Handbook of Nutrition and Pregnancy

NUTRITION AND HEALTH

Adrianne Bendich, PhD, FACN, SERIES EDITOR

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Dedications

To Christopher and Liam—joys of my life—from little boys to young men. Find your passion and make it *your* life.

Carol J. Lammi-Keefe

To my husband Peter and my son Paul. May you too be inspired to follow your dreams.

Sarah C. Couch

To Sandy, Rebecca, and Julia. Thank you for nurturing my life and my work, and for always providing me with food for thought.

Elliot H. Philipson

Series Editor's Introduction

The *Nutrition and Health*™ series of books has, an overriding mission to provide health professionals with texts that are considered essential because each includes: (1) a synthesis of the state of the science; (2) timely, in-depth reviews by the leading researchers in their respective fields; (3) extensive, up-to-date, fully annotated reference lists; (4) a detailed index; (5) relevant tables and figures; (6) identification of paradigm shifts and the consequences; (7) virtually no overlap of information between chapters, but targeted, inter-chapter referrals; (8) suggestions of areas for future research; and (9) balanced, data-driven answers to patient–health professionals' questions, which are based on the totality of evidence rather than the findings of any single study.

The series volumes are not the outcome of a symposium. Rather, each editor has the potential to examine a chosen area with a broad perspective, both in subject matter as well as in the choice of chapter authors. The international perspective, especially with regard to public health initiatives, is emphasized where appropriate. The editors, whose trainings are both research and practice oriented, have the opportunity to develop a primary objective for their book, define the scope and focus, and then invite the leading authorities from around the world to be part of their initiative. The authors are encouraged to provide an overview of the field, discuss their own research, and relate the research findings to potential human health consequences. Because each book is developed *de novo*, the chapters are coordinated so that the resulting volume imparts greater knowledge than the sum of the information contained in the individual chapters.

Handbook of Nutrition and Pregnancy, edited by Carol J. Lammi-Keefe, Sarah C. Couch, and Elliot H. Philipson, is a very welcome addition to the *Nutrition and Health* series and fully exemplifies the series' goals. This volume is especially timely since it includes in-depth discussions relevant to the changing health status of women of childbearing potential around the world. As but one example, there is an extensive chapter on the obesity epidemic that continues to grow even in underdeveloped nations; the chapter includes an analysis of the comorbidities, such as gestational diabetes and related adverse pregnancy outcomes that continue to be seen in increased numbers annually. As indicated by E. Albert Reece, MD, PhD, MBA, in the volume's Foreword, the editors have "...assembled 23 superb chapters on the latest, evidence-based approaches for managing the nutritional requirements of pregnant women in a variety of settings."

This volume has been given the title of handbook because of its inclusive coverage of virtually all of the relevant topics including, but not limited to, the role of nutritional status prepregnancy, during pregnancy, and afterwards; body composition; usual and recommended dietary intakes and intakes in those with eating disorders; dietary components and alternative dietary patterns including vegetarianism and vegan diets; drug–nutrient and drug–supplement interactions; bariatric surgery and pregnancy outcomes; adolescent pregnancy and multifetal pregnancy; pregnancy in HIV-infected women; pregnancy complications including preeclampsia; and the nutritional needs of the lactating woman and her nutritional needs postpartum, whether or not she is breastfeeding. This text is the first to synthesize the knowledge base for the health provider who is counseling both the woman anticipating pregnancy as well as the pregnant woman concerning diet, popular diets and diet supplements, and diet components and their effects on gastrointestinal function. Likewise, this volume contains valuable information for the health provider about the nutritional requirements following pregnancy. In addition to an expected single chapter on specific nutrients such as iron and folate, these essential nutrients are discussed in two chapters from the viewpoints of pregnancy in developed compared to underdeveloped countries, and thus these contrasting chapters will be of great value to the graduate student and academic researcher as well as the practicing nutritionist. Two examples of novel chapters that are unique to this volume include a review of postpartum depression and the nutrients that may be of benefit and a chapter on the role of flavors and fragrances on the fetus and their effects on food preferences later in life. Several chapters contain extensive lists of relevant Internet resources and screening tools that could be implemented in an office setting. Thus, this volume contains valuable information for the practicing health professional as well as those professionals and students who have an interest in the latest, up-to-date information on the full spectrum of data on nutrition and pregnancy and its implications for human health and disease.

The editors of this comprehensive volume are internationally recognized authorities on the role of nutrition in the health of women of childbearing potential and each provides both a practice as well as research perspective. Carol Lammi-Keefe, PhD, is Alma Beth Clark Professor and Division Head, Human Nutrition and Food at the School of Human Ecology, and also has an Adjunct Faculty appointment at the Pennington Biomedical Research Center, Louisiana State University (LSU) in Baton Rouge, LA. Prior to moving to LSU, Dr. Lammi-Keefe served as Professor and Head of the Department of Nutritional Sciences at the University of Connecticut, Storrs, CT. Sarah C. Couch, PhD, is Associate Professor and Chair of Undergraduate Studies in the Department of Nutritional Sciences, College of Allied Health Sciences, University of Cincinnati, Cincinnati, OH. Eliot H. Philipson, MD, currently serves as Vice Chairman, Department of Obstetrics and Gynecology, and Head of the Section of Obstetrics and Maternal–Fetal Medicine, at the Cleveland Clinic Lerner College of Medicine, Cleveland, OH. He is a Diplomate of the American Board of Obstetrics and Gynecology as well as a Diplomate of the American Board in Maternal–Fetal Medicine. The editors are excellent communicators, and they have worked tirelessly to develop a book that is destined to be the benchmark in the field because of its extensive, in-depth chapters covering the most important aspects of the complex interactions between cellular functions, diet and fetal development, and the impact of maternal health and disease states on both optimal pregnancy outcomes and enhanced maternal health and well-being.

