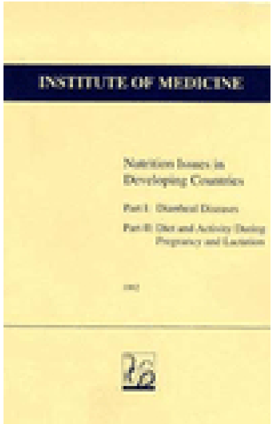

Nutrition Issues in Developing Countries: Part I: Diarrheal Diseases, Part II: Diet and Activity During Pregnancy and Lactation

Subcommittee on Nutrition and Diarrheal Diseases Control, Subcommittee on Diet, Physical Activity, and Pregnancy Outcome, Committee on International Nutrition Programs, Food and Nutrition Board

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Food and Nutrition Board
Institute of Medicine

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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The serpent has been a symbol of long life, healing, and knowledge among almost all cultures and religions since the beginning of recorded history. The image adopted as a logotype by the Institute of Medicine is based on a relief carving from ancient Greece, now held by the Staatlichemuseen in Berlin.
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PART I

DIARRHEAL DISEASES

Introduction

Morbidity and mortality attributable to diarrheal disease in infants and young children can be reduced by a variety of preventive measures and by improved clinical management of those episodes that occur. Previous reports of the Committee on International Nutrition Programs have focused on improved case management, including oral rehydration therapy (NRC, 1981) and appropriate nutritional therapy (NRC, 1985). This report considers the dietary and nutritional factors that may affect the risk of contracting diarrheal disease. Recent evidence indicates that the incidence of diarrheal disease can be diminished by decreasing exposure to enteropathogens that frequently are present in foods, and that the severity (purging rate and duration) and frequency of illness can be diminished by improving the host's nutritional status. This evidence is reviewed and the programmatic implications of these findings are discussed.

Dietary practices are in a state of flux throughout the world. Traditional dietary patterns are being modified by the introduction of an increasing number of commercially produced foods. The development and reorganization of transportation and marketing infrastructures are altering food systems dramatically in all but the most remote rural areas. Women's roles in the work force continue to expand beyond the household. The responses of households to these large-scale social and economic changes typically differ and result in a wide variation of food preparation and eating practices within communities.

Decreased exposure to food-borne enteropathogens is possible through exclusive breastfeeding; improvements in the hygienic preparation, storage, and serving of foods; and possibly, by the use of specific food additives and the application of appropriate food processing and/or packaging techniques.

Unfortunately, there is limited practical experience with program aimed at reducing the incidence of diarrheal disease by these kinds of interventions.

This report provides an overview of factors that are expected to guide the development of nutrition-related strategies for the prevention or amelioration of enteric diseases. Its focus is the relationship among the host's nutritional status, food, food preparation and eating practices, and enteric disease. Its premise is that failure to deal effectively with the food-related causes and nutritional consequences of diarrhea predisposes the host to repeated and increasingly severe nutritional deficiencies and enteric illnesses that too often result in death. Equally important strategies that concentrate on the improvement of water supplies, waste disposal systems, primary health care schemes, and other important public health measures were not considered in order to focus attention on nutritionally related components of programs directed to the control of enteric disease.

This report is designed to assist health planners in the development of programs to reduce diarrheal disease through improved feeding practices.

Chapter 1, the Executive Summary, presents an overview of the report. It looks at determinants of infant and child feeding practices in specific socioeconomic contexts. Breastfeeding as it relates to the mitigation of enteric diseases is highlighted. The conclusions and recommendations are summarized.

Chapter 2 presents an overview of feeding practices and discusses the social, economic, and cultural factors that influence them. However, the extent to which these practices are found in any given community and the specific determining factors must be identified as part of the planning process. Therefore, Chapter 2 also presents an algorithm for identifying the primary determinants in a given situation. The purpose of this algorithm is to assist in the task of identifying the most important factors causing diarrheal disease in a specific region. These are the factors that must be addressed when implementing the changes recommended in Chapter 6, Conclusions and Recommendations.

Chapter 3 reviews the evidence concerning the relationships between diarrheal disease and nutrition. This is followed by a discussion about the scientific basis for the link between breastfeeding and diarrhea prevention, which provides the rationale for emphasizing breastfeeding as part of a campaign to reduce diarrheal disease incidence and severity. Chapter 3 concludes with a presentation of the general principles of nutrition during the weaning period and important biological issues that should be considered in programs designed to improve lactation.

The first part of Chapter 4 discusses diarrhea-causing pathogens in relation to food and feeding practices, including a review of the sources of contamination. The second part of Chapter 4 describes potential interven tions that can be used to reduce contamination in the foods given to infants and young children, particularly with respect to improving food handling.

Chapter 5 presents other information that is essential for developing improved feeding programs: the technical issues concerning food processing, preparation, and storage.

The report concludes with a set of recommendations to guide the process of planning suitable nutrition interventions.

The subcommittee wishes to express its gratitude to the Committee on International Nutrition Programs and the Food and Nutrition Board for their reviews of the drafts of this report. We wish to acknowledge the interest and support of the late Martin J. Forman from the Office of Nutrition, U.S. Agency for International Development (AID). This report is an example of Mr. Forman's strong commitment to the nutritional well being of the world's children. The subcommittee also acknowledges the interest and support of Mr. Forman's successor, Dr. Norge Jerome, and Dr. Nicolaas Luykx also of the Office of Nutrition, AID. The subcommittee also recognizes the contributions of Dr. Sushma Palmer, Director, Food and Nutrition Board who reviewed the report, Ms. Janie Marshall, who provided administrative and secretarial assistance, and Mr. Michael Hayes who edited the report.

Special acknowledgment is due to Drs. Susan Berkow and Virginia Laukaran, Program Officers, Food and Nutrition Board who worked closely with the subcommittee at various stages of this report's preparation. Their contributions were particularly valuable to the subcommittee.

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Summary

Approximately 15 million children died in 1988 Many of these deaths were associated with malnutrition caused by poverty, enteric disease, and limited food intake. In addition to those who died, the health of many more children was significantly impaired, perhaps permanently, by the same adverse conditions that often lead to death. This report provides an overview to guide the development of nutrition-related strategies for the prevention or amelioration of enteric disease. Its premise is that failure to deal effectively with the food-related causes and nutritional consequences of diarrhea predisposes the host to repeated and increasingly severe nutritional deficiencies and enteric illnesses.

Studies of the associations between nutritional status and diarrhea in childhood require inclusion of the cultural, social, and economic factors that influence feeding practices. The factors that require evaluation span from macro-level economic conditions that influence food availability to micro-level factors that include the behavior of the child's care-giver. Despite the complexity of those relationships, it is possible to ascertain the hierarchy of influences that shape infant feeding practices. The following algorithm is suggested to identify the primary determinants of infant and child feeding practices in specific socioeconomic contexts:

1. Are foods that are appropriate for the young child available in the community?
2. Are they available in the household?
3. Does the child receive the appropriate foods?
4. Does the child eat the foods if they are offered?

Nutritional state and susceptibility to infection are interrelated. Many clinical and epidemiological studies indicate that undernutrition is a significant risk factor for diarrheal disease, affecting one or more key parameters of disease incidence, duration, and severity. Although the impaired immune function that is secondary to malnutrition predisposes infants and children to infectious illness, poverty, inadequate food availability, inappropriate foods, and increased transmission of pathogens are each determinants of the high rates of enteric illness in economically developing countries.

Breastfeeding is the single most effective nutritional strategy for protecting infants against enteric disease. Three mechanisms have been proposed by which human milk constituents protect the infant from infection. Two are based on the immunologic constituents of human milk and the third is its high nutrient value. The practice of breastfeeding itself provides a fourth mechanism because it decreases exposure to pathogens.

The protective effects of the constituents of human milk and of the practice of breastfeeding suggest that enhancement of lactation performance should lengthen the time before supplementary foods are required to meet the nutrient requirements of infants and maximize the protection against enteric disease. Available studies suggest that maternal nutritional status influences the volume of milk that is produced and may influence its composition. The effect of maternal nutritional status on milk volume suggests that nutritional status also influences the duration of lactation.

Emphasis is given to the duration of lactation because supplementary and weaning foods can be sources of the transmission of enteric pathogens. Interventions that will decrease their role in the potential transmission of enteropathogens include improved personal hygiene, reduction of storage of weaning foods, improvement of food storage conditions, and the use of processed foods that are resistant to bacterial proliferation.

Such interventions must be accompanied by efforts to improve the nutritional quality of supplementary and weaning foods. Several processes exist for improving the caloric density of foods, enhancing nutrient composition and/or storage stability: e.g., fermentation, germination, and milling and dry cooking (roasting and extrusion) can be used to provide weaning foods with some of the desired characteristics. The selection of either large-or small-scale industrial or home-based technologies should be made after a careful assessment of the costs (e.g., capital and labor) and the suitability of the final product within the context of specific cultures.

The three principal objectives of nutritional interventions intended to reduce diarrheal disease in children are the enhancement of the child's nutritional status, reduction of the risk of infection, and a reduction in the mortality and severity of morbidity following infection. Two general interventions are recommended:

1. the support of the initiation and continuation of exclusive breastfeeding for at least 4 to 6 months and partial breastfeeding for at least I year postpartum, and
2. the improvement of the preparation and use of weaning foods.

Research recommendations are made in seven areas:

1. effecting behavioral change,
2. reduction of enteropathogen transmission,
3. enhancement of breastfeeding and weaning practices,
4. relationships between nutritional status and diarrheal disease,
5. timing of introduction of supplementary foods,
6. nutrient bioavailability, and
7. improved food processing technologies.

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Feeding Practices and Their Determinants

FEEDING PRACTICES, FOOD, AND DIARRHEA RISK

Infant feeding practices have long been recognized as important determinants of specific infections. Gordon et al. (1963) noted the temporal relationship between the onset of weaning and increased rates of diarrhea and coined the term "weanling diarrhea" to describe this association. Since these early epidemiologic investigations, the relationships between infant feeding practices and infectious diseases have been examined in numerous additional studies. These studies have been reviewed (Jason et al., 1984). In the sections that follow, the variety of feeding practices found in different societies is briefly reviewed. These practices carry relatively greater or lesser risk of diarrheal disease for the infant and young children.

SOCIOCULTURAL DETERMINANTS OF BREASTFEEDING

Until the Twentieth Century nearly all infants were breastfed. With the widespread availability of the baby bottle and various forms of processed animal milks the initiation and duration of breastfeeding has become a significant issue. The decision to breastfeed, as well as the duration of breastfeeding, is influenced by social and individual, personal factors; among these are women's work patterns; available health care services and personnel, marketing practices of infant formula manufacturers and urbanization.

Women's Work

Women's employment outside the home does not appear to be a primary determinant of early discontinuation of breastfeeding, but rather the conditions under which women work may be influential (Laukaran et al., 1981). Important aspects of the potential impact of employment on infant feeding decisions include the following: (1) the duration of formal or informal maternity leave, which affects whether the mother has sufficient time with her Want during the initial postpartum period to successfully establish lactation before enduring prolonged intervals of separation from her infant during the work day, (2) the proximity of the work site, which affects the length of intervals of separation between mother and infant; and (3) the frequency and duration of break times during working hours, which determine the number of occasions during the day that a mother is able to breastfeed her child. While work hi the formal sector has been associated with serious constraints to breastfeeding, the seventy of restrictions in the modern work force can be ameliorated by progressive government and corporate policies and specific pieces of labor legislation (Popkin et al., 1979).

In many communities traditional work patterns also place heavy time and energy demands on women. These demands affect breastfeeding. The degree of flexibility in adjusting to these demands is often less during periods when the demand for example, for agricultural labor, is at its peak, so that the impact of women's work on breastfeeding may vary seasonally. Moreover, changing employment activities of men, including migration out of rural areas, affects infant feeding decisions and produces greater variability within communities, based on the economic adjustments of individual households.

Health Services and Personnel

A number of aspects of modern systems of maternity and newborn care are associated with decreased rates of breastfeeding initiation and poor rates of continuation among those who do initiate it (Winikoff et al., 1986b). The features of modern health care found to be associated with lower rates of breastfeeding include the following: (1) delays or interruptions of nursing; (2) routine use of supplemental formula in the hospital and its distribution to the mother at discharge; (3) fixed feeding schedules; (4) lack of knowledge about breastfeeding technique and management among medical and nursing practitioners or a lack of initiative to modify standing procedures to better assist the new mother (AAP, 1982, Lawrence, 1982).

Marketing Practices of Infant Formula Manufacturers

Advertising and product promotion may target the consumer directly, or indirectly through the health practitioner, clinic or hospital (Laukaran et al., 1981). Promotional strategies to consumers often portray formula as superior to breast milk while marketing to practitioners may attempt to deemphasize differences between breast milk and formula, touting improved formulations of the substitute products. The following are some of the ways in which breast milk substitutes reach consumers: (1) provided free to consumers as samples during prenatal medical visits or at hospital discharge; (2) provided at a discount to consumers via hospital dispensaries; (3) lack of restrictions at retail outlets; and (4) provided by medical prescription only at pharmacies.

Urbanization

With the move from rural areas, the factors described above may exert greater influence on women's infant feeding decisions. In cities, hospital births are likely to replace midwife-assisted home births and bring into play the numerous factors associated with modern health care systems. The mother also may find herself without adequate social support for breastfeeding. Finally, advertising for infant formula, both direct and indirect, is more pervasive in urban than rural environments.

Unfortunately, although economic factors play a significant part in decisions about breast versus artificial feeding, the links among urbanization, socioeconomic factors, biological conditions, and cultural decisions, and the ability of mothers to initiate and sustain appropriate milk volumes are poorly understood.

INITIATING BREASTFEEDING: COLOSTRUM AND PRELACTEAL FEEDS

In all continents of the world there are some cultures in which colostrum is discarded; it is also common to find the practice of giving newborns a liquid (prelacteal feed) prior to initiating breastfeeding, whether or not colostrum is given. At present little is known about the biological or social impact of these practices. While there are reasons to hypothesize that the effects may be negative, the evidence to confirm this is not available. In some areas colostrum is regarded as a harmful substance that is capable of causing diarrhea, pneumonia or other illness (Harfouche, 1981; Jelliffe, 1962). In other societies colostrum may be viewed as simply inadequate and is withheld until the point at which the mother judges her milk is mature (Mata, 1979). Within communities, rejection of colostrum is not uniform; some women discard it while others do not (Mata, 1978; Cruz et al., 1970). Intracommunity differences in behavior may be related to the degree of adherence to traditional beliefs, and in some situations the variability may be an indication that the practice of discarding colostrum is open to change.

In many societies herbal preparations or oils are given to newborns as a laxative for the purpose of clearing out the meconium, while in others "lubrication" of the intestinal tract is the motivation for the practice. In some cultures an early supplement (water or water sweetened with sugar or honey) is given only for the first few days of life (Bansal et al., 1973); in others, the practice of giving water continues even after lactation is established.

In some cultures the use of water as a prelacteal feed is a new introduction, rather than a traditional practice. Hospitals often give glucose water to newborns, whether or not they are being breastfed. Usually the water precedes the first nursing which may be delayed for many hours. Health personnel may encourage mothers to continue giving water by bottle after they return home, and whether or not mothers receive instructions to continue this practice, the example set in hospital is often followed. Evidence suggests that this practice increases the prevalence of bottle feeding and decreases the duration of breastfeeding (Winikoff et al., 1986a).

