ADVANCED NUTRITION

Micronutrients
MODERN NUTRITION
Edited by Ira Wolinsky and James F. Hickson, Jr.

Published Titles
Manganese in Health and Disease, Dorothy Klimis-Tavantzis
Nutrition and AIDS: Effects and Treatment, Ronald R. Watson
Nutrition Care for HIV Positive Persons: A Manual for Individuals
and Their Caregivers, Saroj M. Bahl and James F. Hickson, Jr.
Calcium and Phosphorus in Health and Disease, John J. B. Anderson and
Sanford C. Garner

Published Titles
Practical Handbook of Nutrition in Clinical Practice, Donald F. Kirby and
Stanley J. Dudrick
Handbook of Dairy Foods and Nutrition, Gregory D. Miller, Judith K. Jarvis and
Lois D. McBean
Advanced Nutrition: Macronutrients, Carolyn D. Berdanier
Childhood Nutrition, Fima Lifshitz
Antioxidants and Disease Prevention, Harinder S. Garewal
Nutrition and Cancer Prevention, Ronald R. Watson and Siraj I. Mufti
Nutrition and Health: Topics and Controversies, Felix Bronner
Nutritional Concerns of Women, Ira Wolinsky and Dorothy Klimis-Tavantzis
Nutrients and Gene Expression: Clinical Aspects, Carolyn D. Berdanier
Advanced Nutrition: Micronutrients, Carolyn D. Berdanier

Forthcoming Titles
Laboratory Tests for the Assessment of Nutritional Status, 2nd Edition,
H. E. Sauberlich
Nutrition: Chemistry and Biology, 2nd Edition, Julian E. Spallholz,
L. Mallory Boylan and Judy A. Driskell
Child Nutrition: An International Perspective, Noel W. Solomons
Handbook of Nutrition for Vegetarians, Rosemary A. Ratzin
Melatonin in the Promotion of Health, Ronald R. Watson
Nutrition and the Eye, Allen Taylor
Advanced Human Nutrition, Denis Medeiros and Robert E. C. Wildman
Nutrients and Foods in AIDS, Ronald R. Watson
Nutrition and Women’s Cancer, Barbara C. Pence and Dale M. Dunn
ADVANCED NUTRITION
Micronutrients

Carolyn D. Berdanier
Professor, Foods and Nutrition
University of Georgia
Athens, Georgia

Illustrations by: Toni Kathryn Adkins

CRC Press
Boca Raton  London  New York  Washington, D.C.
Series Preface for Modern Nutrition

The CRC Series in Modern Nutrition is dedicated to providing the widest possible coverage of topics in nutrition. Nutrition is an interdisciplinary, interprofessional field par excellence. It is noted by its broad range and diversity. We trust the titles and authorship in this series will reflect that range and diversity.

Published for a scholarly audience, the volumes of the CRC Series in Modern Nutrition are designed to explain, review, and explore present knowledge and recent trends, developments, and advances in nutrition. As such, they will also appeal to the educated layman. The format for the series will vary with the needs of the author and the topic, including, but not limited to, edited volumes, monographs, handbooks, and texts.

Contributors from any bona fide area of nutrition, including the controversial, and welcome.

Ira Wolinsky, Ph.D.
Series Editor
Preface

In the first volume of this two-volume book, Advanced Nutrition: Macronutrients, the needs for the macronutrients were discussed. The absorption, metabolism, excretion, and function of the various sources of energy as well as detailed discussions of the need for water and energy balance were presented. The needs for the micronutrients, as well as explanations of how these nutrients function in the body, were deferred to this, the second volume.