The introductory chapters provide readers with the basics so that the more clinically related chapters can be easily understood. The editors have chosen 42 of the most well recognized and respected authors to contribute the 23 informative chapters in the volume. Hallmarks of all of the chapters include complete definitions of terms, with the abbreviations fully defined for the reader and consistent use of terms between chapters.

Key features of this comprehensive volume include the informative abstract and key words that are at the beginning of each chapter; more than 100 detailed tables and informative figures; an extensive, detailed index; and more than 1,500 up-to-date references that provide the reader with excellent sources of worthwhile information about diet, nutrition, and pregnancy.

In conclusion, *Handbook of Nutrition and Pregnancy*, edited by Carol J. Lammi-Keefe, Sarah C. Couch, and Elliot H. Philipson, provides health professionals in many areas of research and practice with the most up-to-date, well-referenced volume on the importance of nutrition in determining the potential for optimal pregnancy outcome. This volume will serve the reader as the benchmark in this complex area of interrelationships between preconception nutritional status; nutritional needs during pregnancy for those at low as well as high risk for adverse outcomes; postpregnancy nutritional recommendations in both lactating and nonlactating mothers; exercise needs for women during their childbearing years; dietary intakes, micronutrient requirements, global issues such as obesity and HIV infections, and the functioning of the human body during these transitions. Moreover, these interactions are clearly delineated so that students as well as practitioners can better understand the complex interactions. The editors are applauded for their efforts to develop the most authoritative resource in the field of nutrition and pregnancy to date, and this excellent text is a very welcome addition to the *Nutrition and Health* series.

Adrianne Bendich, PhD, FACN
Series Editor

Foreword

I have spent the past several decades investigating the consequences of what happens to infants when their mothers have an imbalance of nutrients, such as glucose, during pregnancy. My laboratory and others have discovered a number of biochemical changes that result from chronically high blood glucose levels related to obesity and diabetes during pregnancy, all of which strongly correlate with damage to the developing fetus.

One of the most important lessons we have learned over the years is that nutrition-related malformations are much easier (and less costly) to prevent than to treat after the fact. Inexpensive folate supplementation, for example, has been shown to significantly reduce the risk of neural tube defects, a neurological birth defect that often has devastating consequences for both the infant and mother.

On the other hand, there is now overwhelming evidence that when it comes to providing optimal nutrition during pregnancy, there is no "one-size-fits-all" approach. For example, we now know that women who are overweight and obese have a higher need for folate supplementation than women of normal weight. Similarly, studies have shown that pregnant women in developing countries or women with HIV often have their own unique nutritional challenges.

It is for the above reasons that it is critically important for healthcare professionals who treat pregnant women to be well-versed in the latest information on proper nutritional support for a broad spectrum of pregnancies. In *Handbook of Nutrition and Pregnancy*, co-editors Carol J. Lammi-Keefe, PhD, RD, at Louisiana State University, Sarah C. Couch, PhD, RD, at the University of Cincinnati, and Elliot H. Philipson, MD, at Cleveland Clinic, have significantly simplified that process by assembling 23 superb chapters on the latest, evidence-based approaches for managing the nutritional requirements of pregnant women in a variety of settings.

In addition to the expected sections (1 and 2) on nutritional requirements during normal and high risk pregnancy, section 3 is devoted to special diets, such a vegetarian and vegan diets, and the potential risks/benefits of using selected nutrients and supplements during pregnancy. Section 4 is devoted to special nutritional requirements during the postpartum period, including the role of nutritional factors in post-partum depression, the number one complication of pregnancy.

The last section (5) is devoted to special issues surrounding the developing world, including the consequences of women transitioning from traditional diets to more western diets. This section also includes an important chapter on nutrition and maternal survival in developing countries and discusses the latest science on the consequences of iron and micronutrient deficiencies on birth outcomes in many regions of the world. The final chapter deals with micronutrient status and pregnancy outcomes in HIV-infected women, the fastest growing population of people infected by the AIDS virus.

A good start in life is important, and maternal nutritional status during pregnancy has repeatedly been demonstrated to be associated with pregnancy outcomes for the infant. This Handbook is designed to make that "good start on life" possible for more and more children by giving doctors, nurses, dieticians, and other health care professionals the tools they need to manage the range of pregnancies they are likely to encounter.

E. Albert Reece, MD, PhD, MBA
Vice President for Medical Affairs, University of Maryland
The John Z. and Akiko K. Bowers Distinguished Professor and
Dean, School of Medicine

Preface

Handbook of Nutrition and Pregnancy is written for the clinician and other healthcare professionals who treat and counsel pregnant women and women of childbearing age. Thus, physicians, physicians' assistants, nurses, and dietitians, in particular, as well as dietetic students and graduate and medical students, will find this book a useful resource. In addition to the historical perspective and background to support recommendations that are provided in each chapter, important for the practitioners, recommendations and guidelines have been summarized and provided in tables that are easy to locate and interpret. It is the intent of the editors that *Handbook of Nutrition and Pregnancy* serves as a reliable resource that is shelved at arm's reach by practitioners and researchers around the world. By combining the historical and background information with the easy-to-use practical information of a handbook, the volume is unique among the contemporary books that deal with the topics of nutrition in pregnancy and outcomes both for the mother as well as for the neonate.

At a time when the scientific community is looking to complete the weaving of the threads between genes and function, and to determine to what extent prenatal and perinatal environmental factors are linked to childhood and adult obesity and chronic diseases and metabolomics, *Handbook of Nutrition and Pregnancy* includes relevant chapters that bring contemporary assessments of nutrition knowledge about these cutting-edge areas and their relationships to the pregnant woman and women of childbearing age. The overall objective is to take the most up-to-date information and to translate it into clinically relevant practice recommendations.