INTRODUCTION OF FOODS IN ADDITION TO BREAST MILK

The weaning process spans the period from the first introduction of nonbreast milk foods or liquids until the time that breastfeeding is discontinued. Unmodified animal milks and infant formulas are common as early weaning foods, and the first nonmilk foods are typically thin gruels (paps and porridges), prepared from the staple cereal, tuber or root crops of a region. Other common first foods are fruit juices, soups or herbal teas. These may not be regarded locally as food and are given for a variety of reasons: Teas prevent illness or give strength; teas "stay the child's hunger," making it possible to increase the time between breastfeedings because breast milk is inadequate to prevent thirst. Studies have shown, however, that supplementary water is physiologically unnecessary if the child is exclusively breastfed (Brown et al., 1986).

There is a wide range, both between and within cultures, in the age at which additional foods, especially protein-rich and energy-dense foods, are given. In the second six months of life, infants in many societies are exposed to an increasingly wider range of food. Often the staple carbohydrate prepared in the manner consumed by adults is offered first. Since the water content of the family preparation is less than that of gruels, the energy concentration of the foods is generally increased.

FEEDING METHODS

A variety of methods are used to give foods to infants and young children that affect the exposure to diarrheal pathogens and the quantity of food the child consumes. In some cultures the mother's hand serves as the utensil from which gruels, water or other liquids are poured into the child's mouth. In other communities, mothers use their fingers to place porridges or soft pastes in the infant's mouth. Feeding bottles have become increasingly common as infant feeding utensils in many parts of the world. Cups and spoons are also used to give foods, but since infants cannot manage these alone, busy mothers often turn to the bottle, which can be propped or easily held by an older sibling.

SEVERANCE: THE CESSATION OF BREASTFEEDING

Depending on the pace of severance and the amount of breast milk being consumed at the time it occurs, the cessation of breastfeeding can put children at increased nutritional risk. In a few cultures, special foods may be offered to the child who is being denied breast milk (Osuhor, 1980). In many societies the cultural ideal stresses gradual reduction of breastfeeding as opposed to abrupt cessation. (Darwish et al., 1982; Sanjur et al., 1970).

Abrupt weaning also occurs particularly in cultures in which pregnancy is thought to spoil a woman's milk. With the onset of a new pregnancy, a woman often resorts to very rapid removal of the child from breastfeeding. Physical separation of mother and child is also used to facilitate abrupt weaning; this practice can be stressful psychologically for the young child.

SPECIFIC DETERMINANTS FOR INTERVENTION PLANNING

Although there are typically several interacting factors that influence feeding practices, it is often possible to discern a hierarchy of influence, given sufficient empirical data. This suggests the utility of the following algorithm in identifying the primary determinants in a given situation:

1. Are foods that are appropriate for the young child available in the community?
2. Are they available in the household?
3. Does the child receive the appropriate food?
4. Does the child eat the foods if they are offered?

Food Availability to the Community

In the industrialized countries of the world most communities have access to many food products. This is not the case in many areas of the developing world. It is not unusual to find that many foods, even locally produced item, are not available to the population because of the marketing decisions of food producers and distributors.

Food Availability at the Household Level

As has been repeatedly documented, the economic conditions of households are a primary determinant of household food availability. The role of economic conditions can be partitioned into two basic sectors: (1) direct food production by the household and (2) household economic resources (especially cash income) that can be allocated to food purchases.

Among land-owning farmers in rural areas, the size and nature of holdings, ecological conditions, and the types of crops and animals raised, greatly influence food availability and the amount of additional food that must be purchased. National and international agricultural and food price policies also have powerful effects on the purchasing power of both rural and urban families. In urban communities, household food production is usually quite limited. The significance of cash income for food availability is readily apparent among rural families who purchase substantial portions of their food. There is a direct, inverse, approximately linear relationship between proportion of income spent on food and total income, with the poorest families expending the largest percentage of income on food (although families with more economic means generally spend more money on food in absolute terms). Household demographic characteristics influence the amount of food available to the household as a unit. The number of wage earners is a significant factor in household income, and household labor availability often affects food production directly.

Economic factors are rarely the sole determinants of food availability to the household. The allocation of household economic resources may be directed to economic and social investment (including education), social prestige symbols (including new technologies) or even alcohol and other recreational expenses.

Food Availability to the Child

Significant factors affect the child's diet: (1) the caretaker's beliefs about foods that are appropriate for the child and perceptions of the child's needs; (2) the caretaker's allocation of time to food procurement and preparation activities; (3) the availability of fuel, water, equipment and other resources for preparation of food for the child; and (4) family food consumption patterns and expectations, including distribution of the household food supply within the family.

Cultural Beliefs

While not all cultures have clearly developed conceptions about the relationship of food to growth or health, virtually all cultures classify some foods as good for young children and others as inappropriate or bad. While many beliefs about what foods to feed children are shared by members of the same community or cultural group, there is also a great deal of intracommunity diversity, especially under conditions of rapid social change, in which exposure to new ideas and generational and educational differences amplify diversity in beliefs.

Ideas about what children require is equally important. These concepts influence the presence of a superfood found commonly among communities that are highly dependent on a single cereal as the major food resource (Jelliffe, 1968). Rice, for example, is a superfood throughout much of Asia, and its provision to children can be seen as sufficient to meet their needs.

Parental perceptions about child development, including perceptions about adequacy of size, rate of growth, and physical appearance, also are influenced by community norms. Therefore, it is probable that in communities where growth retardation is endemic, people's conceptions about children's needs reflect the influence of generations of malnutrition (Pelto, 1987). One mechanism through which growth monitoring may have an influence on feeding practices is its educational impact on parents. Growth monitoring may influence cultural expectations about growth by providing an alternative growth model.

From a cross-cultural perspective it is impossible to make blanket generalizations about the correctness or dangers of traditional cultural beliefs and practices about the foods that are fed to infants and young children. One usually finds positive (health-promoting), negative, and neutral beliefs in all social groups, as well as variation within a group with respect to such beliefs. It is essential that beliefs and practices be evaluated on a specific, case-by-case basis, rather than making a priori assumptions about the positive or negative consequences of widely held traditional beliefs.

Allocation of Caretaker Time for Food Preparation

In recent years there has been increasing attention to the multiple roles—economic, domestic, and child care—that women play. There is often conflict between these roles, particularly conflict of time, one of the scarcest resources in many communities. To the went that infants and young children require special or extra food preparation activities, women may find it difficult to allocate such extra time, particularly when cultural beliefs do not reinforce the value of doing so.

Moreover, women often adopt new feeding practices because they are perceived as time saving. For example, the appeal of bottle feeding is often that it is easier than breastfeeding or that it extends the time between feedings, implying the availability of time free for other activities.

Availability of Fuel Water, and Other Food Preparation Resources

In many, if not most, communities in the developing world, fuel is expensive, in short supply, or, in the case of firewood and other natural fuels, acquired with considerable physical effort and time. A parallel situation exists with water. Conserving fuel and water leads to food preparation practices that are not always consonant with optimal young child feeding. For example, prepared foods are left in ambient temperatures for many hours permitting the growth of pathogens.

Food preparation tools for sieving or pureeing solid foods are frequently unavailable. As a result, young children often are given only the liquid portion of foods prepared for the family, a portion that has low nutrient density.

Family Food Consumption Patterns

Patterns of intra-household food distribution often favor adults over children and males over females. This can be rationalized explicitly in the cultural belief system or occur implicitly as a consequence of serving and eating sequences. In conditions of undernutrition, the consequences of inappropriate food distribution patterns are evident in anthropometric and nutrient intake data. Hence, food scarcity and cultural patterns of food distribution can interact to reduce food availability to young children.

Child Feeding Methods and Practices

The final component of the algorithm proposed above is whether the child actually consumes the food that is available to him or her. There are several folk sayings to the effect that "when the child is hungry, he'll eat," or "a child will eat to meet her needs." However, there is growing reason to doubt the wisdom of conventional beliefs. Anorexia often accompanies illness and malnutrition itself depresses appetite.

Adult cultural patterns restrict eating to two or three times a day in many societies. If young children are expected to conform to these mealtimes, the quantity of total food consumed may be reduced. When children are expected to feed themselves at a very young age, their consumption often is less than when they are fed directly. When caretakers are themselves children, the young child's intake also is often reduced. In addition, parental feeding practices may vary with other circumstances, e.g., during periods of heavy work activity.

In comparison with other social factors that affect the food intake of children, immediate feeding behaviors have received less attention. It can be said, however, that such behaviors probably form an important part of what is sometimes referred to as "maternal competence" or "quality of child caretaking." It is likely that under further scrutiny, the significance of feeding behaviors on food intake of infants and young children will become apparent

SUMMARY

Studies of associations between nutritional status and diarrhea in infancy and childhood require consideration of the cultural, social and economic factors that influence feeding practices. The extent and determinants of breastfeeding, the availability of appropriate weaning foods, and the use by specific communities of foods for infants and children merit careful evaluation. The characteristics that require evaluation span from macro-level economic conditions that influence food availability to micro-level characteristics that include the behaviors of caretakers. Site-specific features of primary importance may be quite restricted in number but are essential to the planning, development and implementation of interventions. Without such localized knowledge one would be in a situation parallel to that of prescribing a medical treatment with no knowledge of the condition's etiology.

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3

Relationships Between Nutrition and Diarrhea

The interaction between malnutrition and diarrheal diseases, as for most infections, is bidirectional; that is, the nutritional state alters the host response to infection and infectious illness alters nutritional state (Scrimshaw et al., 1968). When infections are frequent, especially recurrent diarrheal diseases, the interaction may become circular, with an increasing frequency of infection and a parallel and progressive deterioration in host nutritional status that proceeds to overt protein energy malnutrition if the cycle is not interrupted (Keusch and Scrimshaw, 1986).

Acute, repetitive, or chronic infections are invariably the cause of some degree of nutrient losses due to associated anorexia, catabolism of nutrient stores, and malabsorption due to intestinal infection. Nutritional losses occur in virtually all infected hosts, regardless of their nutritional status at the outset, but the consequences are most visible in those with the least ability to replace the losses. These losses can be exacerbated by the withdrawal of food during the infection and by the usual lack of suitable foods in developing countries that should be fed to convalescents (Beisel, 1977; Keusch and Scrimshaw, 1986; Watson, 1984).

EVIDENCE THAT MALNUTRITION PREDISPOSES THE HOST TO DIARRHEAL DISEASE

Most studies attempting to investigate whether malnutrition predisposes the host to diarrheal diseases have used anthropometric measures as the indicator of nutritional status. The reported outcome measures, such as incidence, duration, or some measure of seventy of diarrhea, have been more variable. Although it is necessary to control the studies for poverty (which can affect both food availability and nutritional status, sometimes in a seasonal fashion), as well as for environmental factors that govern transmission (including the level of sanitation, hygienic practices, water availability, and others), this is not commonly done, because resistance to infection is graded rather than being an all or none phenomenon. Therefore, clinical disease can occur in relatively immune competent hosts from an inoculum large enough to overcome host defenses.

Recent studies have attempted to control for these variables. The results reveal a consistent finding that malnutrition has an adverse effect on diarrheal disease, however there is little consistency from study to study as to the diarrheal disease parameter that is affected. For example, Tomkins (1981) assessed the attack rate and prevalence of diarrhea in 343 Nigerian children, aged 6–32 months, who were observed closely for 3 months. No difference in attack rate was observed between the better nourished children and those with either less than 75 percent of the weight-for-age or less than 90 percent of the height-for-age standard. In contrast, the attack rate was significantly greater in children with less than 80 percent weight-for-height ($P < 0.01$). On average, the duration of diarrhea appears longer in wasted children. They were clinically ill with diarrhea 13.6 percent of the time compared with 7.6 percent of the time for the better nourished children ($P < 0.01$). Tomkins (1981) assumed exposure to pathogens was similar in all children because they drank the same well water and consumed food that was contaminated to a similar degree with *Escherichia coli*. Thus he concluded that differences in attack rates and number of illness days were attributable to nutritional state and that malnutrition resulted in impaired resistance to enteric pathogens.

A more recent well-controlled cohort study of children less than 2 years of age was conducted in Mexico by Sepulveda et al. (1988). Subjects were selected by their weight-for-age, morbidity was determined by weekly home visits, and confounding variables (including seasonal, demographic, and socioeconomic parameters) were controlled. The incidence of diarrhea in children who were poorly nourished (60–75 percent of the weight-for-age standard) increased by 80 percent over that in children who were initially found to be greater than 90 percent of weight-for-age. In addition, malnourished children were more likely to experience multiple episodes of diarrhea, even though no difference in the duration of diarrhea was noted.

Black et al. (1984b) studied the relationship of nutritional status and subsequent diarrheal disease morbidity in 197 Bangladeshi children in a longitudinal, community-based investigation. An important feature of this study was the separation of subjects by etiology of the diarrhea. No difference in disease incidence was detected among groups that were distinguished by nutritional status; however, the duration of illness was 56 percent longer in those infants with weight-for-length of less than 80 percent of the median National Center for Health Statistics (NCHS) standard compared with that in infants who were greater than 90 percent of this benchmark. The effect was also most evident in patients with documented shigellosis or enterotoxigenic *E. coli* infections. The mean duration of illness in patients infected with *Shigella* was 22.2 days compared with 8.8 days in patients in the non-*Shigella*-infected group. Black et al. (1984a) concluded that the increased duration of diarrhea could explain the well-known increase in diarrheal disease prevalence in malnourished children, with no change in incidence being attributable to poor nutrition. The conclusions are supported by similar data obtained in a more recent study in the same area of Bangladesh (Bairagi et al., 1987).

Intervention studies represent another source of available data for evaluation of the relationship between nutritional status and susceptibility to diarrheal disease. Feachem (1983) recently reviewed this topic and found that results of most available studies are inconclusive because the study designs did not allow discrimination between the preventative and the therapeutic effects of feeding on malnutrition associated with diarrheal disease. Because of the close association between diarrheal disease and growth faltering (Black et al., 1984a; Guerrant et al., 1983), it is difficult to make this distinction, especially in populations with a high burden of infection (James, 1972; Trowbridge et al., 1981), where crowding, poor sanitation and personal hygiene, poverty, and inadequate access to health care all contribute to perpetuating both the high prevalence of infection in general and diarrhea in particular.

Nutritional status can potentially influence the severity of diarrheal diseases. Definition of severity is arbitrary, however, and no consistent criteria have been applied in different studies. The stool purging rate in children with enterotoxigenic *E. coli* or rotavirus infection was inversely related to weight-or length-for-age in Bangladeshi children (Black et al., 1984b). This observation is consistent with the more frequent occurrence of severe dehydration in children with rotavirus diarrhea with a low weight-for-age (Black et al., 1984a).

Another criterion of severity is mortality rate. The relevant question is whether there is an association between mortality from diarrhea and nutritional state. An often cited major review of mortality in Latin America concluded that about three-fifths of the infection-related deaths (including those as a result of diarrheal diseases and other infections) in children under 5 years of age occurred in malnourished children, whereas one-third of deaths from other, noninfectious causes were in poorly nourished children (Puffer and Serrano, 1973). Similar data have been reported from Bangladesh and India (Chen et al., 1980; Kielmann and McCord, 1978). Diarrhea specific deaths were tallied separately, irk the Bangladesh study, and a child with a weight-for-age of less than 65 percent of the standard was 3.7 times more likely to die with diarrhea during the following 24 months than children with a better initial nutritional status. In northern India case fatality rates were 3.5 times higher in severely malnourished children than moderately malnourished children, but this level was nearly 20 times higher than the rate for mildly malnourished and well-nourished subjects together (Bhan et al., 1986). In addition, Briend et al. (1987) showed that malnutrition, as indicated by mid-upper-arm circumference (MUAC) measurements, is a strong predictor of mortality within a month of the measurement (relative risk of 20), achieving a specificity of 94 percent and a sensitivity of 56 percent with a MUAC cutoff of less than 110 mm. In the same population, diarrhea was independently associated with a relative risk of death of 4.8, with a specificity of 87 percent and a sensitivity of 42 percent; deaths were almost entirely associated with bloody diarrhea or there was a prolonged duration of greater than 1 week. Causes of death were not assessed in this population.

