tissue
- whole body.

Of the many methods available to measure body composition, a few are highlighted and a short description of each is given. For more detailed information, the books by Forbes (1987) and Heymsfield *et al.* (2005) on human body composition are recommended for further reading.

2.2 Five levels of body composition

Human body composition can be studied at the atomic, molecular, cellular, tissue, and whole body level. These five levels are related to each other. For example, information at the atomic level can be used, subject to certain assumptions, to provide information at the whole body level.

Atomic level

Many chemical elements (atoms) are found in the human body, but the six elements oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus are the most abundant and together account for more than 98% of body weight (Table 2.1). Indeed, the 11 most common elements account for 99.5% of the atomic body composition. This information was initially based on chemical analysis of carcasses, but today the information can also be obtained by *in vivo* neutron activation analysis (IVNAA). The classical chemical cadaver analysis, as carried out mainly in the 1940s, still forms the basis for many *in vivo* techniques that are used to assess body composition.

Table 2.1 Body composition at the atomic level of a 70 kg reference man

Atomic element	Amount (kg)	Amount (% body weight)
Oxygen	43	61
Carbon	16	23
Hydrogen	7	10
Nitrogen	1.8	2.6
Calcium	1.0	1.4
Phosphorus	0.6	0.8
Total	69.4	98.8

Box 2.1

The water content in the body varies with age. In a fetus, the water content slowly decreases from more than 90% after conception to about 80% before delivery at about 7 months of gestation. A newborn has about 70% body water, which is about 82% of the fat-free mass. This value slowly decreases further to 72% of the fat-free mass until the body is chemically mature at age 15–18 years. In general, males have more body water (related to body weight) than females, as their body fat content is lower.

Molecular level

The chemical elements in the human body are bound in molecules and, in very global terms, the main compartments are water, lipids, proteins, minerals, and carbohydrates. The total amount of water in the body is high and, depending on the body fat content, can be as high as 60–70% of total body weight. Total body water can be divided into intracellular water and extracellular water, and the ratio of the two is an important health parameter that is disturbed in many diseases (Box 2.1).

Lipids appear in the human body in different forms. Essential structural lipids such as the phospholipids (cell membranes) and sphingomyelin (nervous system) form only a minor part of the total lipids in the body. The nonessential lipids, mostly triglycerides or triacylglycerol (fat), are the most abundant. They are the energy store of the adult human body, insulate against cold, protect vital organs such as the kidneys against mechanical damage, and, to a certain extent, enhance the body's appearance. In a "normal weight" healthy adult, the amount of body fat varies between 10% and 25% in men and between 15% and 35% in

Table 2.2 Body composition at the molecular level of a 70 kg reference man

Component	Amount (kg)	Amount (% body weight)
Water		
Extracellular	18	26
Intracellular	24	34
Lipid		
Essential	1.5	2.1
Nonessential	12	17
Protein	10.1	14.4
Mineral	3.7	5.3
Carbohydrate	0.5	0.6
Total	69.8	99.4

women. In severe obesity body fat can be as high as 60–70% of body weight.

Body protein varies between 10% and 15%. It is higher in males than in females, as males generally have more muscles. There is no protein storage in the body and, generally speaking, loss of protein coincides with a loss of functionality given the high protein content and high protein turnover rates in vital organs.

The amount of minerals in the body varies between 3% and 5%, again dependent on body fat. Calcium and phosphorus are the two main minerals. They are found mainly in bones. Carbohydrates are found in the body as glucose (blood sugar) and glycogen, a polysaccharide in muscle and liver cells that serves as a short-term energy store. The amount of carbohydrates in the body rarely exceeds 500 g. Table 2.2 gives the body composition of the reference man at a molecular level.

Cellular level

At the cellular level, body composition can be described in terms of body cell mass, extracellular fluids, and extracellular solids. The body cell mass includes the cells with all their contents, such as water, proteins, and minerals. Extracellular fluid contains about 95% water, which is plasma in the intravascular space and interstitial fluid in the extravascular space. Extracellular solids are mainly proteins (e.g., collagen) and minerals (bone minerals and soluble minerals in the extracellular fluid). Body composition at the cellular level is not easy to measure, owing to its complex nature. As will be discussed later, the ^{40}K method can be used to assess body cell mass and some dilution techniques, for example bromide dilution, can be used to assess extracellular water.