A second major goal of this volume is to examine issues that are common to both the developed and the developing worlds and to include chapters that are specific to nutritional and reproductive factors seen mainly in developing countries. These chapters discuss contemporary issues that affect both the woman and the developing infant. For the developed world, contemporary topics for the woman experiencing a normal pregnancy include the Food and Nutrition Board of the National Academy of Science's new dietary reference intakes (DRIs), optimal weight gain, and physical activity/exercise. Part 2 of this book, addressing nutrient needs related to high-risk pregnancies, includes topics on nutrient needs of the pregnant woman who has undergone bariatric surgery, multiple fetuses, eating disorders of women of childbearing age, diabetes, preeclampsia, or HIV/AIDS. The positive and negative effects of specific nutrients and dietary factors are covered in Part 3, including topics on popular diets; vegetarian diets; the need, efficacy, and safety of dietary supplements; folate fortification; iron adequacy; and calcium, vitamin D, and bone health. Part 4 addresses the postpartum period for the mother, with topics on lactation success related to nutrient needs and physical exercise, as well as nutrition and postpartum depression. For the developing world, implications of nutrition transition for the pregnant woman, nutrient adequacy and maternal survival, anemia, and micronutrient status and pregnancy outcomes for HIV-infected women are topics included. Naturally, some topics span both the developed and developing worlds. Our aim has been to include current recommendations and policies, but where these have not been definitively established, to offer guidelines that can be made with reasonable assurances of safety and efficacy, based on current knowledge. For recommendations and policies related to maternal nutrition that have been put in place in the last decade, we review the data, where available, regarding efficacy for the recommendations and policies, e.g., folic acid fortification of the food supply. Students especially will find the coverage of gaps in knowledge useful, while researchers will turn to this volume for information relating to application of the nutrition knowledge.

A third aim of the book, covered in several chapters, is a review of nutritional as well as physiological factors that either increase or decrease the potential for high-risk pregnancies, such as gestational diabetes mellitus, Types 1 and 2 diabetes mellitus, preeclampsia, anemia, and so forth.

Required nutrients are provided primarily by the food we grow in our gardens, fish from the sea or fresh water sources, the animals we tend, or the food we barter for or purchase from markets or supermarkets. Additionally, in the developed world, the market shelves and media ads are now becoming inundated with products and information about nutrient supplements and functional foods/bioactive foods. What roles do and should these products have in the diets of women of childbearing age? How do we go about assessing the importance of these foods in a healthy pregnancy? What can we recommend? The answers to some of these questions are found herein.

In conclusion, *Handbook of Nutrition and Pregnancy* is a comprehensive volume that includes up-to-date information in 23 chapters written by the leaders in the fields of diet, nutrients, ingredients, environmental factors, and physiological consequences, addressing the needs of women of childbearing potential and pregnant women. The volume contains information that permits the reader to answer confidently practical questions from patients, family members, students and researchers, because the information represents the totality of the data rather than findings of a single study. There is not another book in the marketplace that duplicates the breadth of information found herein. Thus, this volume can serve as the benchmark in this field.

Carol J. Lammi-Keefe
Sarah C. Couch
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I

Nutrient and Health Needs During Normal Pregnancy

1 Nutrient Recommendations and Dietary Guidelines for Pregnant Women

Lorrene D. Ritchie and Janet C. King

Summary The requirements for selected nutrients increase appreciably during pregnancy. The recommended intakes for the following nutrients are >25% higher than are the amounts recommended for nonpregnant women: protein, α-linolenic acid, iodine, iron, zinc, folate, niacin, riboflavin, thiamin, and vitamin B_6. The needs for protein, iron, folate, and vitamin B_6 are about 50% higher. Good food sources of these nutrients are grains, dark green or orange vegetables, and the meat, beans, and nuts groups. Additional energy is also required to meet the needs for moving a heavier body, the rise in metabolic rate, and tissue deposition. Approximately 340–450 kcal are needed in the second and third trimesters, respectively. Although these increased nutrient requirements are significant, the same food pattern recommended for nonpregnant women can be recommended to pregnant women because that food pattern meets pregnancy nutrient Recommended Daily Allowances (RDAs) for all nutrients except iron and vitamin E. The shortfall in iron and vitamin E can be provided by any vitamin–mineral supplement supplying at least 10 mg iron and 9 mg vitamin E. Use of a common food pattern for women at all stages in the reproductive cycle enables dietitians and other health care providers to teach pregnant women the elements of a quality diet that will better ensure good health for a life time.

Keywords: Pregnancy, Nutrient requirements, Dietary guidelines, Food patterns, Nutrient intakes, Diet counseling

1.1 INTRODUCTION

Nutrient needs typically increase more during pregnancy than during any other stage in a woman's adult life. Additional nutrients are required during gestation for development of the fetus as well as for growth of maternal tissues that support fetal development. The materials required for this rapid growth and development depend on supply from the maternal diet. However, because of the differing roles nutrients play in tissue development and growth as well as nutrient-specific changes in maternal homeostasis during pregnancy, nutrient requirements do not increase uniformly. Changes in the efficiency

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of absorption from the gastrointestinal tract and excretion by the renal system, as well as changes in maternal storage or tissue reserve, are examples of homeostatic mechanisms that must be considered in establishing nutrient requirements during gestation. Because the demand for some nutrients is great relative to others, care must be taken in selecting the optimal diet during pregnancy.

The purpose of the first section of this chapter is to describe the Dietary Reference Intakes (DRIs) for pregnancy, outline how they compare to the DRIs in the nonpregnant state, and explain the physiological reasons for adjusting nutrient requirements during pregnancy. Emphasis is on nutrients with relatively high increases in demand relative to prepregnancy. This does not imply that other nutrients are not critical for a healthy pregnancy outcome, but that if increased intake for nutrients with the largest relative demand is achieved, and a mixed diet is consumed, then it is likely that the needs for other nutrients will be met as well. In the subsequent section of the chapter, nutrient requirements are translated into foods according to the most recent dietary guidelines.