Mortality data from hospitalized children show the same trends; however, these data are likely to be biased because of the admission of children with more clinically severe cases of diarrhea to the hospital. A study from Bangladesh used multivariate analysis to evaluate the risk factors for death in children with diarrheal disease (Samadi et al., 1985). Increased mortality was associated with malnutrition, and all of the increased risk was accounted for by the use of hyponatremia as a criterion. Case fatality rates were also higher among patients with *Shigella* infection, which was more frequently associated with malnutrition than was infection from other pathogens (Islam and Shahid, 1986). Deaths in patients with shigellosis also correlate with bacteremia in hospitalized patients; deaths were caused by either the infecting pathogen itself or other gram-negative organisms (Struelens et al., 1985). Bacteremia is, in turn, associated with age (patients who are less than 1 year of age), weaning, and nutritional status. Finally, a close relationship between mortality during an episode of diarrhea and nutritional state on admission, as assessed by MUAC, has been shown in Bangladeshi children (Briend et al., 1986).

IMMUNOLOGICAL CONSEQUENCES OF MALNUTRITION

Nutritional factors are known to affect immunologic function. Several reviews have documented and evaluated published data (Chandra and Newberne, 1977; Keusch and Farthing, 1986; Keusch et al., 1983; Watson, 1984). While the mechanisms and specific nutritional causes are not yet clear, there is general agreement that single or multiple deficits in immune function do occur in malnourished hosts. Moreover, a consistent pattern of immunologic defects is found in the malnourished subjects, including depressed cell-mediated immunity, as indicated by anergy to delayed-type hypersensitivity antigens *in vivo*; a reduction in the number of circulating T lymphocytes and impaired *in vitro* responses to mitogens and specific antigens; diminished activity of the serum complement system, particularly activation via the alternative pathway; and a reduction in the mucosal secretory immunoglobulin A (sIgA) concentration and specific antibody activity. These various functional alterations are associated with maturational arrest of T cells at the level of the thymus gland, increased *in vivo* degradation and reduced synthesis of serum complement, and impaired production of sIgA. Defects in cell-mediated and/or mucosal immunity could have important effects on host susceptibility to diarrheal disease pathogens. A direct relationship between skin test reactivity to a panel of antigens and the subsequent morbidity from diarrheal diseases in malnourished Bangladeshi children has been reported by Koster et al. (1987). Nutritional deficits without anergy did not explain any of the variance not attributable to malnutrition with anergy.

THE CONTRIBUTION OF DIARRHEA TO MALNUTRITION

It is not difficult to demonstrate that infections cause a deterioration in nutritional status. Mata (1978) carried out prospective studies of growth and disease in a cohort of Mayan Indian children who were studied intensively from birth to 3 years of age. Diarrheal diseases were very frequent and were strongly associated with diminished food intake and growth faltering. Using similar methods Mata (1980) found that in comparison, the Guaymi Indians in Costa Rica, who consumed a diet similar to that of the Mayans that was inadequate in energy and protein, had lower morbidity rates due to diarrhea and better growth.

Other field studies support the contention that infection exerts a significant negative influence on nutritional status. For example, Rowland et al. (1977) found that diarrheal disease in The Gambia, West Africa, is the major cause of growth retardation in young children, resulting in a 50 percent decrease in expected monthly weight gain during the first few years of life. Diarrhea prevalence was associated with a significant decrement in both linear growth and weight gain. Rowland and colleagues calculated that if diarrhea had not been present, the children would have grown at a velocity equivalent to that of the NCHS reference population. Black et al. (1984a) also found a similar decrease in expected weight gain (34 percent) in

Bangladeshi infants during periods of high diarrheal disease prevalence. The magnitude of the growth faltering associated with diarrhea is variable and may depend on the age of the individual, the season, the etiologic agent, dietary intake, and food preparation and feeding practices. Such factors may vary from place to place. Thus, a significant effect of age was noted by Martorell et al. (1975) in Guatemala, but not by Rowland et al. (1977) in The Gambia. Rowland et al. (1977) also reported that the effect of diarrhea on weight gain was least apparent during the months of highest diarrheal disease prevalence, when all children grew poorly, regardless of the presence of diarrhea. These observations suggest that other seasonal factors have a greater adverse influence on growth than diarrheal disease does.

HUMAN MILK AND DIARRHEAL DISEASES

Comparisons of morbidity between human milk-fed and formula-fed infants have demonstrated that there are significantly fewer or less severe illnesses in breastfed infants (Cunningham, 1979; Duffy et al., 1986; Grulee et al., 1934; Mata et al., 1967; Woodbury, 1922), and a few studies have found no differences (Adebonojo, 1972; Fergusson et al., 1978; NRC, 1972), but no researchers have reported increases in morbidity among human milk-fed groups (Feachem and Koblinsky, 1984). Breastfeeding also protects against mortality (Briend et al., 1988; Victora et al., 1987). Most studies associate the lowest morbidities in those who are exclusively breastfed and the highest rates of illness in those who are completely weaned. Morbidity in partially breastfed infants lies between those extremes (Butz et al., 1984; Habicht et al., 1986). In one longitudinal study, estimates of the potential impact of exclusive breastfeeding on rates of diarrhea during the first 6 months of life showed that interventions that successfully motivate adoption of this feeding practice could dramatically reduce infant morbidity. Continued breastfeeding for more than 6 months, although not practiced exclusively, was still associated with reduced risk of illness.

The protective effect of breastfeeding may be explained by reduced exposure to fecally contaminated foods and feeding utensils or by the anti-infective components of breast milk. Also, growth factors that are present in human milk may hasten intestinal mucosal renewal and recovery from enteric infections.

The benefit provided by breastfeeding was of greater magnitude for diarrheal prevalence than for incidence (Brown et al., 1989). This suggests that breastfeeding not only lessens the risk of new illnesses but also shortens the duration of those illnesses that occur. This phenomenon might be explained by the ingestion of a smaller infectious dose of pathogens by more intensively breastfed infants, by more rapid recovery from the infection, or by reduced infection-induced malabsorption and secondary diarrhea. In one clinical study, stool volume was reduced among breastfed infants with diarrhea compared with that among infants whose breastfeeding was discontinued during the early phase of therapy; these observations suggest that breast milk itself may reduce the severity of illness and hasten recovery (Khin-Maung-U et al., 1985).

Nonetheless, data presented in favor of human milk's direct protective effects are disputed because of confounding environmental and demographic variables that are difficult to control (Bauchner et al., 1986; Habicht et al., 1986), e.g., the degree of preventable contamination of other infant foods, the number of caretakers with whom the index child has contact, and the behavioral characteristics of the caretaker. Each of these variables is a potential determinant of morbidity.

Protective Factors in Human Milk

Three mechanisms have been proposed by which human milk constituents directly protect the infant from infection. Two are based on the immunologic factors in human milk, and the third is based on human milk's high nutritive value. The relative protective contributions of human milk's immunologic and nutrient constituents are difficult to estimate.

Potentially protective proteins in human milk can be classified into antigen-specific and non-antigen-specific agents. They have been the subject of numerous reviews (Goldman and Goldblum, 1985; Welsh and May, 1979).

The major functioning important whey proteins are lactoferrin and sIgA. Lactoferrin is a non-antigen-specific factor. It binds iron avidly, and thereby presumably limits iron availability to bacteria (Griffiths and Humphreys, 1977). Lactoferrin may also modulate inflammatory responses by inhibiting complement (Goldman et al., 1986), and has been reported to act synergistically with sIgA to enhance the antibacterial effects of peroxidase (Moldoveanu et al., 1982).

Secretory IgA is the major antigen-specific component in human milk Specific activity against a wide array of enteric and respiratory bacterial and viral pathogens is found in human milk (Goldman and Goldblum, 1995). The attachment of sIgA to the glycocalyx of epithelial cells in the microvilli of the small intestine may block the attachment to the intestinal tract by infectious agents (Nagura et al., 1978). The concentrations of most immunologically active proteins appear to fall after the first 2 or 3 months of lactation and subsequently either rise (e.g., lysozyme) or remain stable (e.g., lactoferrin and sIgA). Immunoprotein concentrations generally rise or remain constant after the onset of gradual weaning (Goldman et al., 1983).

Growth factors also have been identified in human milk (Klagsbrun, 1978; Moran et al., 1983). These factors may promote the maturation of the infant's gastrointestinal epithelium, and thereby augment mucosal barriers against the penetration of the gastrointestinal tract by antigens.

The relationships among breastfeeding, specific anti-pathogen activities in human milk, and specific enteric illnesses have not been examined completely. Breastfeeding appears to ameliorate shigellosis (Mata et al., 1967). Although the evidence is mixed, rotaviral diarrhea appears to be milder in breastfed infants, and not all anti-rotaviral activity is associated with specific antigenic properties (Duffy et al., 1986). Cholera and infections with *Giardia lamblia* are less likely in infants of women with high titers of specific sIgA in their milk (Glass et al., 1983; Nayak et al., 1987).

Lactation Performance

The enhancement of lactation performance is expected to minimize the need for supplementary foods to meet the nutrient requirements of infants and to maximize the protection afforded in the practice of breastfeeding and the immunologic constituents of human milk. Lactation performance is defined from measurements of the quality and volume of milk that is produced, the duration of adequate milk production, and/or infant growth. Available studies suggest that milk volume is more sensitive to maternal nutritional status than is milk composition (Garza and Butte, 1985). Most studies have focused on total nitrogen, lactose, and fat. Few studies have measured micronutrients in milk produced by women whose nutritional status has been documented carefully (Lönnerdal, 1986). Nonbehavioral maternal and environmental factors that may influence the duration of lactation also have received limited attention.

Generally, the fatty acid composition and the concentrations of the fat-and water-soluble vitamins of milk are affected most by diet. Protein concentrations are influenced by selected dietary conditions, but the effects appear to be relatively limited. Lactose, mineral, trace element, and electrolyte concentrations appear to be relatively resistant to wide variations in maternal intakes.

Effects of Maternal Nutritional Status on Lactation Performance

A relationship between maternal nutritional status and lactation performance has been demonstrated among poorly nourished women. Longitudinal studies of poorly nourished, lactating Bangladeshi mothers from an underprivileged, periurban community demonstrated that average milk production and fat and energy concentrations in milk were similar to those described for well-nourished women. Fat and energy concentrations in milk and the amounts produced per day were greater in women with larger triceps skinfold thickness, or arm circumference; and increases in body weight were associated with increases in the amounts of milk and all macronutrients produced. Milk production, however, declined significantly before the major harvest period, when food was least available (Brown et al., 1986).

Manjrekar et al. (1985) found that women who consumed 1,100 to 1,500 kcal/day produced insufficient volumes of milk within the first 4 months of lactation. Women who delivered low-birthweight infants produced insufficient milk volumes by 2 months postpartum. This and other similar studies, however, are complicated by the early return of women to work outside the home whereby the frequency of breastfeeding must be reduced or breastfeeding must be stopped entirely.

The effects on lactation performance of superimposing high levels of activity on a woman with a marginal nutritional status were investigated in The Gambia. Breast milk composition remained relatively stable through an periods of the year, but breast milk output was minimal during the farming season, when activity was highest. Reductions in milk output of up to 10 percent were observed in mothers 3 to 12 months postpartum who kept their infants with them while they worked outside the home; reductions of 25 percent were seen in mothers who were separated from their older infants during the work day (Roberts et al., 1982). Impaired lactation performance may result from heightened activity, shortfalls in nutrient intakes during periods of intense work, or maternal and infant separation.

In well-nourished women with Western life-styles, successful lactation is compatible with gradual weight reduction and energy intakes of approximately 2,200 kcal/day. The mother's dietary protein, carbohydrate, and fat intake apparently has no detectable impact on milk quantity. Milk fat composition is influenced by dietary fat. Most studies of well-nourished women report no significant interactions between milk quantity and quality and maternal weight, height, metabolic size, body surface area, change in body fat, prepregnancy weight, and weight gain during pregnancy (Butte et al., 1984b).

Effects of Food Supplementation, on Lactation Performance

Several studies have examined the effects of food supplementation on lactation performance (Forsum and Lönnerdal, 1980; Girija et al., 1984; Gopalan, 1958). The body of information neither supports nor refutes a positive effect from this type of intervention. Failure to control complex intervening variables in supplemental trials accounts substantially for the present state of knowledge. Variations in the degree of malnutrition or undernutrition, differences in the quantity and quality of the supplement used, the difficulty in measuring compliance, the possibility that the supplement is used to replace rather than augment dietary intake, and the wide variability in protocols make available studies difficult to evaluate.

In studies conducted in India, women with baseline diets of 1,700 kcal/day and 40 g of protein/day were provided food supplements that contributed an added 30 g of protein and 417 kcal/day. Differences in the milk yield of supplemented and unsupplemented women were noted, but only from the third month postpartum on. After that time, the supplemented group produced 30 percent more milk than control women (Girija et al., 1984). Studies in animals also have shown a positive influence of supplements during lactation.

Not all studies, however, have concluded that improvements in maternal intakes lead to enhanced milk production. In studies of Gambian women with baseline diets of approximately 1,600 kcal/day, approximately 700 kcal/day was added to the diet. No changes in milk production were detected (Prentice et al., 1983) in supplemented groups.

Data from protein supplementation trials published by Edozien et al. (1976), Forsum and Lönnerdal (1980), and Gopalan (1958) suggest that protein supplementation increases milk volume. The specificity of protein for increasing milk volume, however, is not certain. Gopalan (1958) attempted to control one confounding variable, energy intake. Energy consumption was maintained at 2,900 kcal/day both before and after protein supplementation. A positive effect on milk volume was reported with protein supplementation.

Manipulation of Immunologic Protein Factors in Human Milk

Maternal nutritional status appears to influence the concentrations and total amounts of immunologically active proteins produced in human milk, but available data are inconsistent. Some studies report decreases in the concentrations of immunological protein in the milk of undernourished women (Miranda et al., 1983), whereas others find no differences between such women and control women (Cruz et al., 1982). Nevertheless, the significant reductions in milk volume that are expected with maternal undernutrition would reduce the protective effects of human milk if the efficacy of immunological proteins is dose-related.

No effective means of enhancing the concentrations of nonspecific protective components in human milk have been identified. While the specificity of sIgA in human milk depends on the mother's antigenic exposure, the mechanism responsible for the presence of specific sIgA in human milk is understood only partially, and a successful strategy for the enhancement of specific sIgA levels directed against enteric pathogens has not been demonstrated in humans.

WEANING FOODS

Following the period during which exclusive breastfeeding can support adequate growth, improvement in the nutritional status of target populations through feeding interventions requires the timely introduction of nutritious complementary foods and improved dietary therapy of common childhood illnesses. Planning each of these interventions requires, in turn, knowledge of locally available foods; the nutritional content and quality of these foods; and the social, economic, cultural, and seasonal constraints to their appropriate use under different circumstances.