While most vitamins function at the metabolic level, the discoveries of how some of the vitamins and minerals work at the genomic level are quite exciting. Finally, we have an understanding of the pathophysiology of the plethora of diseases labeled nutrient deficiency disorders. Beriberi, pellagra, anemia, scurvy, embryonic and fetal malformation, rickets, osteoporosis, and a number of subtle (and not so subtle) disorders are finally connected to specific nutrients such that we can now understand why certain symptoms develop when an inadequate intake occurs. We have also come to understand, in part, the genetic diversity of the many species that require these nutrients. Nutrient-gene interactions as well as nutrient-nutrient and nutrient-drug interactions have become major research endeavors by nutrition scientists throughout the world. These scientists are truly hybrids in the world of science. They must have expertise in nutrition, biochemistry, physiology, and genetics, and if they are interested in human nutrition they must also understand human social systems and human medicine or have a physician collaborator.

Nutrition science is not as simple as finding a nutrient and determining its function. Today’s science requires a far more complicated approach. The techniques of yesteryear are no longer adequate by themselves. The techniques of other disciplines must be brought to bear as well. The student will make new discoveries by studying the present database and finding the gaps in our knowledge. Nowhere is this as apparent as in the study of the micronutrients. While the animal of primary interest is the human, most research uses animals of other species because of the need to make organ, cell, and subcell measurements that are impossible to perform in the human. For this reason, the scientist needs to be all-inclusive in the study of nutrient needs.

Interspecies comparisons provide ample opportunities to learn how specific nutrients function and interact with other nutrients. After all, nutrition is a composite science requiring skills of integration and comprehension of the whole living system.
Acknowledgments

The author wishes to express her sincere thanks to the faculty and students of the University of Georgia Nutrition Science graduate program for their unfailing encouragement to prepare this volume. Particular appreciation is extended to Art Grider and Mary Ann Johnson for reading the initial drafts of the minerals section. In addition, the author is very grateful to Dr. Donald McCormick of Emory University and Dr. Dennis Medieros of Ohio State University whose meticulous reading of the manuscript provided much-needed revisions. Without their careful evaluation the present book would not have been possible. Needless to say, countless hours were expended by Kathy Adkins White and Tonya Whitfield to prepare the text and illustrations. Their expertise and dedication are much appreciated. Lastly, this text would not have been possible without the contributions of Dr. Mark Failla of the University of North Carolina at Greensboro. His intuitive thinking and excellent organization of the vast body of knowledge about the micronutrients provided the framework for the book. Without this starting point the integration of the various aspects of the micronutrients would have been a daunting task. Thanks Mark!
Carolyn D. Berdanier, Ph.D., is a Professor of Nutrition at the University of Georgia in Athens, Georgia. She received a B.S. degree from The Pennsylvania State University and M.S. and Ph.D. degrees from Rutgers University in Nutrition in 1966. After a post-doctoral fellowship year with Dr. Paul Griminger at Rutgers, she served as a Research Nutritionist with the Human Nutrition Institute which is part of ARS, a unit of the U.S. Department of Agriculture. In 1975 she moved to the University of Nebraska College of Medicine where she continued her research in nutrient gene interactions. In 1977 she moved to the University of Georgia where she served as Head of the Department of Foods and Nutrition. She stepped down from this post ten years later and devoted her full time efforts to research and teaching in her research area. Her research on the diet and genetic components of diabetes and vascular disease has been supported by NIH, USDA, U.S. Department of Commerce, The National Livestock and Meat Board, and the Egg Board. She is a member of the American Institute of Nutrition, the American Society for Clinical Nutrition, The Society for Experimental Biology and Medicine, American Diabetes Association, and several honorary societies in science. She has served on the Editorial Boards of the FASEB Journal, The Journal of Nutrition, and Nutrition Research and Biochemistry Archives. She has also served as a Contributing Editor for Nutrition Reviews and Editor of the AIN News Notes. Current research interests include studies on aging, the role of diet in damage to mitochondrial DNA, and the role of specific dietary ingredients in the secondary complications of diabetes.
# Table of Contents

## Unit 1
**Micronutrients, Human Health and Well Being**
- I. Overview
- II. Assessment
- III. Factors Affecting Micronutrient Needs