1.2 NUTRIENT RECOMMENDATIONS FOR PREGNANCY

The DRIs, released from 1997 to 2005 by the Institute of Medicine of the National Academies (IOM), differ from previous recommendations [1]. The recommendations continue to be based on scientifically valid experiments with emphasis on in vivo studies in humans (rather than in vitro or animal experiments), reliable intake data, and whenever possible, measurements of relevant biomarkers. In the most recent recommendations, however, the role of nutrients in promoting and protecting health is emphasized. Prevention of nutrient deficiencies was not the only criterion used. Further, differences in the strength of the scientific evidence available for establishing nutrient requirements were delineated. For nutrients with sufficient available evidence, an RDA was established equivalent to the amount needed to meet the nutrient requirements of nearly all (≈97.5%) healthy individuals for a given gender and stage of life. When insufficient evidence was available to formulate an RDA, an Adequate Intake (AI) was provided. An AI is typically based on the amount that people normally consume, and, because it involves more expert discretion, must be applied with greater caution than does an RDA. Despite these differences, both RDAs and AIs are reference values for normal, healthy individuals eating a typical mixed North American diet. A given individual may have physiological, health, or lifestyle characteristics that require tailoring of specific nutrient values.

Table 1.1 outlines the most recent DRIs for women 19–30 years old. The changes from nonpregnancy differ slightly between younger and older women for several nutrients (as noted in the table footnotes), but in general these differences are small and for the majority of nutrients recommendations do not vary by maternal age.

During the first trimester of pregnancy, nutrient needs generally do not increase above the nonpregnant state. Although the fetus is undergoing rapid developmental change early in gestation, most of the nutrients for growth in maternal and fetal tissues are required later in pregnancy. For this reason, the DRIs were generally based on needs during the last half of pregnancy. To allow for optimal storage and accumulation of functional reserve in early pregnancy, however, recommendations were not varied by trimester, with the exception of dietary energy (see discussion below).

Table 1.1
Dietary Reference Intakes for Women 19–30 Years of Age. (Adapted from [4, 14, 19, 29, 30, 31, 36, 39])

Nutrient	*Nonpregnancy*	*Pregnancy*	*Increase (%)*	*Criterion for increase*	*Comment*
Energy and macronutrients					
Energy (kcal/day)	2,403	2,855	19	Maternal and fetal deposition	a
Carbohydrate (g/day)	**130**	**175**	35	Fetal brain glucose utilization	
Total fiber (g/day)	25	28	12	Extrapolation based on increased energy intake	b
Protein (g/day)	**46**	**71**	54	Maternal and fetal deposition	
n-6 PUFA (g/day)	12	13	8	Median linoleic acid intake from CSF II	c
n-3 PUFA (g/day)	1.1	1.4	27	Median α-linolenic acid intake from CSF II	
Elements					
Calcium (mg/day)	1,100	1,100	0	Adequate adjustments in maternal homeostasis in pregnancy	–
Fluoride (mg/day)	3	3	0	Limited data available to suggest increased need in pregnancy	–
Phosphorus (mg/day)	**700**	**700**	0	Adequate adjustments in maternal homeostasis in pregnancy	–
Chromium (mcg/day)	25	30	20	Extrapolation based on average maternal weight gain	d
Copper (mcg/day)	**900**	**1,000**	11	Maternal and fetal deposition	d
Iodine (mcg/day)	**150**	**220**	47	Maternal and fetal deposition and for maternal iodine balance and prevention of goiter during pregnancy	
Iron (mg/day)	**18**	**27**	50	Maternal and fetal deposition, basal losses, and expansion of hemoglobin	d
Magnesium (mg/day)	**310**	**350**	13	Maternal and fetal deposition of lean body mass	b
Manganese (mg/day)	1.8	2	11	Extrapolation based on average maternal weight gain	d
Molybdenum (mcg/day)	**45**	**50**	11	Extrapolation based on average maternal weight gain	d
Selenium (mcg/day)	**55**	**60**	9	Fetal deposition	
Zinc (mg/day)	**8**	**11**	38	Maternal and fetal deposition	b

(continued)

Table 1.1
Dietary Reference Intakes for Women 19–30 Years of Age. (Adapted from [4, 14, 19, 29, 30, 31, 36, 39])

Vitamins					
Choline (mg/day)	425	450	6	Median intake from CSF II	d
Folate (mcg/day)	**400**	**600**	50	Maintain normal folate status	e
Niacin (mg/day)	**14**	**18**	29	Maternal and fetal deposition plus increased energy utilization	
Pantothenic acid (mg/day)	5	6	20	Maternal and fetal deposition	
Riboflavin (mg/day)	**1.1**	**1.4**	27	Maternal and fetal deposition plus increased energy utilization	d
Thiamin (mg/day)	**1.1**	**1.4**	27	Maternal and fetal deposition plus increased energy utilization	d
Vitamin A (mcg/day)	**700**	**770**	10	Fetal liver vitamin A deposition	b
Vitamin B_{12} (mcg/day)	**2.4**	**2.6**	8	Fetal deposition and changes in maternal absorption	
Vitamin B_6 (mg/day)	**1.3**	**1.9**	46	Maternal and fetal deposition	d
Vitamin C (mg/day)	**75**	**85**	13	Amount needed to prevent scurvy in infant and estimated fetal transfer	d
Biotin (mcg/day)	30	30	0	Limited data available to suggest increased need in pregnancy	d
Vitamin D (mcg/day)	5	5	0	Daily accretion in pregnancy is small	
Vitamin E (mg/day)	**15**	**15**	0	Circulating concentrations normally increase in pregnancy; lack of clinical deficiency	
Vitamin K (mcg/day)	90	90	0	Comparable concentrations in pregnancy; lack of clinical deficiency	
Water and Electrolytes					
Water (l/day)	2.7	3	11	Median intake from NHANES III	b
Chloride (g/day)	2.3	2.3	0	Limited data available to suggest increased need in pregnancy	

Potassium (g/day)	4.7	4.7	0	Daily accretion in pregnancy is small
Sodium (g/day)	1.5	1.5	0	Daily accretion in pregnancy is small

RDAs are in *boldface type*, AIs are in *Roman*.