Nutrient Composition of Common Foods

The nutrient compositions of foods can be measured by standard analytic techniques and are usually expressed per unit weight of raw edible portions. Although the data base for food composition is constantly expanding, information is currently available primarily for macronutrients (protein, fat, and carbohydrate), total metabolizable energy ("calories"), and selected vitamins and minerals (Rand, 1985). Additional tables of amino acid content, carbohydrate profiles (sugars, starches, and nonstarch polysaccharides or fiber), fatty acid composition, and trace element concentrations of limited numbers of foods are also becoming available or are under development. Food composition tables have been prepared for different regions of the world. These composition tables consider locally available and commonly consumed products.

Unfortunately only small numbers of samples have been analyzed for each type of food, and it has been found that the nutrient compositions of individual foods vary greatly. Thus, food composition tables—although indispensable for planning diets—provide fairly crude guidelines of the actual amounts of nutrients consumed (Cameron and Hofvander, 1983).

The major nutrient sources are (1) the staple foods, which provide the majority of energy and protein as well as some vitamins and minerals; (2) fruits and vegetables, which are important additional sources of vitamins and minerals; (3) animal products, which can supplement the amount and quality of dietary protein, specific vitamins, and minerals; and (4) fats, oils, and sugars, which can enhance the energy density of mixed diets. The staple foods include cereals, such as wheat, rice, maize, and millet; roots and tubers, such as white potatoes, sweet potatoes, yams, and cassavas; and pulses or legumes, such as peas, beans, and groundnuts.

Cereals are composed mostly of carbohydrate (primarily starch and nonstarch polysaccharides), protein (at a level between 6 and 14 percent of dry weight), and little fat. Nutrients are not distributed equally throughout the anatomic structures of grains, so the final nutrient composition of a cereal product depends on the degree of milling and other types of food processing (see Chapter 5). The outer layers of the grain contain relatively higher concentrations of protein, vitamins, and fiber, whereas the endosperm is generally higher in starch. The germ is relatively rich in protein, fat, and some vitamins. The water-soluble vitamins of the husk can be partially transferred to the endosperm by parboiling, which also improves the storage characteristics of the grain. Cereals are important quantitative sources of protein, but their protein quality is limited by the inadequate content of selected essential amino acids (WHO, 1985).

Tubers, like cereals, have a high starch content and may contain reasonably good levels of protein. However, the water content of unprocessed roots and tubers is substantially greater than that for cereals. While the concentration of nutrients per unit of raw weight of tubers is lower than that for cereals, the ratio of protein to energy for some tubers, such as white potatoes, may be similar to that for some cereals. On the other hand, cassava is very low in protein, and the limited amount of protein it contains is of poor quality. Unlike the cereals, fresh tubers contain sizable quantities of ascorbic acid.

Legumes are rich in protein and starch and can be good sources of calcium, iron, and B vitamins. Some (e.g., soybean and groundnuts) are excellent sources of edible oils. Although dry legumes contain between 20 and 40 percent protein, the digestibility and quality of the protein can be restricted, respectively, by the presence of protease inhibitors and by a relative deficiency of the essential amino acid methionine. However, the relative excess of lysine in legumes makes them excellent complementary protein sources for the cereals, which in turn can compensate for the inadequate levels of methionine in the legumes (Bressani, 1977). Thus, if sufficient amounts of legumes are provided to overcome the reduced digestibility of vegetable diets, appropriate mixtures of these vegetable protein sources can yield diets with a protein quality that is indistinguishable from that of reference animal protein.

Fruits and vegetables are primarily valued as sources of vitamins and minerals. Dark pigmented fruits and vegetables are major sources of vitamin A precursors and provide ascorbic acid, folic acid, other B vitamins, iron, and other minerals.

Dairy products contain readily digestible protein of excellent quality and are rich in calcium and vitamins. Animal products are the only food source of vitamin B_{12}. These foods tend to be expensive, and they often contain lactose, which may not be well tolerated in amounts greater than 1 g/kg per feeding when provided as the sole source of nutrients for children with diarrhea. However, milk is generally well tolerated when mixed in small amounts with staple foods, even by children with diarrhea and by children with clinical evidence of lactose malabsorption (Brown et al., 1980). Because only small amounts of these products are required to improve protein quality and content of the diet, the issue of cost and lactose intolerance may not be an important limiting factor for their use in a mixed diet.

Because the bulkiness of the diet may limit the amounts of nutrients that are consumed, separated fats and oils that contain high amounts of energy per unit volume can make a valuable contribution to the diet. Likewise, sugars can be considered dense in energy since they can enter into solution, thereby adding energy to liquid or semiliquid diets without increasing their volume. Current recommendations to lower the consumption of fat and cholesterol to reduce the risk of cardiovascular disease is of little concern to most people in developing countries, where the intakes of fats and animal products are extremely low after the period of weaning. When fat intakes beyond infancy are greater than 30 percent of dietary energy and a substantial proportion of the fat is provided by saturated fatty acids (as in animal fats, coconut oil, and palm oil), some consideration of the possible cardiovascular risk is warranted.

Bioavailability of Nutrients

The quality of the mixed diet is a function of the nutrient content of the diet and the bioavailability of its nutrients. The bioavailability of nutrients, which can be defined simply as the efficiency of absorption and utilization or retention of the nutrients that are present in food, can vary substantially and has often not been well characterized. It is determined in part by nutrient content, food processing, the physiological status of the host, interactions among components of. the mixed diet, and the presence of antinutritional factors. The effects of food processing techniques on nutrient bioavailability and on microbial contamination are discussed in more detail in Chapter 5.

NUTRIENT REQUIREMENTS OF INFANTS AND YOUNG CHILDREN

Age-specific nutrient requirements and recommended intakes or allowances are published by national and international authorities (WHO, 1985; NRC, 1980). Recommended allowances of all nutrients except energy are calculated by estimating average population requirements and by adding a quantity to account for individual variability and bioavailability from usual food sources. Recommended intakes of energy usually are calculated by a factorial approach, which is the sum of average estimates of the needs for maintenance, growth, and activity.

Nutrient needs during periods of catch-up growth (5–8 kcal and approximately 0.4 g of protein per gram of desired gain of lean body mass) are reasonable supplements to baseline requirements if accelerated growth is desirable during illness-free intervals (NRC, 1985). Estimates of energy intake for a range of weight gains during convalescence have been published (NRC, 1985). The recommended intakes of most micronutrients are likely sufficient for adequate growth unless micronutrient deficiency states are present. Estimates of nutrient needs calculated from recommended levels of intake, however, should not be used by themselves as a target of strategies to ameliorate or prevent enteric disease. Rather, the morbidity and growth response of the child should be used to monitor the adequacy of general food safety and dietary intake.

Until recently, little information has been available regarding the relationship between growth during infancy and the normal volumes and composition of human milk consumed in the first 4 to 6 months of life by breastfed infants (Butte et al., 1984b; Chandra, 1981; Dewey and Lönnerdal, 1982; Picianno et al., 1981). This has prevented the resolution of apparent discrepancies between the projected volumes of milk required to meet energy and protein requirements estimated by factorial approaches and the volumes of milk consumed by apparently healthy infants (Waterlow and Thomson, 1979). With few exceptions, the milk intake of infants of well-nourished women range from 600 to 900 ml/day. Well-nourished, breastfed infants consume approximately 100 to 120 kcal/kg during the first month of life; their energy intakes decrease to approximately 70 to 90 kcal/kg by the fourth month and appear to remain at that level for at least 8 to 9 months, even after solid foods are added to their diet. Those energy intakes appear to be substantially lower than the intakes of formula-fed infants (Fomon et al., 1971; Montandon et al., 1986).

Most recent studies of infants who live in favorable environments indicate that the exclusively breastfed infant's weight-for-age, weight-for-length, and less frequently, length-for-age percentiles demonstrate statistically significant negative trends after the third month of postnatal life (Butte et al., 1984a; Garza et al., 1987; Hitchcock et al., 1985). Generally, cohorts of breastfed infants appear to gain weight during the first 2 to 3 months of life at a more rapid rate than is expected on the basis of the NCHS reference population. In later months infants appear to reduce the rate of weight gain relative to that of the reference population, even when supplementary foods are available ad libitum. Although such trends commonly are not sufficiently severe in economically developed countries to arouse clinical concern, they support the view that human milk may become limiting by the third or fourth month of life (Waterlow and Thomson, 1979). That conclusion, however, is based on the acceptance of NCHS growth curves as normative standards, despite their derivation from observations of infants who were principally formula-fed. The general persistence of negative trends in growth percentiles of breastfed infants whose diets are supplemented ad libitum with solid foods and who live in favorable environments suggests that NCHS growth curves may not be appropriate and that as a result health practitioners may identify growth faltering prematurely.

An important caveat in this discussion is that there are no convincing data to show that infants in areas with high endemic rates of enteric infections can maintain comparable rates of growth as their counterparts in more privileged environments, when both groups of infants consume similar amounts of human milk. If the effects of unsanitary environments on infant health are to be compensated for by specific human milk constituents, infants must provide sufficient stimulation to the breast to increase milk production when needed, and the mammary glands' response to the infant and the environment must be timely. Failure by either mother or infant may result in progressive nutrient deficits. Most data from economically developing countries indicate that milk volumes and contents are similar or lower than those observed in economically developed settings (Brown et al., 1986; Jelliffe and Jelliffe, 1978; Prentice et al., 1983).

SUMMARY

The nutritional state of the host and susceptibility to infection are interrelated in the broadest sense. Most of the clinical and epidemiological studies reviewed indicate that malnutrition is a bona fide risk factor for diarrheal disease, affecting one or more key parameters including incidence, duration, and severity of illness. One mechanism for this is impaired immune function secondary to malnutrition; however, poverty, inadequate food availability or kinds of food, and increased transmission of pathogens can each have major affects. Whether or not nutrient losses as a result of infection become clinically manifest depends on the individual's nutritional status at the outset of infection, the duration and severity of the infection, and the availability of energy-dense and high-quality foods during convalescence.

If the individual is well nourished initially, the illness is short, and appropriate foods are available, catch-up growth during convalescence can be rapid and the impact of the infection may not be detectable. These conditions are rarely present in developing countries.

Breastfeeding is also protective. Three mechanisms have been proposed by which human milk constituents protect the infant from infection. Two are based on immunologic factors in human milk and the third is the high nutrient value of human milk. The practice of breastfeeding provides a fourth mechanism, as it decreases exposure to potential pathogens.

Weaning foods consist of mixtures of ingredients formulated to supplement the nutrients from human milk. They must be calorie-and nutrient-dense and preferably formulated on the basis of the nutrient content and bioavailability of locally available foods.

Age-specific nutrient recommendations made by national and international health agencies are useful guides for planning diets (WHO, 1985; NRC, 1980). Allowances for catch-up growth also are available in a separately published report (NRC, 1985). Neither standard, however, is a substitute for growth and gastrointestinal morbidity as an index of the nutrient adequacy and safety of the diet. The appropriateness of accepted references for the assessment of growth in breastfed infants is difficult to evaluate. Relationships among growth, intakes of human milk, and milk composition require improved definition in breastfed infants who live in areas with high endemic rates of enteric infections.

Available studies suggest that maternal nutritional status influences the volume of milk that is produced and may influence its composition. Assessments of the effects of maternal supplementation on lactation performance, however, neither support nor refute a positive effect of this type of intervention. The few studies that have assessed the impact of protein supplements suggest that milk volume may be increased by increments in protein intake. The effects of maternal-infant separation and varying degrees of physical activity among women complicate the interpretation of available data. No effective strategies for enhancing the immunologic content of milk as a means of enhancing human milk's protective effects have been described. The enhancement of lactation performance is expected to benefit gastrointestinal morbidity in infants.

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4

Feeding Practices, Food, and Diarrhea Risk

FOOD CONTAMINATION

Enteric pathogens are transmitted by the fecal-oral route, and foods ingested by children are major vehicles of this transmission. In developed countries, the enteric pathogens most commonly associated with food-borne disease are *Salmonella sp., Staphylococcus aureus, Clostridium perfringens*, and *Bacillus cereus* (Horwitz, 1977). *Salmonella* also occurs in developing countries, but it is not responsible for a large fraction of episodes. *S. aureus, C. perfringens*, and *B. cereus* almost certainly cause enteric illnesses in children in developing countries, but the importance of these agents is unknown. These organisms have been implicated in outbreaks occurring in food service establishments and the home. Outbreaks are defined as two or more persons with a similar illness and an epidemiologic and laboratory investigation which confirms that a food was the source of illness. The incrimination of *S. aureus* or *C. perfringens* as the cause of an outbreak is particularly problematic since both organisms are normally found in stools of healthy people. Phage typing or serotyping of the isolates from stools of a number of ill individuals and from food is required to determine that these agents are responsible for the outbreak. The incrimination of these agents as a cause of a single case of enteric illness is almost impossible. However, if these foodborne enteric pathogens can cause outbreaks involving multiple individuals, they can certainly cause single, sporadic cases in susceptible individuals.

In developing countries, enteric pathogens can be found in at least half of the children with endemic diarrhea, with most of the agents being bacterial (Black et al., 1982b). The most commonly found bacterial pathogens in children in developing countries are enterotoxigenic and enteropathogenic *E. coli* and *Shigella sp*. They can be transmitted by means of contaminated food, although the relative importance of this route compared with water contamination or direct person-to-person transmission is unknown. Other bacterial pathogens, such as *Campylobacter jejuni* or vibrios also could be transmitted by food in developing countries. It is also likely that certain viral pathogens, such as 27nm viruses like Norwalk virus, and parasitic agents, such as *Entamoeba histolytica, Giardia lamblia*, or *Cryptosporidium sp*. are often ingested with food. The offending organism may be present in raw foodstuffs or it may be introduced during food preparation or storage. It then replicates under suitable temperature and pH conditions. These conditions, which can also occur because of critical defects in food handling in developed countries, are very common in household settings in developing countries. Bacterial multiplication may be particularly important for some pathogens, such as enterotoxigenic *E. coli* or vibrios, that require a large ingested dose to cause disease.

Food control investigations often use enumeration of indicator organisms, rather that isolation of pathogens (Frank and Barnhart, 1986). These organisms, predominantly *E. coli*, are indicators of fecal contamination, since that is their usual origin. Coliform or fecal coliform indicators have been used extensively to assess water quality, and the presence of any coliforms in water is considered unacceptable for potable water (APHA, 1989). The presence of indicator bacteria in food simply suggests that there is a risk that food also is contaminated with an enteropathogen. In settings with poor sanitation and hygiene, that risk of contamination is determined in part by the frequency of enteropathogens in the stools of healthy people, and the prevalence of diarrhea during which higher numbers of enteropathogens are excreted.

FECAL CONTAMINATION OF WEANING FOOD IN DEVELOPING COUNTRIES

In studies done in Bangladesh, El Salvador, India, Indonesia, Jamaica, Peru, and The Gambia, high levels of fecal bacteria were found in the milk or formula given to infants (Barrell and Rowland, 1979; Black et al., 1982b; Black et al., 1989). A similar hazard of fecal contamination has also been demonstrated with traditional weaning foods (Black et al., 1982a, 1989; Rowland et al., 1978). Cereal gruels and other foods specially prepared for infants were the most frequently and heavily contaminated. Pathogens, namely, enterotoxigenic *E. coli* and *Salmonella sp*. and possible pathogens, including *Aaromonas hydrophila* and *Vibrio cholerae* non-O group one, have been isolated from foods consumed by infants in studies done in The

Gambia, Bangladesh, and Peru (Black et al., 1982a, 1989; Rowland et al., 1978).