## Unit 2
**Integration of the Functional Aspects of Vitamins and Minerals**
- I. Overview
- II. The Role of Micronutrients in Gene Expression
- III. Synthesis of Purines and Pyrimidines
- IV. Micronutrients as Stabilizers

## Supplemental Readings

## Unit 3
**Fat-Soluble Vitamins**
- I. Vitamin A
  - A. Structure and Nomenclature
  - B. Chemical Properties
  - C. Biopotency
  - D. Sources
  - E. Metabolism of Vitamin A
    - 1. Absorption
    - 2. Transport
    - 3. Degradation and Excretion
  - F. Functions of Vitamin A
    - 1. Protein Synthesis
    - 2. Reproduction and Growth
    - 3. Vision
  - G. Hypervitaminosis A
  - H. Recommended Dietary Allowance
- II. Vitamin D
  - A. Overview
  - B. Structure and Nomenclature
  - C. Physical and Chemical Properties
  - D. Biopotency
  - E. Methods of Assay
  - F. International Units (IU)
  - G. Metabolism of Vitamin D
    - 1. Absorption
    - 2. Transport
    - 3. Metabolism
    - 4. Function
      - a. Regulation of Serum Calcium Levels
      - b. Mode of Action at the Genomic Level
  - H. Vitamin D Deficiency
  - I. Hypervitaminosis
  - J. Recommended Dietary Allowances
III. Vitamin E
   A. Overview
   B. Structure and Nomenclature
   C. International Units and Methods of Analysis
   D. Chemical and Physical Properties
   E. Sources
   F. Metabolism
      1. Absorption and Transport
      2. Intracellular Transport and Storage
      3. Catabolism and Excretion
      4. Function
   G. Hypervitaminosis E
   H. Deficiency
   I. Recommended Dietary Allowance

IV. Vitamin K
   A. Overview
   B. Structure and Nomenclature
   C. Biopotency
   D. Chemical and Physical Properties
   E. Chemical Assays
   F. Bioassays
   G. Biosynthesis
   H. Antagonists, Antivitamins
   I. Sources
   J. Absorption
   K. Metabolism and Function
   L. Deficiency
   M. Recommended Dietary Allowance

Supplemental Readings

Unit 4

Water-Soluble Vitamins
   I. Ascorbic Acid
      A. Overview
      B. Structure, Physical and Chemical Properties
      C. Sources
      D. Absorption, Metabolism
      E. Distribution
      F. Function
      G. Deficiency
      H. Toxicity
      I. Recommended Dietary Allowance

   II. Thiamin
      A. Overview
      B. Structure
      C. Thiamin Antagonists
      D. Assays for Thiamin
      E. Sources
      F. Absorption and Metabolism
      G. Biological Function
H. Deficiency
I. Recommended Dietary Allowance
J. Toxicity

III. Riboflavin
A. Overview
B. Structure, Chemical and Physical Properties
C. Sources
D. Assay
E. Absorption, Metabolism
F. Functions
G. Deficiency
H. Recommended Dietary Allowance

IV. Niacin
A. Overview
B. Structure, Physical and Chemical Properties
C. Sources
D. Absorption, Metabolism
E. Function
F. Deficiency
G. Recommended Dietary Allowance

V. Vitamin B₆
A. Overview
B. Structure, Physical and Chemical Properties
C. Sources
D. Absorption, Metabolism
E. Function
F. Deficiency
G. Recommended Dietary Allowance

VI. Pantothenic Acid
A. Overview
B. Structure, Chemical and Physical Properties
C. Sources
D. Absorption and Metabolism
E. Function
F. Deficiency Symptoms
G. Recommended Dietary Allowance

VII. Biotin
A. Overview
B. Structure, Physical and Chemical Properties
C. Sources
D. Absorption, Metabolism
E. Function
F. Deficiency
G. Recommended Dietary Intake