PUFA polyunsaturated fatty acids, *CSF II* Continuing Survey of Food Intakes by Individuals, 1989–1991, US Dept. of Agriculture, Agricultural Research Service, *NHANES III* Third National Health and Nutrition Examination Survey, 1988–1994, Center for Disease Control, National Center for Health Statistics.

[a]For healthy moderately active individuals, third trimester; requirements for first trimester are not increased above nonpregnancy, and requirements for second trimester are 2,708 kcal/day. Subtract 7 kcal/day for females for each year of age above 19 years.

[b]Percent increase for pregnant women 14–18 y is slightly *lower* than for age 19–30 years.

[c]Percent increase for pregnant women 31–50 y is slightly *higher* than for age 19–30 years.

[d]Percent increase for pregnant women 14–18 y is slightly *higher* than for age 19–30 years.

[e]Low maternal folate status in very early pregnancy (before women typically know they have conceived) has been associated with the birth of offspring with a neural tube defect (NTD). Therefore, the nonpregnant DRI for women in their childbearing years was formulated for preventing NTDs. In view of evidence linking the use of supplements containing folic acid before conception and during early pregnancy with reduced risk of NTDs in the fetus, it is recommended that all women capable of becoming pregnant take a supplement containing 400 mcg of folic acid every day in addition to the amount of folate consumed in a healthy diet.

For most nutrients, the criterion for the increase in the nutrient recommendation was based on deposition in the fetus and maternal tissues (e.g., placenta, amniotic fluid, breast tissue, fat storage), with adjustments made for changes in nutrient absorption, urinary excretion, and/or storage during pregnancy, when these were relevant and well characterized. For most nutrients, limited data were available to adjust the DRIs on the basis of changes in maternal homeostasis. Surprisingly, nutrient balance studies or supplementation trials during pregnancy have been conducted infrequently. When no direct data were available for determining the additional daily requirement for a nutrient during pregnancy, increased nutrient needs were extrapolated based on a median weight gain of 16 kg reported for women with good pregnancy outcomes [2] and the estimated nutrient need per unit of weight gain. In other cases, the median intake of pregnant women from national diet surveys was used. A brief description of the needs for select nutrients during pregnancy and the rationale for increased nutrient requirements follows. Focus was placed on those nutrients with relatively high increases in requirements above the nonpregnant state.

1.2.1 Macronutrients

1.2.1.1 Energy

Energy needs during pregnancy vary according to a woman's basal metabolic rate, prepregnancy weight, amount and composition of weight gain, stage of pregnancy, and physical activity level. It is estimated that on average a pregnant woman requires a total of 85,000 additional calories over the course of 40 weeks of pregnancy, which extrapolates to approximately 300 extra calories per day [3]. For most women, however, energy needs in the first trimester of pregnancy are minimal. While the first trimester is characterized by rapid development of fetal organs and tissues, these processes are not very energy intensive. Maternal basal metabolic rate, for example, does not measurably increase until the fourth month of pregnancy when notable increases in growth of the uterus, mammary glands, placenta and fetus, and increases in blood volume and the work of the heart and respiratory system begin. As a woman's weight increases, she also requires more energy to accomplish the same amount of physical work such that even if physical activity levels remain unchanged from prior to pregnancy, the energy costs of these activities increase.

When the new DRIs for macronutrients were released in 2005 [4], a new approach was used to estimate the energy requirements of pregnancy. Since total energy expenditure (TEE) had been measured using doubly labeled water in several hundred pregnant women, those data were used as the basis for the recommendation. The Estimated Energy Requirement (EER) for pregnancy is derived, therefore, from the sum of the TEE in nonpregnant women plus a median change in TEE of 8 kcal/week plus 180 kcal/day in the second and third trimesters to account for the energy deposition in tissue gained. At 20 weeks' gestation, the additional energy required totals 340 kcal/day; at 34 weeks gestation the additional energy need is 450 kcal/day. Table 1.2 illustrates how energy needs for pregnant women vary with body mass index (BMI) and physical activity level.

Because energy needs are influenced by a variety of factors, they can vary dramatically between individuals. For this reason, monitoring weight gain during pregnancy is the best way to ensure adequacy of energy intake [5]. The IOM [3] released recommendations for

Table 1.2
Estimated Energy Requirements (*EER*) for Women 30 Years of Age During Pregnancy. (Adapted from [4])