Source of Contamination

Water often is used for the preparation of liquids and other foods given to infants, and if it is fecally contaminated, it can contribute to the contamination of weaning foods. Water that has been mixed with milk or other foods often is ingested before it has been boiled adequately or given some other treatment, as indicated by the demonstrated high levels of fecal coliforms and by the isolation of specific pathogens, such as enterotoxigenic *E. coli* (Black et al., 1982b). In addition, the limited availability of water contributes to poor personal and domestic hygiene, which leads to food contamination.

Feeding bottles and nipples are possible sources of contamination of milk (Phillips et al., 1969). For example, in Nigeria 48 percent of feeding bottle nipples had *E. coli* contamination, and enteropathogenic *E. coli* was found on 24 percent of the nipples (Elegbe et al., 1982). In Peru, 35 percent of nipples and 23 percent of feeding bottles contained *E. coli*, which were also commonly found on spoons (Black et al., 1989). Cups, spoons, feeding bowls, can openers, and the hands of food preparers have also been found to be contaminated, although to a lesser degree than feeding bottles. In fact, boiled teas served in cups in Peru were rarely contaminated, but the same teas served in feeding bottles contained *E. coli* in 31 percent of the samples (Black et al., 1989).

Poor personal hygiene of food handlers, inadequate cooking, and storage of food at improper temperatures (Frank and Barnhart, 1986) are also important determinants of fecal coliform contamination and growth in food in households in developing countries. These households also have overcrowding, poor sanitation, and insufficient water. An important specific hygienic practice is handwashing (Feachem, 1984). Limited evidence indicates that a substantial reduction in diarrhea rates can be achieved by improved handwashing practices. The feasibility and essential components (e.g., quantity of water and/or soap) of hygiene education programs remain to be determined.

Raw foods are often contaminated with coliforms, although this is less of a problem with dry foods than with foods having a high moisture content With the application of beat, usually boiling, they are usually heated to sufficient temperatures to kill the bacteria. However, secondary contamination often occurs from the introduction of contaminated utensils or hands into the foods. The bacteria thus introduced can then multiply in the food.

A very serious hazard in food preparation is the storage of food at ambient temperature in households in developing countries. The proportion of foods with contamination and the count of indicator organisms were found to increase with the length of storage time after preparation in studies done in Bangladesh and The Gambia (Black et al., 1982a; Rowland et al., 1978). In other studies weaning foods such as gruels were found to be contaminated, and it was demonstrated that there is an even greater increase in bacterial contamination if consumption is delayed. It is likely that the seasonality of bacterial diarrheas, with a predominance in the warmer months, reflects the greater survival and multiplication of pathogens in food at higher environmental temperatures (Black et al., 1982b).

A special concern with regard to storage is that the heat-resistant spores of some pathogenic bacteria, such as *C. perfringens* and *B. cereus*, survive cooking and can germinate and multiply during subsequent storage. Inadequate reheating then permits ingestion of high numbers of the pathogens, and even subsequent boiling is not sufficient to destroy heat-stable toxins such as the emetic toxin of *B. cereus*. The importance of these factors is unknown since the role of organisms such as *C. perfringens* or *B. cereus* in diarrhea in people in developing countries is poorly understood.

Microbial survival or multiplication is affected by the chemical, physical, and microbiological characteristics of food (Genigeorgis, 1981). Survival or growth of enteropathogens in food can be reduced or eliminated through alteration in specific characteristics, such as the microbial flora, pH, moisture content, oxidation-reduction potential, available nutrients, natural inhibitors of microbial growth, or addition of food preservatives. Each of these has been used to inhibit bacterial growth in processed foods. Many have also been used in traditional food preparation methods because they delay food spoilage caused by microbial growth, although few have been purposefully used to inhibit enteropathogen multiplication in weaning foods in developing countries.

One of the most important factors with regard to multiplication of enteropathogens is the degree of competition from other organism in the food. Food-borne pathogens are not strong competitors and are rather easily suppressed by the nonpathogenic flora of the food. This inhibition of pathogen growth or of production of toxins can be mediated by a decrease in pH from the microbial production of certain acids, hydrogen peroxide, or other inhibitory substances (including antibiotic-like substances), or by microbial competition for essential nutrients. Milk products fermented by lactobacilli (e.g., yogurt) contain lactic acid, hydrogen peroxide, and antibiotic-like substances, which may inhibit the growth of enteropathogens.

Relationship of Weaning Food Contamination to Diarrhea

The relationship between weaning food contamination and diarrhea can be inferred from available evidence. The high relative risk observed in infants given weaning foods (even supplementary water) compared with that observed in exclusively breastfed children in many countries suggests that food contamination may cause diarrhea in these children. The high levels of fecal contamination and the isolation of specific pathogens from some weaning foods further support the supposition that weaning foods are an important vehicle for transmission of enteric pathogens, and in one study there was a significant relationship between the degree of fecal contamination of weaning food and a child's annual incidence of diarrhea associated with enterotoxigenic *E. coli* (Black et al., 1982a).

POTENTIAL INTERVENTIONS TO REDUCE WEANING FOOD CONTAMINATION

Personal and Utensil Hygiene

The greater availability of water, improved sanitary conditions, and enhanced concern about domestic hygiene would likely reduce transmission of enteropathogens via foods, as well as by other routes. Specific hygienic behaviors such as handwashing have been shown to reduce the incidence of diarrhea, even in developing countries (Feachem, 1984).

Virtual elimination of feeding bottles has been successfully accomplished in Papua New Guinea and has been reported to reduce the rate of diarrhea. Even if their elimination cannot be achieved, improved cleansing of bottles and nipples may reduce the risk of contamination of milk or formula by (1) boiling of bottles and nipples and (2) using disinfectant solutions (commonly, 1 percent hypochlorite solution). Proper use of such procedures is often difficult because poor households may have only one feeding bottle, which is constantly in use, i.e., it contains milk or formula that is consumed by the infant "on demand" or the proposed methods are not applied appropriately. One study in Nigeria reported that soaking of bottle nipples in hypochlorite solution is associated with a marked reduction in bacterial contamination, even in comparison to working with detergents (Elegbe et al., 1982).

Holding of Food Between Cooking and Saving

The storage of weaning foods for many hours in the home provides an opportunity for secondary contamination of foods from feeding utensils or hands, for germination of spores, for multiplication of enteropathogens, and for production of enterotoxins. Reheating to a proper temperature for sufficient time, which is not commonly done, would avert the problems that arise from storage, except for those caused by heat-resistant toxins. Without refrigeration it is difficult to achieve a sufficiently cool temperature to limit microbial multiplication in hot tropical climates. However, the safest practice would be to eat all foods at each setting and to prepare new servings, at least for infants, at the next meal. If this cannot be done, leftover foods should be reheated for a sufficient amount of time and at a sufficient temperature to kill pathogenic bacteria.

SUMMARY

Infant feeding practices are important determinants of diarrhea in infants and children in developing countries. Since contaminated weaning foods are an important route of transmission of enteric pathogens, reduction in food contamination should reduce the incidence of diarrhea. Interventions might include improved personal and utensil hygiene, reduction of storage time of weaning foods, or improvement of storage conditions or the use of processed, e.g., fermented foods that resist contamination. Such interventions should become important components of programs to control diarrhea.

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5

Processing Techniques Suitable For Weaning Foods

PROCESSING

Various food processing techniques and additives have the potential to enhance the nutrient bioavailability, nutrient density, food safety, storage stability, palatability, and convenience of supplemental foods suitable for weaning mixtures or to promote nutrition repletion following diarrheal episodes. Some of these are applicable for use at home, while others require the equipment and skills available in a small-or medium-scale food factory (Bressani et al., 1984).

Processing Techniques

Roasting

Roasting describes a process that dry cooks a cereal, legume, or oil seed. The resulting dry ground products can be mixed with sugar and oil and moistened to form a ball that can be fed by hand to an infant or child. Because of the limited ability of roasted products to absorb water, the nutrient density is high. High processing temperatures produce a pleasant toasted flavor that improves palatability and inactivates enzymes and antinutritional factors but also denatures heat-labile vitamins.

Roasting can be accomplished by shaking the grains in a heated pan or by immersing and agitating them in hot salt or sand. Large-scale roasting equipment with improved thermal efficiency that requires only a moderate level of skill to operate is available. Roasting loosens the seed coats, making them easy to remove before the product is ground. Although roasting is one of the least expensive cooking processes, it is limited to whole gains and products with uniform piece sizes. Roasting dries grains and destroys much of the surface microflora, thus increasing the shelf life if the product is protected from moisture and insects.

Germination

Soaked whole grams can be sprouted prior to cooking to increase vitamin levels, reduce the molecular weight of the carbohydrates that are present, and increase the availability of essential amino acids and relative nutritional value of the food (Wang and Fields, 1979). The amylases, released during germination hydrolyze starch to shorter-chain carbohydrates and sugars, facilitating digestibility and reducing viscosity at elevated concentrations to increase the caloric density of foods (Mosha and Svanberg, 1983). Once sprouted, grains have to be dried if they are to remain stable. Heating during or following drying increases flavor and acceptability.

Milling

Milling, a spectrum of processes, cleans and separates the components of grains (germ, bran, endosperm) and reduces their size. Mining has the beneficial effect of lowering fiber and bulk but it is at the expense of a lowered vitamin and mineral content in the remaining flour.

Cleaning steps associated with milling can remove insect and microbiological contamination of raw materials. The mined product, however, is more susceptible to insect damage if it is not protected in packaging that is puncture resistant and resealable Bacteriological growth is not a concern in mined products as long as they have less than a 15 percent moisture content.

Milling lowers the phytates present in the bran of many cereal grams and legumes that interfere with the absorption of starch, calcium, minerals, and trace elements. Tannins, which are present in the seed coats of many pigmented cereals, can inhibit the digestion of protein and starch if they are not removed during milling. Simple mills can replace the labor-intensive and time-consuming pounding, grinding, and handwinnowing techniques that are commonly used. Mills consisting of stone or metal grinding parts and blowers can be manufactured locally.

Milling by itself does not produce a supplementary food. Instead, mined ingredients are more suitable and convenient for formulating supplemental foods. Milled flours cooked with water form thick gruels with low nutrient density and protein content. Beans, legumes, lentils, oil, and sugar can be added to reduce these shortcomings.

Large multistep mills increase the efficiency of separation and size reduction. These mills can produce fine flour, but require imported equipment and extensive technical skill for operation and maintenance. Large flour mills usually include a fortification step to replace the vitamins and minerals that are lost during the milling or bleaching process.

Baking

Baking is used to produce nutritionally dense biscuits containing fat, sugar, and vegetable and animal proteins. Biscuits can be crumbled, and water or milk can be added to make a gruel. Older children eat biscuits directly as a ready-to-eat supplementary food. Individual biscuits provide a degree of portion control and can be very acceptable to children.

Baked products are quite digestible and can be fortified to increase the levels of vitamins, minerals, and protein. Biscuits baked at high temperatures are dry and can be stored for long periods of time. To increase the shelf life, packaging is required to reduce insect infestation and moisture uptake. Baked products normally require expensive refined ingredients such as shortening (off), flour, leavening, and sugar; this increases the cost and may limit their production.

Cooking

Cereal, legume, and oil seed based products are typically prepared by boiling in 70–90 percent water to completely cook and gelatinize the starch to form a thick paste. The gruels have a low nutrient density unless amylase (sprouted grains) is used to hydrolyze some of the starch to reduce the viscosity at higher solids concentrations. The use of ground beans instead of whole beans added directly to boiling water can reduce cooking time by a factor of 10 (Nelson et al., 1978).

Cooking processes affect digestibility in a variety of ways. When heated, the starch granules readily permit water absorption, a process known as gelatinization (Olkku and Rha, 1978). Raw starch is resistant to enzymatic hydrolysis (Jenkins et al., 1986) and digestion before gelatinization occurs. However, the cooking of sorghum in excess water decreases rather than increases digestibility.

There are several factors present in some foods that also decrease the digestibility and/or absorption of specific nutrients that are denatured by heat during cooking. For example, protein digestibility is reduced by the protease inhibitors present in legumes (Aykroyd and Doughty, 1964) unless the inhibitors are inactivated by heating.

The cooking or reheating of foods can destroy vegetative forms of enteropathogens. The temperature necessary depends on the time of exposure, with only a short interval (less than I minute beating temperature) at greater than 75°C are required. Even at these temperatures, however, heat-resistant spores survive. This is of concern when food is held between the time of cooking and serving. Foods held at temperatures between 20 and 50°C allow bacteria to multiply rapidly.

Products cooked with high levels of moisture must be either sterilized in a package or dried if they are to remain stable for any extended period of time. Packaging and sterilization are expensive. Moreover, once the sterile package is opened, the product becomes very susceptible to contamination and spoilage. Both heat and radiation can sterilize, but radiation is unlikely to have applicability in developing countries.

Drying

Water must be available for spore germination, microbial growth, and toxin production. Drying and the addition of solutes, such as NaCl or sucrose, to the food depresses the water activity (a_w) according to the nature of the solute. Water activity is defined as the ratio of the water vapor pressure of the food to that of pure water. The minimum a_w for multiplication varies with the microorganism (with bacteria being most sensitive) and is affected by other food conditions, such as temperature or pH. Fresh foods have an a_w above 0.98 and are very susceptible to spoilage and multiplication of enteropathogens. Most bacteria do not multiply at an a_w lower than 0.9, but some may grow in foods with an a_w as low as 0.75 (saturated NaCl). Values this low, however, are attainable only for dried foods, which can be stored for extended periods of time.

Drying is an effective preservation technique, although it is relatively inefficient and expensive because of the large quantities of heat required. Thermal efficiency increases with increasing drying temperature and dryer design improvements, but these enhancements require greater operator skill to minimize product damage. Solar drying has been suggested as a low-cost alternative, but it is not suited to drying pastes. Long drying times associated with solar drying can also lead to product deterioration as a result of bacterial growth before drying is complete.

Cereal paste drying is commonly done on the surface of hot drums or by spraying the paste into heated air. The resulting dry, precooked products form smooth gruels when they are reconstituted with water. Supplementation with non-fat dried milk or soy protein and vitamin-mineral mixtures improves the nutritional quality. Proper packaging is necessary to protect the product from insects and moisture, but it is costly bemuse of law product density.

Extrusion

Extruded products are formulated from mixtures of cereals, legumes, and oil seeds and are completely precooked for easy reconstitution and use. They can be fortified with vitamin and minerals (Harper and Jansen, 1985). The process has been used successfully to produce nutritious foods that have been distributed in dry packaged form through both commercial and governmental programs.

Extrusion heat processes dry food ingredients by friction between the food and a high-speed screw. Low-cost extruders, which process foods at moistures of less than 20 percent, have the lowest capital and operating costs and can produce fortified, packaged, stable food products for an additional cost of 30–50 percent of the cost of the raw ingredients.

Mechanical disruption of the cell walls and starch of plant products occurs during extrusion cooking, facilitating digestion and absorption. This mechanical breakdown of starches reduces the viscosity of gruels made from extruded cereals to enhance their caloric density. The high-temperature heat treatment effectively pasteurizes the product. Six-month storage requires packaging to provide resistance to moisture and insects.

Fermentation

A variety of fermentation processes have been used with cereals to increase digestibility, palatability, and shelf life. Some of these products have served as weaning foods (Steinkraus et al., 1983). These processes normally begin by soaking the whole grain for 24–72 hours. Wet grinding follows to remove some of the hull and gem. Fermentation at 30–50 percent moisture requires another 24–72 hours at approximately 30°C, using a mixed culture of acid-forming bacteria. Before consumption, water is added to give a 7–10 percent solids concentration, and the Mixture is brought to a boil to produce a gruel. These foods are most common in Africa, but similar processes are used in most countries.