VIII. Folic acid
A. Overview
B. Structure, Chemical and Physical Properties
C. Sources
D. Absorption, Metabolism
E. Function
F. Deficiency
G. Recommended Dietary Allowance

IX. Vitamin B$_{12}$
A. Overview
B. Structure, Chemical and Physical Properties
C. Absorption, Metabolism
D. Function
E. Deficiency
F. Recommended Dietary Allowance

Supplemental Readings

Unit 5

Other Organic Nutrients

I. Choline
A. Overview
B. Structure, Chemical and Physical Properties
C. Sources
D. Absorption, Metabolism
E. Function
F. Deficiency
G. Requirement

II. Carnitine
A. Overview
B. Structure, Physical and Chemical Properties
C. Sources
D. Absorption, Metabolism
E. Function
F. Deficiency
G. Requirement

III. Inositol
A. Overview
B. Structure, Physical and Chemical Properties
C. Absorption and Metabolism
D. Function
E. Deficiency
F. Requirement

IV. Other Compounds with Biologic Activity
A. Overview
B. Pyrroloquinoline Quinone
C. Ubiquinone
D. Orotic Acid
E. Para-Aminobenzoic Acid (PABA)
F. Lipoic Acid
G. Bioflavinoids
H. Pseudovitamins

Supplemental Readings

Unit 6

Minerals and Living Systems

I. Overview
II. Bioavailability
III. Apparent Absorption
IV. The Periodic Table and Mineral Function
   A. Lewis Acids and Bases
V. Mineral Absorption as Related to RDA

Supplemental Readings

Unit 7

**Macrominerals**
   I. Overview
   II. Sodium
      A. Regulation of Serum Sodium
      B. Function
   III. Potassium
   IV. Chloride
      A. Function
   V. Calcium
      A. Overview
      B. Sources
         1. Food Mixtures
      C. Bioavailability, Absorption
         1. Apparent Absorption
         2. Physiological Status
         3. Mechanisms of Absorption
      D. Calcium Transport, Blood Calcium Regulation
      E. Function
         1. Bone Mineralization
         2. Cell Signaling
         3. Calcium and Cell Death
         4. Muscle Contraction
      F. Deficiency
      G. Recommended Dietary Allowance
   VI. Phosphorus
      A. Overview, Recommended Dietary Allowance
      B. Function
   VII. Magnesium
      A. Overview
      B. Absorption, Metabolism, Excretion
      C. Function
      D. Deficiency
      E. Recommended Dietary Allowance

Supplemental Readings

Unit 8

**Trace Minerals**
   I. Overview
   II. Toxicity of Microminerals
   III. Antagonisms and Interactions among Trace Minerals
   IV. Iron
      A. Overview
      B. Absorption, Metabolism, Excretion
         1. Iron-Containing Materials in the Body
C. Recommended Dietary Allowance
   1. Iron Needs
D. Deficiency Disease
E. Pharmacological Action
F. Toxicology
V. Zinc
   A. Overview
   B. Absorption, Metabolism, Excretion
   C. Function
   D. Deficiency
   E. Status
   F. Toxicity
VI. Copper
   A. Overview
   B. Absorption, Metabolism, Excretion
   C. Function
   D. Deficiency
   E. Abnormal Copper Status
   F. Copper Need
VII. Selenium
   A. Overview
   B. Absorption, Metabolism, Excretion
   C. Function
   D. Deficiency
   E. Toxicity
   F. Recommended Dietary Allowance
VIII. Iodine
   A. Overview
   B. Absorption, Metabolism, Excretion
   C. Deficiency
   D. Recommended Dietary Allowance
IX. Molybdenum
   A. Overview
   B. Absorption, Excretion, Function
   C. Food, Sources, Recommended Intake
X. Manganese
   A. Overview
   B. Absorption, Excretion, Function
   C. Food Sources, Recommended Intake
XI. Cobalt
   A. Overview
   B. Toxicity
   C. Requirement
XII. Other Minerals
Supplemental Readings