		EER	
Height m (in)	*PAL*	*Prepregnancy BMI of 18.5 kg/m²*	*Prepregnancy BMI of 24.99 kg/m²*
First trimester			
1.50 (59)	Sedentary	1,625	1,762
	Low active	1,803	1,956
	Active	2,025	2,198
	Very active	2,291	2,489
1.65 (65)	Sedentary	1,816	1,982
	Low active	2,016	2,202
	Active	2,267	2,477
	Very active	2,567	2,807
1.80 (71)	Sedentary	2,015	2,211
	Low active	2,239	2,459
	Active	2,519	2,769
	Very active	2,855	3,141
Second trimester			
1.50 (59)	Sedentary	1,965	2,102
	Low active	2,143	2,296
	Active	2,365	2,538
	Very active	2,631	2,829
1.65 (65)	Sedentary	2,156	2,322
	Low active	2,356	2,542
	Active	2,607	2,817
	Very active	2,907	3,147
1.80 (71)	Sedentary	2,355	2,551
	Low active	2,579	2,799
	Active	2,859	3,109
	Very active	3,195	3,481
Third trimester			
1.50 (59)	Sedentary	2,075	2,212
	Low active	2,253	2,406
	Active	2,475	2,648
	Very active	2,741	2,939
1.65 (65)	Sedentary	2,266	2,432
	Low active	2,466	2,652
	Active	2,717	2,927
	Very active	3,017	3,257
1.80 (71)	Sedentary	2,465	2,661
	Low active	2,689	2,909
	Active	2,969	3,219
	Very active	3,305	3,591

For each year below 30, add 7 kcal/day; for each year above 30 subtract 7 kcal/day
PAL physical activity level
[a]Derived from the following regression equation based on doubly labeled water data:
EER = 354 − 6.91 × age (years) + PA × (9.36 × wt [kg] + 726 × ht [m]),
where PA refers to coefficient for PAL
PAL = (total energy expenditure) / (basal energy expenditure)
PA = 1 if PAL ≥ 1 < 1.4 (sedentary)
PA = 1.12 if PAL ≥ 1.4 < 1.6 (low active)
PA = 1.27 if PAL ≥ 1.6 < 1.9 (active)
PA = 1.45 if PAL ≥ 1.9 < 2.5 (very active)

weight gain during pregnancy based on prepregnancy weight status. For women classified as being within a normal weight range prior to pregnancy (BMI 19.8–26 kg/m^2), the recommended weight gain is 11.3–15.9 kg (25–35 lbs.), and the recommended rate of weight gain is 0.9–1.8 kg (2–4 lbs.) in the first trimester and about 0.5 kg (1 lb.)/week thereafter. A slightly higher total gain of 12.7–18.1 kg (28–40 lbs.) is recommended for underweight women (BMI < 19.8). A slightly lower total gain of 6.8–11.3 kg (15–25 lbs.) and at least 6.8 kg (15 lbs.) is recommended for women who, prior to pregnancy, are overweight (BMI > 26–29) and obese (BMI > 29), respectively. Even among obese women, inadequate weight gain during pregnancy can lead to increased risk of preterm delivery [6].

The additional energy requirements of pregnancy are small relative to the needs for many other nutrients. While an extra 340–450 kcal could be consumed by simply adding a glass of 2% milk and a small sandwich, this would not meet increased nutrient needs for pregnancy. The fact that the relative increase for many other nutrients is more dramatic than for energy indicates the importance of emphasizing nutrient-dense foods during pregnancy. Following the dictum of "eating for two" may result in excessive maternal weight gain. Further, for obese women, sedentary women, and women whose activity levels decline during pregnancy (e.g., bed rest) the recommendations of 340–450 kcal/day may be too high. On the other hand, underweight women, young adolescent mothers who are still growing (<14 years), and women carrying multiple fetuses may need 500 kcal/day or more [7].

The goal is to avoid both ends of the spectrum, both excessive energy intake as well as inadequate energy intake. Overnutrition and excess weight gain in pregnancy impart risk of gestational diabetes, macrosomia, delivery complications such as shoulder dystocia, cesarean delivery and post operative problems, difficulty initiating breastfeeding, and risk of subsequent maternal and child obesity [8–10]. Conversely, undernutrition and inadequate weight gain during pregnancy can lead to impaired intrauterine growth and consequent low birth weight of the newborn. In addition to complications at birth, intrauterine growth retardation has been associated with metabolic abnormalities in adulthood, such as hyperlipidemia, hypertension, cardiovascular disease, glucose intolerance, and type 2 diabetes [10, 11].

1.2.1.2 Protein

During pregnancy, additional dietary protein is used for fetal growth, placental development, production of amniotic fluid, increased maternal blood volume, and gain of other maternal tissues. Increases in protein needs mirror maternal and fetal growth rates; early in pregnancy, the requirements for extra protein are relatively small, but increase progressively as pregnancy proceeds. Approximately 82% of the total demand for the 925 g of protein required for maternal and fetal needs is accumulated over the last half of gestation [12]. Inadequate maternal protein intake incurs risk of low birth weight.

A factorial approach was used to calculate the protein DRI during pregnancy. The summation of the additional lean tissue accumulated in pregnancy and the additional protein required to maintain an increased body weight were estimated as outlined in Table 1.3. By the second half of pregnancy, this translates into a 25-g/day increased requirement for a total of approximately 70–75 g/day (or 1.1 g protein per kg of body weight per day) [4].

Table 1.3
Derivation of Protein Requirements During Pregnancy. (Adapted from [4])

Maintenance of increased body weight			*Fetal and maternal tissue deposition*			
Average weight gain (kg)[a]	*Estimated average requirement (g/kg/day)*[b]	*Additional protein required(g/day)*	*Protein deposition (g/day)*	*Utilization efficiency of dietary protein*	*Additional protein required (g/day)*[c]	*Total increase in protein required for pregnancy (g/day)*[d]
12.8	0.66	8.5	5.4	0.43	12.6	25

[a]Average for trimesters 2 and 3; protein requirements in trimester 1 are estimated to be minimal
[b]Estimated average requirement for maintenance of protein in adults
[c]Based on slope of regression line of protein intake versus nitrogen balance (recalculated from [13])
[d]Adjusted for normal variation to meet the needs of 97.5% of pregnant women

The relative increased need above nonpregnancy is greater for protein (54% increase) than for any other nutrient. However, because protein intakes tend to be high relative to needs in the nonpregnancy state, averaging approximately 60 g/day for nonpregnant women [4], inadequate protein intake is not common in the United States, even among pregnant women. However, vegans and women carrying multiple fetuses may need to pay close attention to their protein intakes.