Control of temperature, moisture, and type of inoculum alters the pH and flavor of the finished product. The final pH ranges between 3.4 and 3.8

because of the fermentation of sugars to lactic, acetic, and other short-chain acids. Since most bacteria grow best at about pH 7.0 and few grow at lower than pH 4, the lowered pH inhibits bacterial growth and extends the shelf life to approximately one day.

Fermentation produces a strong acidic flavor, increases protein digestibility, and relative nutritional value. Fermentation can also reduce cyanide toxicity in cassava and sorghum, trypsin inhibitors in soybeans, and the antinutritional character of phytate and tannins.

A significant disadvantage of the fermentation process is the lengthy preparation time required. Further, the products have a low caloric density and low protein quantity and quality. These deficiencies can be overcome by hydrolysis of the starch by enzymes from sprouted grains and the addition of vegetable protein sources such as lentils, legumes, or oil seeds before fermentation. Shelf-stable fermented products require drying, which significantly increases complexity and cost, but it adds to the convenience and the ability to expand distribution.

Other Fermentations

Yogurt and souring of milk are other examples of beneficial acidic fermentations which extend the shelf life and the utility of milk products as supplemental foods. Such fermentation also reduces the level of lactose in the finished product, when lactose intolerance is an important factor. Acidification of milk with lactic acid and lactobacilli was studied in The Gambia and was found to inhibit bacterial growth only to a slight degree, but *E. coli* counts in acidified or nonacidified milk samples reached similar high levels after 4–8 hours (Barrell and Rowland, 1980).

Fermenting soy with fungi produces a variety of traditional foods such as tofu, tempeh, and miso. Acidification of soybeans, either by fermentation or the addition of lactic acid, prevented growth of *B. cereus* in the production of tempeh and other fermented foods (Nout et al., 1987). These products have higher concentrations of protein but often use salt to control the microflora in the fermentation. This characteristic, however, diminishes the product's value as a supplemental food for rehabilitation of children with diarrhea.

Food Additives

Natural inhibitors of microbial growth, such as carbonyl, sulfur, or nitrogenous compounds; fatty acids; and other antimicrobial agents can be found in various foods. Their potential role as additives in controlling pathogens is poorly understood, and their potential toxic effects are unknown. No fully suitable food preservative is currently available.

In most cases it is preferable to rely on more than one factor to inhibit microbial growth, and often these combined factors have additive or even synergistic effects (Genigeorgis, 1981). It is possible that some combination of factors, for example, pH, the presence of sodium chloride or some other solute (affecting the a_w), and temperature may have an inhibiting effect for up to several hours. Except possibly for low-pH-fermented foods, it is unlikely that any combination of factors will permit prepared weaning foods to be held for longer periods of time, necessitating that primary consideration be given to dry foods that can be reconstituted before use or prepared fresh at each serving.

It has been suggested that supplementation of formula or milk with antibodies against a range of enteropathogens could provide protection against diarrheal illnesses to infants. It has been shown that infants fed a formula containing cow milk immunoglobulin A excreted intact bovine immunoglobulins in their stool, but there is only limited evidence that such an approach would be efficacious in protecting infants from enteric diseases (Brüssow et al., 1987; Ebina et al., 1985; Tacket et al., 1988). Furthermore, even if the approach is efficacious, it is unlikely to be a feasible intervention to prevent diarrhea among children in developing countries. At best the approach might be used to protect high-risk infants for a short period of time in some settings, such as during hospitalization. But even for this limited application to be feasible, certain production and processing problems must be solved.

Various bacterial organisms found in or added to food have been said to produce an intestinal microbial flora that protects the host against colonization with enteropathogens. These organisms, such as *Lactobacillus acidophilus, Lactobacillus bulgaricus*, and *Streptococcus faecium*, appear to survive passage through the stomach and remain in the upper small intestine for up to 6 hours (Clements et al., 1983). Although a protective effect has been found in some animal models, no preventive or therapeutic effect has been found in limited studies in humans.

Selection of Processing Location

Home and Village Preparation

With proper education and a variety of foods, mothers and/or caretakers can prepare nutritious supplemental foods at home or in a communal village setting (Valyasevi et al., 1984). Because the availability and cost of ingredients change with season and circumstance, nutritional knowledge is required to ensure proper formulation. Suggested food mixtures (Cameron and Hofvander, 1983) consist of cereal, legumes or lentils, animal protein, vegetables, sugar, and oil or fat in proportions to give a composition similar to that presented in Table 5-1. Vitamin supplementation normally depends on the addition of green or leafy vegetables and fruit since vitamin supplements are not common in developing countries.

The use of local foods and ingredients reduces food costs and increases familiarity and acceptability. Major deterrents to this approach are the time required and the need for a separate cooking utensil to prepare a special food for a single child. This can be overcome by using village-level preparation of larger batches of food by mothers who share the food preparation responsibilities. The home and village preparation of foods containing legumes and lentils increases protein content, increases the cooking time, and requires the use of expensive and/or scarce cooking fuel (Harper and Tribelhorn, 1985).

Central Processing

Low-cost, shelf-stable supplementary foods made in factories and then distributed to the village appear to have their greatest utility in situations in which low-income families live in urban areas or the mother or caregiver is working. Hofvander and Underwood (1987) have described other circumstances in which the availability of centrally processed foods has particular value, for example, during failure of lactation in the mother, when catastrophe decreases food supplies, or when political upheaval dislocates families. Centrally processed foods have utility when convenience and time savings become critical to their use.

A variety of central processing techniques have been used to produce nutritious food blends for weaning and supplementation (Harper and Jansen, 1985). Some of the processes are oriented toward the intermediate scale (500–1,000 kg/hour) and require lower skill levels and little imported processing equipment or technology. Other processes are adaptations of procedures used in developed countries to produce precooked cereals; they typically operate at capacities of several tons per hour and use imported equipment and technology. All are capable of producing a fully cooked, convenient, nutritious, and hygienic food product.

TABLE 5-1 Proposed Composition for Supplementary Foods

	Amounts per 100 Grams	Amounts per 100 kcal
Protein[1] (g)	20	5.2
Fat (g)	10	2.6
Crude fiber[2] (g)	5	1.3
Acid-insoluble ash (g)	0.05	—
Vitamin content[3]		
Vitamin A, as retinol (µg)	400	100
Vitamin D (cholecalciferol) (µg)	10	2.5
Vitamin E (-tocopherol) (µg)	5	1.25
Ascorbic acid (µg)	20	0.52
Thiamine (µg)	500	125
Riboflavin (µg)	800	200
Niacin (mg)	9	2.20
Vitamin B_6 (µg)	900	220
Folic acid (µg)	100	27
Vitamin B_{12} (µg)	2	0.52
Mineral content		
Calcium (mg)	800	200
Phosphorus (mg)	800	200
Iron (mg)	10	2.7
Iodine (µg)	70	18

[1] Protein with a Score of 65 and PER 2.2 (Casein: 2.5).
[2] Crude fiber higher than this may be acceptable, although it would require clinical testing.
[3] The values for vitamins and minerals are considered minimal except in the case of vitamin D, where no further increase is desirable. The excess of each vitamin added during processing should be no greater than that needed to maintain label requirements ova the expected shelf life of the product.
SOURCE: Food and Agriculture Organization/World Health Organization. 1982. Codex standard for foods for special dietary uses including foods for infants and children and related Code of Hygienic Practice, 1st ed. Codex Alimentarius 9:(I) Rome, Italy.

The costs of centrally processed foods vary with the types of processes and products, scale of processing operation, and the fraction of the production capacity used. The lowest cost processes are roasting and low-cost extrusion, which add processing and packaging costs equivalent to about 30–50 percent of the cost of the raw ingredients. Intermediate cost processes include baking and high-moisture extrusion and add 50–100 percent of the cost of the raw ingredients. The highest cost processes are those that use high moisture cooking or fermentation and that require redrying. These processes may add 100–300 percent of the cost of the raw ingredient costs to the finished product.

Centrally processed foods should be analyzed to ensure that they are free of pathogenic microorganisms, toxins, or other deleterious materials and that they meet nutritional guidelines such as those described by the Food and Agriculture Organization of the World Health Organization of the United Nations (FAO/WHO, 1982).

COMPARISON OF STRATEGIES FOR SUPPLYING SUPPLEMENTAL FOODS

Table 5-2 summarizes the reasons why both home and village and central processing are used to prepare weaning and supplementary foods (Valyasevi et al., 1984). The biggest advantage for village-prepared foods is cost and familiarity, whereas centrally processed foods are more easily prepared and have greater nutrient density.

Precooked, centrally processed food is prepared by adding potable water, reducing the demand on cooking utensils and fuel, and meets the nutritional requirements of the child if it is fed to the child in proper amounts. Further, central processing techniques can increase the caloric density and facilitate fortification. Centrally processed foods often incorporate low-cost protein and fat-rich ingredients, such as dehulled whole soybeans, which are not commonly used in home or village preparations because of the lack of availability or difficulty in their preparation and use.

Centrally processed supplementary foods have a higher cost. Costs range between US$0.50 and US$2.50/kg of dry food in a package. The proportion of cost associated with processing, packaging, and distribution varies between products and systems used, but increases the cost of the raw ingredients by 30 percent or more. Individual circumstances determine whether the nutritional value and convenience of the product justify the price since any increase can reduce the availability of the product to the poorest mother or caregiver or reduce the unsustainability of government distribution program.

The shelf lives of centrally processed products are normally in excess of 6 months, with packaging protecting dry products from insects and moisture. Once opened, the products are vulnerable to deterioration. Assuming 50 g or more is fed per day, a 500-g package will be open for a maximum of 10 days, which minimizes such problems. Bacterial deterioration occurs if dry products become moistened.

TABLE 5-2 A Comparison of Techniques Used to Prepare Nutritious Foods for Weaning and Supplementation

Home-or Village-Prepared Foods	Centrally Processed Precooked Foods
Advantages:	
• Lower cost by minimizing packaging and distribution • Cooking reduces risks associated with contamination • Traditional and familiar	• Easy preparation • Higher nutrient density and improved digestibility • Increased shelf life • Formulated and fortified to meet nutritional requirements • Accommodates nontraditional ingredient, thereby expanding food supply
Disadvantages:	
• More preparation time and effort • Requires special knowledge to formulate adequate food • Needs more fuel for cooking and a separate cooking utensil • Generally not fortified with vitamins and minerals	• Increased cost associated with packaging and distribution • Less familiarity • Sharing if taken home

SUMMARY

Appropriately constituted weaning foods are necessary for infants to maintain normal growth when the quantity of breast milk becomes insufficient. Similar calorie-dense and nutritious foods can also be used to rehabilitate children after bouts of diarrhea and improve their nutritional status to better resist future exposure to diarrhea-causing agents.

A number of food processes exist that can make suitable weaning foods. They vary in their ability to produce a completely satisfactory food product from the perspective of caloric density, nutritional composition, and storage stability. Fermentation, germination, and milling can be used to provide weaning foods with improved attributes. Processes such as roasting and extrusion that require little moisture are the lowest-cost small-scale industrial technologies, but they are not readily available to home application. Central processing of weaning foods increases their cost but improves their quality and convenience. Home preparation is time-consuming but increases familiarity and lowers the cost.

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6

Conclusions and Recommendations

The rapid rates of growth and development of infants and young children require that feeding practices be continuously adjusted. Feeding regimens that are appropriate for the 3-month old are inadequate when the infant is 6 to 8 months of age, and practices suitable at those ages are unsatisfactory at later stages of infancy. Data that assess this process have led to the following conclusions and recommendations.

CONCLUSIONS

- Undernutrition, as assessed by anthropometric criteria, predisposes infants and children to diarrhea and to its duration and severity.
- Sociocultural determinants of feeding practices must be incorporated in the design of interventions targeted at improving nutritional status and risk of enteric disease.
- Exclusive breastfeeding for as long as practical and as long as an infant's normal growth is maintained minimizes a child's risk of enteric disease.
- Maternal nutritional status appears to affect milk volume; its impact on milk quality is more variable and less understood.
- The continuation of breastfeeding after the introduction of complementary/supplementary foods provides partial protection to the infant against enteric disease.
- Enteric pathogens are transmitted by the fecal-oral route, and foods ingested by children are major vehicles of this transmission.
- Utensils used for food preparation, storage, and feeding are common sources of bacterial contamination. Weaning foods given to young children are common routes of transmission for some bacterial

enteropathogens. Furthermore, initial fecal contamination of foods, poor hygiene practices in food preparation, and poor food storage practices contribute to food contamination.

- Unacceptably low nutrient densities often limit the appropriateness of traditional weaning or supplementary foods.
- Specific hygienic behaviors related to feeding practices, eg., handwashing, reduce the incidence of diarrhea in people in developing countries, and additional interventions to reduce food contamination should be evaluated.
- Multiple rather than single approaches (eg., adjustment of pH, high solute concentrations, and reduced water content) are more reliable for the inhibition of bacterial growth in foods.
- Evaluations of food processing options must consider food preferences, availability of raw ingredients, capital and labor requirements cost, local child feeding practices, and the sociocultural acceptance of foods produced.

RECOMMENDED INTERVENTIONS

Nutritional interventions intended to reduce diarrheal disease in children have three principal objectives: (1) enhancement of the child's nutritional status, (2) reduction of the risk of infection, and (3) reduction in mortality and severity of morbidity following infection.

Interventions to meet these objectives should be targeted at (1) support of the initiation and continuation of exclusive breastfeeding for at lent 4 to 6 months postpartum and partial breastfeeding for at least 1 year and (2) improvements in the preparation and use of appropriate weaning foods.

Factors that discourage mothers from breastfeeding should be countered by educating mothers, nurses, physicians, and other health care providers and business and other community leaders. We must stress (1) the value of breastfeeding to infant health, (2) improve our knowledge of infant feeding practices among diverse communities and the consequences of local practices to infant health, (3) create environments and policies that encourage breastfeeding among mothers who work outside the home, (4) ensure the availability of sufficient and appropriate food for nursing mothers, and (5) ensure the appropriate use of nonhuman milk products when they are medically indicated.

Efforts should be directed toward the reduction of bacterial contamination of home-prepared and commercially prepared foods fed to children and toward the improvement of the nutrient content, bioavailability, and caloric density of supplementary and weaning foods with reduced preparation time and fuel consumption. Maternal education programs that emphasize appropriate practices of food handling are indicated. Such programs must be developed and implemented within a well understood cultural context to minimize barriers to change and to maximize effectiveness within communities. Such programs should improve household hygienic and food preparation practices, eg., handwashing and water use; use of proper storage conditions for prepared food; use and cleaning of utensils for feeding and food preparation; identification of cultural concepts of infant foods; enhancement of the preparation and use of nutritionally and culturally appropriate foods; and when indicated, improvement of food storage habits, food preparation techniques, fuel use, and family food consumption patterns.

Programs are needed to adapt food processing techniques to local needs. These efforts should lead to culturally appropriate foods with high caloric densities and nutrient bioavailabilities; the foods should require small amounts of fuel and short times for their preparation, and they should be within the economic reach of targeted populations.

RESEARCH RECOMMENDATIONS

The focus on nutritional strategies to reduce the risk of diarrhea and to minimize its severity and duration moves pediatric health objectives beyond child survival. The following research recommendations are made with that general objective as their goal.