Table 2.3 Body composition at the tissue level of a 70 kg reference man

Tissue/organ	Amount (kg)	Amount (% body weight)
Muscle	28	40
Adipose tissue	15	21.4
Blood	5.5	7.9
Bone	5	7.1
Skin	2.6	3.7
Liver	1.8	2.6
Total	57.9	82.7

Tissue level

Cells with equal functions form tissues, including muscular, connective, epithelial, and nervous tissue. Bones are connective tissue and consist mainly of hydroxyapatite, $[Ca_3(PO_4)_2]_3Ca(OH)_2$, bedded in a protein matrix. A rather simple body composition model at the tissue level would be:

$$\text{Body weight} = \text{adipose tissue} + \text{skeletal muscle} + \text{bone} + \text{organs} + \text{rest}$$

Several of these components can now be measured with, for example, computed tomography (CT) or magnetic resonance imaging (MRI) for adipose tissue; creatinine excretion or *N*-methyl-histidine excretion in 24 h urine for skeletal muscle; dual-energy X-ray absorptiometry (DXA) for bones; and MRI or ultrasound for organs. Body composition at the tissue level is given in Table 2.3.

Whole body level

Body composition measurements at the whole body level use simple body parameters to give an insight into body composition. Formulae, based on statistical relationships that have been established in earlier studies between body parameters (e.g., skinfold thickness) and information on body composition (e.g., body fat by density), also enable the assessment of body composition. Another example is the assessment of body water based on weight, height, age, and gender.

2.3 Relationships between different levels of body composition

The five levels of body composition are interrelated. This means that information at one level can be trans-

Box 2.2

Adipose tissue is made of adipocytes, which are cells that store triglycerides in the form of small fat droplets. Adipose tissue contains about 80% triglycerides and some 1–2% protein (enzymes), and the remaining part is water plus electrolytes. During weight loss adipose tissue decreases: the actual fat loss will be about 80% of the actual weight loss.

lated to another level. This is important as it forms the basis of many techniques used to determine body composition. In the context of this chapter, only a few examples are given. After determining the amount of calcium in the body by, for example, IVNAA (atomic level), the amount of bone can be calculated assuming that a certain amount of total body calcium is in the skeletal tissue. Determination of total body potassium (by ^{40}K or IVNAA) enables the assessment of the body cell mass, as most of the body potassium is known to be intracellular. Skinfold thickness measurements (total body level) enable the assessment of body fat (molecular level). Formulae used for these calculations are component based, property based, or sometimes a combination. Component-based formulae are based on fixed relationships between components. An example is the calculation of total body water from measured hydrogen: the chemical formula of water determines the factor. Property-based formulae are based on established statistical relationships between variables. An example is the prediction of body fat percentage (body composition parameter) from skinfold thickness (property) (Box 2.2). Property-based formulae tend to be population specific, which limits the widespread application.

Most body composition techniques that are in use today are based on assumptions, often derived from carcass analyses or experimentally derived from observational studies. Violation of these assumptions leads to biased results, and some methods are more prone to bias than others. In the following short description of different methodologies, the most important assumptions are highlighted.

2.4 Body composition techniques

Body composition techniques can be described in terms of direct, indirect, and doubly indirect methods.

Table 2.4 Methods used to determine body composition

Direct	Indirect	Doubly indirect
Carcass analyses	Densitometry	Weight/height indices
IVNAA	Deuterium oxide dilution	Skinfolds/ultrasound
	^{40}K counting	Circumferences/diameters
	More-compartment models	Impedance
	DXA	Infrared interactance
	CT/MRI scans	Creatinine excretion

IVNAA, *in vivo* neutron activation analysis; DXA, dual-energy X-ray absorptiometry; CT, computed tomography; MRI, magnetic resonance imaging.

- In direct methods, the body component of interest is determined directly without or with only minor assumptions. Examples are chemical carcass analyses and IVNAA for the atomic components.
- In indirect techniques, the body component of interest is determined indirectly. Examples are the determination of body protein from body nitrogen, assuming a constant conversion factor of 6.25 from nitrogen to protein, and the determination of body cell mass using ^{40}K. In both examples, assumptions are used. These assumptions may not be valid in the given situation or for the subject(s) under study and hence could lead to biased results.
- Doubly indirect methods rely on a statistical relationship between easily measurable body parameter(s) and the body component of interest. Examples are the assessment of skeletal muscle mass by creatinine excretion and the assessment of body fat from skin-fold thickness. Table 2.4 gives an overview of the most common methods.