1.2.2 Water-Soluble Vitamins

Requirements for most water-soluble vitamins increase during pregnancy. Folate and vitamin B_6 will be emphasized in the following discussion because increases in demand associated with pregnancy are relatively high (50% for folate, 46% for vitamin B_6), and average intakes of these water-soluble vitamins relative to requirements are generally lower than for other water-soluble vitamins.

1.2.2.1 Folate

Folate is involved in single-carbon transfer reactions, notably important for the synthesis of nucleic acids and certain amino acids for new cell and tissue production. Erythrocyte folate is considered the best marker of long-term folate status in pregnancy; serum folate can also be used but reflects more recent changes in dietary intake. With inadequate folate intake, serum and erythrocyte folate concentrations decline, and megaloblastic anemia can develop. Impaired folate status during pregnancy may be involved with adverse outcomes such as pregnancy complications, spontaneous abortion, preterm delivery, and low birth weight [14]. Results from supplementation trials suggest that an additional 200 mcg of dietary folate equivalent* is required to maintain optimal folate status during pregnancy [15].

Neural tube defects (NTDs), a group of heterogeneous malformations involving neural tissue in the brain and/or spinal cord, occur in less than 1 per 1,000 births in the United States [16]. The etiology of NTDs is an ongoing area of research; however, inadequate maternal folate status prior to and in the first few weeks after conception appears to play a role in at least some cases of neural tube defects. According to 1999–2000 National Health and Nutrition Examination Survey (NHANES) data, the average folate intake of 20- to 39-year-old women in the United States is 327 mcg/day [17]. Results from supplementation studies suggest that women capable of becoming pregnant should consume an additional 400 mcg/day of folic acid from supplements and/or fortified foods in addition to consuming food folate from a varied diet.**

It is recommended that women consume 400 mcg/day of synthetic folate at least 1 month prior to conception to optimize folate status at the time of neural tube closure [5]. Based on evidence from randomized controlled trials, it has been estimated that this level of folate supplementation could prevent up to half of NTD cases [18]. A 19%

*Dietary folate equivalents are used to account for the differences in bioavailability between food folate (≈50% bioavailable) and folic acid used in supplements and food fortification (~85% available)[15].

**Available evidence suggests that synthetic folic acid (found in supplements and fortified foods) is more effective at preventing neural tube defects than is food folate [15].

reduction in NTD prevalence occurred after the mandatory fortification with folate of enriched breads, cereals, flours, and other grain products in 1998 [16]. It should be noted that the additional 400 mcg/day folic acid supplementation is not included in the recommendations for pregnant women because by the time a woman is normally aware that she is pregnant, the window of opportunity for the effective prevention by folate of NTD (due to the embryological timing of the initial development and closure of the neural tube) has passed.

1.2.2.2 Vitamin B_6

Vitamin B_6, in the form of pyridoxal phosphate, is a coenzyme involved in over 100 metabolic reactions, most of which involve amino acid and protein metabolism. During pregnancy, vitamin B_6 plays important roles in the synthesis of nonessential amino acids, heme, erythrocytes, immune proteins, and hormones. In observational studies, vitamin B_6 has been positively associated with improved pregnancy outcomes such as reduced incidence of preeclampsia and higher Apgar scores and neonatal behavior [3]. Results from randomized, controlled supplementation trials suggest limited clinical benefit of vitamin B_6 supplementation [19]. However, few such trials have been done and few pregnancy outcomes have been investigated.

Maternal and fetal accumulation during pregnancy totals approximately 25 mg, which translates into an increase in the daily requirement of about 0.25 mg after accounting for an average 75% bioavailability of food B_6 and allowing for increased weight of the mother [15]. Because the needs for vitamin B_6 predominate in the last half of pregnancy and because vitamin B_6 is not stored in the body to any appreciable extent, increased intake in early pregnancy is not likely to be adequate to meet needs later in pregnancy. Therefore, the DRI was set at an additional 0.6 mg/day [15].

1.2.3 Minerals

1.2.3.1 Iodine

Iodine needs increase during pregnancy for the synthesis of thyroid hormones. Maternal iodine deficiency during pregnancy can result in the enlargement of a woman's thyroid gland, development of goiter, and hypothyroidism. Maternal hypothyroidism increases the risk of a variety of poor fetal outcomes including stillbirth, spontaneous abortion, congenital anomalies, mental retardation, deafness, spastic dysplegia, and cretinism [3]. To avoid risk of harm to the fetus, maternal iodine deficiency should be corrected prior to conception.

During gestation, fetal iodine deposition is approximately 75 mcg/day. Results from iodine balance studies as well as iodine supplementation trials to prevent thyroid enlargement and goiter during pregnancy corroborate that an additional 70 mcg/day is required to cover the pregnancy needs of 97–98% of the population during pregnancy [20].

1.2.3.2 Iron

If iron is not readily available from the diet, then iron from maternal liver stores is mobilized. Thus, the production of fetal hemoglobin is usually adequate even if the mother is severely iron deficient, and anemia in the newborn due to iron deficiency is relatively rare. However, maternal iron deficiency is relatively common, and anemia is the most common nutrition-related complication of pregnancy. Although the prevalence of anemia in pregnancy is difficult to quantify, it has been estimated that 2–4% of pregnant women in the United States suffer from anemia [21]. In the majority of cases (≈90%), it is due to a deficiency of dietary iron. Maternal iron deficiency increases the risk of premature delivery and consequent low birth weight and may reduce a mother's risk of tolerating hemorrhage during delivery and postpartum iron deficiency [22].