Behavioral Modification

Research programs are needed to develop improved implementation schemes for the interventions recommended in this report. Methods for effecting behavioral changes in specific cultural contexts are of particular importance because many recommended interventions target specific behaviors.

Transmission of Enteropathogens

Studies of the roles of hygienic practices, household resources, and food storage and preparation techniques in the transmission of enteropathogens should be emphasized.

Enhancement of Breastfeeding and Weaning Practices

Understanding of infant feeding practices and factors that shape them remains limited. Of particular importance is an improved understanding of factors that lead to the introduction of foods other than human milk. Similarly, limitations in the understanding of human lactation physiology restrict the design of effective interventions. For example, there is limited information that identifies how the content of protective factors in milk may be enhanced; there is also limited information about the nutritional factors that limit the duration of effective lactation.

Relationship Between Nutritional Status and Diarrheal Disease

Additional studies are needed to evaluate the influence of infant supplementary feeding programs on morbidity and mortality as a result of diarrhea. Because malnutrition's impact on the incidence and severity of diarrhea may differ among diarrheas with diverse etiologies, study subjects should be grouped by diarrheal etiology. Studies should be designed to discriminate between malnutrition as a contributing cause of diarrhea and malnutrition as a result of diarrheal disease in specific ecologic settings.

Timing of Supplementary Food Introduction

Studies are needed to correlate supplementary food intake to functional outcomes. The usefulness of anthropometric criteria as a proxy for functional capacities is not clear unless frank growth failure is present. Results of such studies are expected to help identify the optimal duration of exclusive breastfeeding and the optimal timing for the introduction of other foods.

Nutrient Bioavailability and Caloric Density

Studies are needed that examine physiologic parameters and the properties of foods that influence nutrient bioavailability and caloric density. The results of such studies should help identify improved formulations of foods and appropriate processing techniques for their production.

Improved Food Processing Technologies

Studies and demonstrations are needed that examine alternative small and moderate scale food processes which will expand the utility of foods, increase storage stability, improve caloric density, reduce preparation time and minimize fuel use for cooking and hygiene purposes.

PART II

DIET AND ACTIVITY DURING PREGNANCY AND LACTATION

1

Summary

To obtain a comprehensive view of the impact of women's diet and physical activities on pregnancy outcome, lactation, and health, the Subcommittee on Diet, Physical Activity, and Pregnancy Outcome of the Committee on International Nutrition Programs examined the available data on the patterns of physical activity of women in developing countries and the variations that occur during pregnancy and lactation. The goals were to provide descriptive information as a basis for the interpretation of other data and to determine the extent to which women in the developing world are known to reduce or otherwise alter their activities and diets as a result of childbearing.

Although the interest in this subject arose from the desire to address the problems of women whose work requires them to perform heavy physical labor during pregnancy, the committee defined its task in terms of women's physical activities, rather than work, for several reasons. In developing countries, women's occupational roles are often multiple and difficult to define. Women may spend substantial amounts of time in agricultural work; however, if this is not paid labor or cash cropping, it may not be defined as work or employment. In addition, routine household tasks, such as pounding and grinding grain, carrying water, or washing clothes by hand, which are often not defined as work in employment studies, may be very strenuous physically and may require a prolonged energy expenditure. For this reason, the subcommittee was charged to focus on the physical activity encompassed in all of these activities. Psychological stress is highly relevant to women in poor circumstances in developing countries, and although its effects were considered important, they were judged to be beyond the scope of this review.

The subcommittee included several kinds of data in its review. Studies that have focused on women's employment rather than physical activity *per se* were reviewed, and their relevance to the subcommittee's task was assessed. then, to have a broad perspective, reports of energy expenditure research were examined for pregnant and nonpregnant women in developing countries, and to the extent that data were available, consideration was given to the type and duration of physical activity performed. Information on the dietary, metabolic, physiological, and endocrine adaptations to pregnancy in well-nourished women was also reviewed as they pertain to energy expenditure and physical activity.

Most of the data on maternal work and employment were from developed countries. there are some problems in extrapolating these data to developing countries as the kinds of work that are most taxing would be most relevant and would differ from that in developed countries. Data on the impact of physical activity on cardiovascular and placental function were examined to determine their significance for the mother, the fetus, and the newborn infant. Animal studies and epidemiological research pertaining to gestational duration, fetal growth, fetal loss, and congenital malformations were also included. The subcommittee also reviewed the available data on the impact of physical activity on lactation as an outcome of pregnancy and on maternal postpregnancy nutritional status.

In general, the subcommittee concluded that field-based studies are needed to quantify the intensity, frequency, and effort of physical activity under natural conditions during pregnancy. These studies should include changes that occur during the course of pregnancy, including their effect on different outcome measures such as maternal and infant morbidity and mortality. Presently, very few studies on humans or even animals shed any light on this topic.

Many women in developing countries are chronically malnourished, as demonstrated by stunting, low weight-for-height, and low fat stores. They are also more likely to have iron deficiency anemia. In part because of increases in maternal weight during pregnancy, the energy cost of weight-bearing tasks also increases. These findings are highlighted throughout the report. It is intriguing to find that pregnant women in developing countries seem to achieve energy balance despite limited diets and high levels of physical exertion. It is not known if this is due to some adaptive mechanism or to measurement error.

Socioeconomic status, women's employment in rural and urban environments, consequent physical activity, and its effect on the outcome of pregnancy are reviewed in Chapter 2. It is pointed out that both pregnant and nonpregnant women in developing countries perform physical work for prolonged periods of time under unfavorable environmental conditions.

The physiology of pregnancy and nutritional status is reviewed in Chapter 3. Some of the existing human data indicate that mild physical activity does not adversely influence the outcome of pregnancy in well-nourished populations. However, animal studies employing a combination of severe and acute exercise and severe undernutrition, reviewed in Chapter 3, have shown that these result in a decrease in uterine blood flow and could result in fetal compromise. It should be noted, however, that the results from animal models cannot always be extrapolated to humans. Many of these studies were performed on sheep, and quadrupeds have less of a problem returning blood from the limbs to the heart, and placenta transfer is often different.

In Chapter 4, the subcommittee reviews the data on physical activity, productivity, and physical work capacity and how they affect gestation and the outcome of pregnancy. The subcommittee also looks at the effect of chronic and acute maternal undernutrition on the metabolic adaptations to pregnancy and, consequently, its outcome.

As discussed in Chapter 5, the subcommittee concludes that low energy intake during pregnancy has detrimental effects on fetal growth and possible negative effects on gestational duration. The detrimental effects of decreased energy intake on fetal growth are exacerbated in women with poor prepregnancy nutritional status.

Available epidemiological data as described in Chapter 5 do not permit firm conclusions about the effects of physical activity on the duration of gestation. The evidence (from developed countries) regarding strenuous exercise and prolonged mild exertion suggests a possible deleterious effect on gestational duration. Although a negative impact on fetal growth is less well documented, some evidence suggests that it may be greater in undernourished women.

In Chapter 6, the impact of physical activity and diet on lactation is reviewed. The influences of physical activity and fat storage are reviewed as functional aspects of energy stores. Some field studies of lactation performance are described.

There are few epidemiological data on the level and type of interaction (i.e., simply additive or synergistic) of physical activity and nutrition as they affect pregnancy and its outcome. Women in the developing world, including those who are pregnant and lactating, are frequently engaged in moderate to high levels of physical activity that are not offset by increases in energy intake. This imbalance appears to be reflected by low weight gain during pregnancy, impairment of intrauterine growth, and decreased ability to sustain milk production. Further studies are needed to more fully clarify this relationship. These and other conclusions and recommendations are summarized in Chapter 7.

Gestational weight gain represents a balance between nutrient intake and energy expenditure. Supplementation programs seem to be most effective in poorly nourished women; however, research should focus on what groups may most benefit from supplementation programs or a reduction in physical activity. The epidemiological evidence is very strong that fetal growth increases with increasing gestational weight gain.

Physical activity, particularly heavy work, appears to exacerbate the adverse effects of poor nutritional status on lactation. the subcommittee knows of no information on how various physiological adjustments to physical activity influence lactation performance. It is recommended that studies should be undertaken to examine the effects on lactation as measured by milk volume, composition, feeding frequencies, and infant growth.

Since there are so few data available addressing women's postpartum health and nutrition, the conclusions of the subcommittee are based almost exclusively on complications and immediate outcomes of pregnancy. The subcommittee recommends that future studies include outcome variables related to women together with those related to infants.

Additional studies should also be carried out to explore the possible association between malnutrition and physical activity during pregnancy with complications of delivery. These complications may include the outcome of Caesarean section, maternal mortality, and congenital anomalies.

Implementation of health care services geared toward women's health, including prepregnancy and pregnancy nutritional status and health care, would also be helpful. These services should be able to monitor women who have had complicated pregnancies and deliveries, particularly those who have previously given birth to low-birthweight infants. These services should also support breastfeeding, while considering both the infant's growth and the mother's nutritional status. Current evidence suggests that programs to reduce physical activity would also be most effective in this group; however, more research needs to be done in this area. Many other of the most obviously needed measures fall outside the realm of this report. Some of these are increased access to education (both formal and informal), support for child care (especially for women who are heads of households), improved opportunities for employment, access to technology that saves time and heavy physical activity, and more legislation to protect pregnant women from strenuous physical activity.

2

Overview of the Socioeconomic and Health Status of Women in Developing Countries

To provide the reader with a fuller understanding of the forces that women in developing countries are subject to during prepregnancy, pregnancy, and lactation, the subcommittee judged it useful to present a summary of the socioeconomic and health conditions of women living in developing countries. This chapter is not a detailed sociological review, but it highlights those areas that affect women most during those times.

ECONOMIC SITUATION AND FOOD AND NUTRITION IN DEVELOPING COUNTRIES

While developed nations managed to recover from the 1981–1982 world recession, with the exception of East and Southeast Asian countries, most developing countries have continued to experience a decrease in their per capita gross domestic product (GDP). At the end of 1984, average per capita GDP in Latin America and the Caribbean was as low as the 1976 level; in Africa, per capita GDP experienced a decline of more than 3 percent per year in the 1981–1983 period. Because of the increase in interest rates around the world, the cost of repaying past debts has increased, becoming a heavy burden on the balance of payments and impairing a reallocation of the scarcer resources. This, in turn, has led many countries to diminish their real per capita expenditures in the social sectors. By 1985, austerity measures were being implemented in half of the developing countries; and the effects of these measures, combined with those of a lower GDP, included a serious deterioration of already low living standards for large sectors of the population. The situation in many of these countries has been compared with the Great Depression of the 1930s (UNICEF, 1987; 1988; WHO, 1987).

By 1980, a number of countries were producing less food per capita then was produced in the mid-1970s. Since then, per capita energy availability has been increasing in Latin America, the Middle East, North Africa, and East Asia; it has been decreasing in Sub-Saharan Africa and in Southern Asia. In many developing countries, an increasing proportion of the population is falling below the level of poverty. This has serious implications for food consumption levels and nutritional status. By 1985, starvation affected large portions of the population in Africa, and hunger was still prevalent in Asian and Latin American countries (WHO, 1987). Depending on the indicators and cutoff points used, estimates of the malnourished population vary considerably. It is likely that by 1985, at least 430 million of the world's people suffered from malnutrition, and by 1987, severe malnutrition had become very prevalent in Sub-Saharan Africa (WHO, 1987).

STATUS OF WOMEN: HEALTH AND SOCIAL ISSUES

It is estimated that 25 to 35 percent of households in the developing world are headed *de facto* by women because of divorce, separation, desertion, or long-term migration of husbands or because women had children out of wedlock (Tinker, 1979a). These women, who are the poorest in every country, typically are responsible for earning income to support their families.

By the end of the 1976–1985 "Decade for Women," the conditions for the majority of women in developing countries had changed only marginally. Despite the fact that women work nearly two-thirds of the total hours worked, they constitute only one-third of the world's official labor force, receive only one-tenth of the world's income, and own less than 1 percent of its property (WHO, 1985a). However, some of the conditions for the advancement of women are being met in some developing countries. Although wide regional variations still exist among countries, access of young females to education is improving, as is their access to health care services, including family planning (WHO, 1987).

Literacy

While the proportion of adult literacy increased in the 1970–1980 period from 52 to 60 percent due to population growth, the absolute number of illiterates increased from 731 million to 800 million. The mentioned increase in the adult literacy rate has taken place without altering the gender gap that favors the male's literacy rate over the female's. While in 1970, 60 percent of males and 43 percent of females aged 15 and over were literate, by 1980 this proportions had risen to 68 and 51 percent, respectively, keeping the same 17 percentage points of difference.

As a consequence, almost two-thirds of illiterate adults in developing countries are women. According to 1980 estimates, the general level of adult illiteracy was 60 percent in Africa, 40 percent in Asia and the Pacific, and 20 percent in Latin America (WHO, 1987).

Fertility

The total fertility rate, as estimated for the 1975–1980 and 1980 –1985 periods, is following a downward trend worldwide, being 3.9 and 3.5 respectively (live births/women) (WHO, 1987).

Except for African countries, where total fertility rates are the highest in the world and have kept stable at 6.6 for the periods mentioned, the total fertility rate in all other regions is lower and falling, albeit at a faster rate in Southeast Asia and the western Pacific than in the Americas and the eastern Mediterranean countries (Table 2-1).

TABLE 2-1 Total Fertility Rates by WHO Region, 1975-1985

	Africa	Americas	South-East Asia	Europe	Eastern Mediterranean	Western Pacific	World
1975-1980	6.6	3.4	5.1	2.4	6.3	3.2	3.9
1980-1985	6.6	3.2	4.5	2.3	6.0	2.5	3.5

Based on: United Nations, World population prospects: Estimates and projections as assessed in 1982. New York, 1985.
SOURCE: WHO, 1987.

ACCESS TO HEALTH CARE

Family Planning

It has been estimated that 45 percent of married women of reproductive age worldwide used a contraceptive method in 1980–1981. However, when the People's Republic of China was excluded, this proportion fell to 38 percent. This proportion varied from very low levels in Africa (11 percent) to low levels in South Asia (24 percent), intermediate levels in Latin

America (43 percent), and rather high levels in East Asia (69 percent) (WHO, 1987). Even though most countries provide some form of public support for family planning programs, generally within the maternal and child health care programs, reduced geographical and economic access to family planning services is a limiting factor for millions of couples who do not desire additional children, but who are not using any effective method of family planning (WHO, 1987).

Infant and Child Mortality

During 1975–1985, the infant mortality rate decreased in approximately 150 countries. However, in more than 25 percent of the world's countries, which represent 29 percent of the world's population, infant mortality rates still are higher than 100 per 1,000 live births (Table 2-2).

TABLE 2-2 Infant Mortality Rate per 1,000 Live Births, by WHO Region, 1975-1985

Mortality Rate (per 1,000 live births)	Number of Countries						
	Africa	Americas	South-East Asia	Europe	Eastern Mediter-ranean	Western Pacific	Total
Below 50	2	24	4	30	7	13	80
50.0-99.9	9	7	3	2	8	3	32
100 and more	32	3	4	—	7	1	47
Subtotal	43	34	11	32	22	17	159
No information	1	—	—	3	—	3	7
Total	44	34	11	35	22	20	166

SOURCE: WHO, 1987.

However, this downward trend has slowed or even reversed as a consequence of economic deterioration (UNICEF, 1987).