2.5 Direct methods

Carcass analysis

The (chemical) analysis of carcasses is a time-consuming exercise and requires very precise approaches to the task. The carcass has to be carefully dissected into the different tissues that are then exactly weighed, after which the chemical analyses have to be performed. To avoid errors it is important that no unaccounted water losses occur during the analytical work. As early as the nineteenth century, it was recognized that the variation in chemical body composition was reduced when results were expressed as a fraction of the fat-free body. The data on the chemical composition of only a few human cadavers form the basis for the assumptions that are normally used in indirect methods. These chemical analyses were performed in five men and one woman. It was concluded that, on the basis of FFM, the mean amounts of water, protein, and minerals in the body are 72.6%, 20.5%, and 6.9%, respectively. The variability in these figures is about 13% for protein and minerals and 4% for water. Although one can question the quality of these data as a basis for other methods (low number, high variation in age, variation in gender, some carcasses were not analyzed immediately after death), they form the basis for many indirect and doubly indirect body composition methods. Chemical carcass analysis also revealed that the amount of potassium in the FFM is fairly constant. This fact is used as the basis for the calculation of the amount of FFM or for body cell mass from total body potassium, determined by ^{40}K scanning.

In the 1980s, cadaver studies were performed again in the "Brussels study." Unfortunately, only information at a tissue level and not at atomic or molecular level was collected. However, the need for cadaver studies has greatly diminished given that the same information can now be obtained *in vivo* by IVNAA.

In vivo *neutron activation analysis*

IVNAA is a relatively new body composition technique that allows the determination of specific chemical elements in the body. The body is bombarded with fast neutrons of known energy level. The neutrons can be captured by chemical elements (as part of molecules) in the body, resulting in a transition state of higher energy for that element – energy that is finally emitted as gamma rays. For example, capture of neutrons by nitrogen results in the formation of the isotope ^{15}N, which will emit the excess energy as gamma rays:

$$^{14}\text{N} + {}^{1}\text{n} \rightarrow {}^{15}\text{N}^{*} + \text{gamma rays}$$

where ^{14}N is nitrogen with atomic mass 14, ^{15}N is nitrogen with atomic mass 15, and ^{1}n is a neutron.

With IVNAA, many elements in the body can be determined, including calcium, phosphorus, nitrogen, oxygen, potassium, and chlorine.

The information obtained at the atomic level can be converted to more useful information. For example, from total body nitrogen total body protein can be calculated as 6.25 times the total nitrogen, assuming that body protein consists of 16% nitrogen. The advantage of the method is that the chemical body composition can be determined *in vivo* and can be compared with other, indirect, techniques. For fundamental studies and for validation of existing techniques in special groups of subjects, for example in different ethnic groups, elderly subjects, obese subjects, or in the diseased state, the methodology can be of great importance. The disadvantage of IVNAA is not only the price. The subject is irradiated, with the radiation dose used depending on the number and kind of elements to be determined. It is relatively low for nitrogen (0.26 mSv) but high for calcium (2.5 mSv).

2.6 Indirect methods

Densitometry

The densitometric method assumes that the body consists of two components, a fat mass, in which all "chemical" fat is located, and the FFM, which consists of (fat-free) bones, muscles, water, and organs. Chemically, the FFM consists of water, minerals, protein, and a small amount of carbohydrate, the last often being neglected. The density of the fat mass is 0.900 kg/l and, from carcass analysis data, the density of the FFM can be calculated as 1.100 kg/l, depending on the relative amount of minerals, protein, and water in the FFM (Box 2.3).

The density of the total body depends on the ratio of fat mass to FFM. Once the density of the body has been determined, the percentage of fat in the body (BF%) can be calculated by Siri's formula (Box 2.4):

$$\text{BF\%} = (495/\text{body density}) - 450$$

Body density can be determined by several techniques, the oldest and perhaps most accurate being underwater weighing. Behnke first used the technique, showing that excess body weight in American football players was not the result of excess fat but of enlarged muscle mass.

In underwater weighing, the weight of the subject is first measured in air and then while totally immersed in water. The difference between weight in air and weight under water is the upwards force, which equals the weight of the displaced water (Archimedes' law),