The total requirement for iron during pregnancy is approximately 1,070 mg, most of which is accumulated over the last half of pregnancy [20, 23]. A large part of iron needs (≈500 mg) are used by the bone marrow for blood hemoglobin synthesis [9]. Red blood cell mass increases by approximately 33%, and blood volume increases by about 50% over the course of a healthy pregnancy [24]. An augmented blood supply is required for extra blood flow to the uterus and placenta, the extra metabolic needs of the growing fetus, and increased perfusion of other maternal organs, especially the kidneys for removal of the additional generation of metabolic waste products during pregnancy. Fetal iron storage also occurs, primarily during the last trimester. It has been estimated that 250–300 mg are accumulated in fetal and placental tissues [9].

Although the efficiency of absorption of dietary iron may increase during pregnancy,*** the daily increased requirement of 9 mg/day is not easy to achieve by diet alone. Further, women rarely enter pregnancy with optimal iron stores [9]. The 50% increase in the iron requirement during pregnancy compared to prior to conception is larger than for any other nutrient except protein. However, while average intakes of pregnant women are generally sufficient to meet pregnancy needs for protein, dietary intakes of iron tend to be low relative to requirements. The average intake of women in the United States is approximately 13 mg/day [17], below the nonpregnant DRI of 18 mg/day. The typical US diet contains about 6 mg iron per 1,000 calories. A pregnant woman consuming an additional 400 kcal/day is therefore likely to consume only 2.5 mg/day additional iron, less than a third of the 9 mg/day increase recommended.

Because of the inherent difficulties in meeting the DRI for iron in pregnancy, the Centers for Disease Control and Prevention recommends an iron supplement of 30 mg/day for all pregnant women, beginning at the first prenatal visit [25]. When hemoglobin levels are low, a 60–120 mg/day iron supplement may be prescribed. Because large amounts of iron can interfere with the absorption of other trace minerals important during pregnancy, pregnant women taking over 30 mg/day of iron should also take 15 mg of supplemental zinc and 2 mg of supplemental copper [20].

1.2.3.3 Zinc

Zinc is another nutrient with a large (38%) increase in demand during pregnancy relative to the nonpregnancy state. Zinc is involved in the synthesis of deoxyribonucleic acid, ribonucleic acid, and ribosomes and is therefore required for gene expression, cell differentiation, and cell replication. In rare cases of maternal zinc deficiency due to acrodermititis enteropathica, a genetic inability to absorb dietary zinc properly, increased risk of congenital malformations in the newborn occurs [26]. Supplementation trials involving populations with habitually low zinc intakes suggest that increased zinc is also important for preventing premature delivery and promoting proper neurological development in the fetus [20].

***Absorption of non-heme iron increases; the efficiency of heme iron, which is normally very high, does not notably increase during pregnancy.

The total requirement for zinc has been estimated as 100 mg for synthesis of maternal and fetal tissues, most of which is accumulated during the last half of pregnancy [27]. The efficiency of absorption of zinc during pregnancy does not appear to change sufficiently to meet zinc needs in the absence of an increased dietary intake [28]. The increased recommendation for zinc of 3 mg/day in pregnancy is based on the accumulation of fetal and maternal zinc of 0.73 mg/day during the last quarter of pregnancy, accounting for a 27% efficiency of absorption [20].

1.2.4 Nutrients without Increased Requirements during Pregnancy

The fact that requirements for some nutrients do not increase during pregnancy does not imply that these nutrients are not critical to maternal and fetal health. Calcium is a case in point. The needs of the fetus for calcium are substantial, averaging 300 mg/day. However, due to homeostatic adjustments, the dietary requirements for calcium do not change during pregnancy. An integrated system of hormones, namely parathyroid hormone and 1,25-dihydroxyvitamin D, regulate intestinal absorption, urinary excretion, and bone flux of calcium. During pregnancy, the efficiency of calcium absorption increases by nearly 50%, such that fetal needs appear to be met without increasing calcium intake or net losses of maternal bone mineral [11, 29].

Even though the DRI for calcium does not increase during pregnancy, it should be noted that many women fail to meet calcium requirements. According to data from the 1999–2000 NHANES, the average calcium intake of women of childbearing age is 797 mg/day, far below recommended levels [16]. Phosphorus absorption is also increased in pregnancy by changes in calcitropic hormone concentrations. Therefore, as with calcium, the DRI in pregnancy for phosphorus remains the same as for nonpregnant women [30].

For some of the other nutrients, the available evidence is generally not sufficient to warrant recommending an increased intake during pregnancy (e.g., biotin, vitamin K, vitamin E, chloride, fluoride). For yet other nutrients, the intake of nonpregnant women already appears ample to meet the small increased demands during gestation (e.g., sodium, potassium, vitamin D) [15, 20, 30–32].

1.3 DIETARY GUIDELINES

The *Dietary Guidelines for Americans* translates scientific information on nutrient requirements and dietary characteristics that promote good health into recommendations and advice for the food intake by the general public. Thus, the *Dietary Guidelines* is the backbone of nutrition education efforts throughout the country. They also reflect nutrition policy in the United States because it provides the basis for the all federal food and nutrition programs, i.e., food stamps; Women, Infants, and Children (WIC); school meal programs; and emergency feeding efforts.

The first edition of the *Dietary Guidelines* was released in 1980, and then it has been revised every 5 years. The sixth, and latest, edition was released in 2005 [33]. The first five editions of the *Guidelines* consisted of 7 or 10 statements providing guidance on how to adopt a pattern of eating that supports good health. The statements were remarkably consistent from one edition to the next [34]. Common themes in all five editions included eating a variety of foods, maintaining body weight, and limiting dietary fat, sugar, sodium, and alcohol intakes. A recommendation to eat foods with adequate starch