The principal causes of neonatal mortality in the world are related to the perinatal period. For example, in a study by Haas et al. (1987), they showed that proportionally growth-retarded infants had nearly twice the mortality rate of full-term, appropriate-weight infants, and disproportionally growth-retarded infants had 2.9–5.7 times the mortality rate. Infants delivered before 37 weeks of gestation had 23–100 times the mortality rate of full-term infants born at normal weight. Postnatal mortality in developing countries is due mainly to malnutrition and infection in children under 5 years of age, particularly respiratory and diarrheal diseases. Nutritional deficiency is the associated cause in 61.9 percent of the deaths from infectious diseases (Puffer and Serrano, 1973).

Mortality rates are lower for female children Compared with those for males. The female advantage is accentuated more during fetal life, infancy, and childhood. However, cultural values and lifestyles can cancel or even reverse this natural advantage. For example, feeding practices favor male children over female children. This discrimination occurs more frequently in societies in which the status of women is low.

Maternal Mortality

In the majority of developing countries, most deaths among women of reproductive age are due to maternal mortality. However, the rate is still considerably underestimated due to a failure to record both deaths and cause of death. It has been estimated that 500,000 women die each year from pregnancy-related causes. The maternal mortality rate in various African countries may be as high as 550 times that in some European countries. By 1985, only 75 of the 117 developing countries that were WHO member states were able to provide information on maternal mortality (WHO, 1987).

In developing countries, the main causes of maternal deaths are hemorrhage (often with anemia as an underlying cause) and sepsis. In some Latin American countries, up to 50 percent of maternal mortality is due to illegal abortion (WHO, 1987).

Nutritional Anemia

While nutritional anemia affects members of both sexes and people in all age groups, the problem is more prevalent among women and contributes to maternal morbidity and mortality, as well as to low birth weight. Table 2-3 gives rates of nutritional anemia for pregnant women from selected developing countries. It has been estimated that nutritional anemia affects almost two-thirds of the pregnant and 50 percent of the nonpregnant women in developing countries. The estimated prevalence of nutritional anemia among pregnant women in South Asia is over 65 percent, while in Latin America it is 30 percent, in Oceania it is 25 percent, and in Europe it is 14 percent (WHO, 1987).

TABLE 2-3 Prevalence of Anemia During Pregnancy

Country	Prevalence[a] (%)	Reference
India	62	Khanna, 1977
Togo	47	USAID, 1977
Tunisia	38	Kallal, 1978
Chile	32	Foradori, 1976
Latin America	22	Cook et al., 1971
Sao Paulo, Brazil Medellin, Colombia Guatemala City, Guatemala Mexico city, Mexico Caracas, Venezuela		

[a] Percent anemic: hemoglobin concentrations of <11 mg/100 ml.
SOURCE: WHO, 1987.

Low Birth Weight—Health and Nutritional Status of the Mother

Since birth weight is substantially determined by the health and nutritional status of the mother, the prevalence of low birth weight reflects the health and social status of women and of the communities into which children are born (WHO, 1987). The birth weight of the infant is perhaps the single most important predictor of survival and is also a strong predictor of growth and development.

Unfortunately, most of the studies on which the figures in Table 2-4 are based do not distinguish between prematurity (gestational age of fewer than 37 weeks) and intrauterine growth retardation. In most developing countries, the majority of infants are born at home or in other locations outside of hospitals. Women are often unsure of the date of their last menstrual period, and investigators are generally content to collect accurate birthweight measurements for defined populations. Villar and Belizan (1982), however, have analyzed data from 11 different regions in the developed world and 25 areas in developing countries. In developing countries, they found that most low birth weight appears to be due to intrauterine growth retardation, whereas in developed countries (especially those with the lowest rates of low birth weight), most is due to prematurity. The relative rates of intrauterine growth retardation in developing countries compared with those of developed countries (6.6-fold higher) are far greater than the relative rates of prematurity (2.0-fold higher).

Breastfeeding

According to a review and analysis of 200 studies on breastfeeding and its duration, carried out in 86 countries, the patterns of incidence, duration, and suckling frequency vary widely between and within regions, as well as between rural and urban populations and between social classes (WHO, 1987).

Most infants born in rural African areas are breastfed for a period of I to 2 years, while in urban areas, fewer children are breastfed. In most of South Asia, breastfeeding is the norm, with an average duration of 6 months in urban areas and of 1 to 2 years in rural areas. In East Asia, 80 percent to 95 percent of infants in rural areas are breastfed, as are 80 percent of infants in urban areas; however, in urban areas, supplementary feeding starts at about 3 months and breastfeeding duration is shorter. In Latin America, a higher proportion of newborns are breastfed than in South or East Asia or Africa, but the average duration varies widely. Duration is longer in rural areas, especially in Central America and the Caribbean, but it is still shorter than in Africa and Asia; in urban areas the pattern is one of early supplementary feeding and subsequent weaning (WHO, 1987).

PHYSICAL ACTIVITIES OF PREGNANT WOMEN IN DEVELOPING COUNTRIES

In developing countries, women's roles include both income-producing and household-production activities. Income-producing activities are often essential for the household to function, especially among poor women, whose contribution to the family income is particularly important. In addition to labor force participation, women are responsible for maintaining the household, which includes child rearing, food processing and preparation, and fuel and water gathering. Because of the lack of adequate transportation, running water, and easy access to fuel or electricity, these basic activities often require that heavy burdens be carried for long distances daily. Rather than purchasing preprocessed food at a high cost or paying others to supply water and fuel, women provide the labor. Thus, household-production roles often result in income savings for the family.

In developing countries, women are traditionally undercounted in estimates of labor force participation, in part because of the definitions used to describe labor force participants. The international guidelines are adopted from categories that are appropriate only to the developed world. For example, activities in nonformal employment sectors such as street vending or producing foods in the home are not included in definitions of labor force participation, yet they very often contribute enough income or lower household expenses sufficiently to ensure the family's survival. According to international guidelines, farm wives in industrial nations are often assumed not to be working, yet in developing countries, they may work on agricultural activities as much as or more than their husbands (Tinker, 1979b).

TABLE 2-4 Mean Birth Weight and Low Birth Weight Prevalence, by Country

Region and Country	Mean Birth Weight (g)	Low Birth Weight (%)
North America		
United States	3,299	6.9
Canada	3,327	6.0
Europe		
Norway	3,500	3.8
Sweden	3,490	4.0
United Kingdom	3,310	7.9
France	3,240–3,335	5.6
West Germany	3,356	5.5
Italy	3,445	4.2
Czechoslovakia	3,327	6.2
Hungary	3,144–3,162	11.8
Latin America		
Guatemala	3,050	17.9
Mexico	3,019–3,025	11.7
Brazil	3,170–3,298	9.0
Chile	3,340	9.0
Colombia	2,912–3,115	10.0
Africa		
Tunisia	3,210–3,376	7.3
Egypt	3,200–3,240	7.0
Nigeria	2,800–3,117	18.0
Kenya	3,143	12.8
Tanzania	2,900–3,151	14.4
Zaire	3,163	15.9
Asia		
Iraq	3,540	6.1
Iran	3,012–3,250	14.0
India	2,493–2,970	30.0
Pakistan	2,770	27.0
Malaysia	3,027–3,065	10.6
Indonesia	2,760–3,027	14.0
Japan	3,200–3,208	5.2
China (People's Republic)	3,215–3,285	6.0

SOURCE: WHO, 1980a, 1984a.

Bearing in mind, therefore, that official figures are likely to be underestimates, the economically active female labor force participation can be examined for different parts of the developing world. Africa (except for Muslim countries) has the highest proportion of women in the active labor force, with up to 47 percent of women in Botswana and 32 percent in Nigeria reported to be active. In Asia, with the exception of the People's Republic of China, female labor force participation is also high; for example, 27 percent of women in India are recorded as being economically active. Caribbean countries with populations that are primarily of African descent, such as Jamaica and Haiti, have female labor force participation rates of 46 and 26 percent, respectively, while Central America (10 percent) and South America (13–18 percent) have lower rates. The Arab states have the lowest rates, with 2–5 percent of women counted as being economically active (UNDP, 1980). A major reason for these different rates is development programs, the extent that women participate in agricultural labor. Table 2-5 gives the estimated percentage of women in the agricultural labor force in different parts of the world.

TABLE 2-5 Women as Percentage of Agricultural Labor Force and Percentage of Population That Is Urban

		Women in Agricultural Labor	
Region	No. of Countries	Force[a] (%)	Urban Population[b] (%)
Sub-Saharan Africa	40	46	18–53
North Africa, Middle East	16	31	42
South, Southeast Asia	19	45	26–28
Central, South America	19	18	63–84
Caribbean	07	40	56

[a] Dixon, 1982.

[b] UNFPA Assistance and Population Data Sheet, 1986.

In addition to these activities, women also bear the children. In developing countries, fertility rates are high, and a woman who is either breastfeeding or pregnant, or both, is not uncommon. Although the importance of their income production or savings activities to family survival is great, pregnancy does change to some extent the amount and type of physical activities in which women are involved.

Jimenez and Newton (1979) have examined cultural practices related to work and pregnancy using data from the Human Relations Area Files, a reference source of anthropological studies. Among the 122 societies studied, 45 percent expected a woman to continue with full duties until the onset of labor. In fewer than 5 percent of the societies, pregnant women are expected to perform light duties only, but most Societies expected partial or full duties to continue for most if not all of the 9 months of pregnancy.

Patterns of Energy Expenditure and Intake and Low Birth Weight

In developing countries, patterns of energy expenditure during pregnancy are of particular concern since women generally consume diets lower in energy and have lower prepregnant weights than women in developed countries. Weight gains during pregnancy are also lower. The prevalence of chronic malnutrition is reflected in the high prevalence of low-birthweight infants. Low birth weight may also be due as much or more to the effects of work in a hot environment directing blood away from the uterus. (For a summary of mean birth weights and low birthweight rates both in developed and developing countries, see Table 2-4). Energy intakes are at least 500 calories less among women in developing countries compared with those seen among women in developed countries (Tables 2-6a and 2-6b). However, caution must be exercised when interpreting intake data from community-based surveys and studies.

Few studies have specifically examined the activity patterns of pregnant women in developing countries. Of those that have examined variations in activities by pregnancy status, most have shown that pregnant women perform the same types of activities as nonpregnant women. However, they generally also show that during the last trimester, and particularly during the last month, women try to reduce the amount of time spent in the most strenuous activities.

In a year-long study of work output and pregnancy in a Javanese village, frequent and repeated time-use studies of 44 households examined the evolution of individual pregnancies and revealed that the work patterns and income-generating activities of women were only minimally disrupted by pregnancy (White, 1984).

Among women studied in Papua New Guinea (Greenfield and Clark, 1975), as reported by Durnin (1976; 1980), energy expenditures were measured among pregnant, lactating, and nonpregnant women by using 24-hour diaries of activities and the oxygen consumption for typical activities. It was found that the energy expenditures decreased in the last 3 months of pregnancy, when women walked less, worked in their gardens for shorter periods of time, and spent more time sitting.

Similar results have been reported by Roberts et al. (1982) in The Gambia. Also using 24-hour diaries, they noted that the total active time spent by women declined during pregnancy, especially during the last trimester. During the last month of pregnancy, women lowered their activity level to 75 percent of that of nonpregnant women by reducing the amount of housework and nonessential activities, such as those done for leisure. The stage of pregnancy, however, did not affect the time women spent at working on their farms. Even in the month before delivery, they continued to spend as much time there as the nonpregnant, nonlactating women in the study. During the farming season, women did not reduce the amount of time spent farming, but they did reduce the amount of strenuous farming-related activity.

A recent study in India used a 24-hour recall of rural southern Indian women's activities during pregnancy and lactation (McNeill and Payne, 1985). Pregnant women spent less time working in the fields compared with nonpregnant, nonlactating women (51 and 161 minutes/day, respectively) and more time in personal activities, mainly resting (969 and 678 minutes/day, respectively).

Except for the studies indicated above, data are limited on the activity patterns specific to pregnancy, but because women in developing countries seem to vary little the types of activities they perform while they are pregnant, a review of the literature based on types of activities of an women may give useful estimates for those who are pregnant. However, it must be taken into account that there may be qualitative changes in the way tasks are performed. The following section discusses urban and rural women separately because their daily activities demand different energy expenditure levels.

Activity Patterns of Women in Rural Areas

A typical Zambian woman's day during the planting season is described in Table 2-7, showing the amount of physical activity performed each day by a woman in rural Africa. Much of this activity involves bending, walking, and carrying loads; all of these activities are more difficult for pregnant women. To estimate the weight of loads women carried, it was assumed that a woman commonly carries a child (up to age 3 years), firewood or other fuel source, water, and often, agricultural products.

TABLE 2-6a Reported Energy Intakes of Childbearing Women in Developing Countries

Source	Country	Energy Intake (kcal/d)
Pregnancy		
Prentice (1980) (wet season)	The Gambia	1,350–1,450
Oomen and Malcolm	New Guinea	1,360
Gopalan	India	1,400
Venkatacnalam	India	1,410
Lechtig et al.	Guatemala	1,500
Gebre-Medhin and Gobezie	Ethiopia	1,540
Rajalakshmi (1980)	Ethiopia	1,540
Mora et al.	Colombia	1,620
Prentice (1980) (dry season)	The Gambia	1,600 1,700
Arroyave	Guatemala	1,720
Maletnlema and Bavu	Tanzania	1,850
Demarchi et al.	Iraq	1,880
Bagchi and Bose	India	1,920
Thanangkul and Amatyakul	Thailand	1,980
Mata et al.	Guatemala	2,060
Lactation		
Prentice (1980) (wet season)	The Gambia	1,200–1,300
Karmarkar et al.	India	1,300
Devadas and Murthy	India	1,400
Karmarkar et al.	India	1,440
Arroyave	Guatemala	1,600
Rajalakshmi	India	1,620
Prentice (1980) (dry season)	The Gambia	1,600–1,750
Martinez and Chavez	Mexico	1,950

SOURCE: Whitehead, 1983.

TABLE 2-6b Reported Energy Intakes of Childbearing Women in Developed Countries

Source	Country	Breastfeeding	Nonbreastfeeding
English and Hitchcock	Australia	2,460	1,880
Thomas et al.	Scotland	2,716	2,125
Naismith and Ritchie	London, U.K.	2,930	2,125
Whichelow	London, U.K.	2,728	2,070
Abrahamsson and Hofvander	Sweden	2,280	—
Sims	United States	2,124	—
Whitehead et al.	Cambridge, U.K.	2,295	2,029
Rattigan et al.	Perth,	Australia 2,305	—

SOURCE. Whitehead, 1983.

TABLE 2-7 A Zambian Woman's Day During the Planting Season

Activity	Time Spent (hours)
Waking up in the morning (5 a.m.)	—
Walking 1–2 km to field with baby on back	0.50
Ploughing, planting, hoeing until 3 p.m.	9.50
Collecting firewood and carrying it home	1.00
Pounding or grinding grain or vegetables	1.50
Fetching water (1–2 km or more each way)	0.75
Lighting fire and cooking meal for family	1.00
Dishing out food, eating	1.00
Washing children, herself, clothes	0.75
Going to bed at about 9 p.m.	0.00
TOTAL	16.00

The following estimates can be applied: The average age of a carried child is 18 months, and the mean weight of an 18-month old in a developing country is 9 kg. The average daily consumption of water in a rural area where piped water is not available is about 20 liters per person. Thus, for a family of six, at least 120 liters of water (or about 30 gallons) weighing more than 250 pounds must be transported daily. Although the mother may not be the only person carrying the water from the source to the home, one person can carry up to 50 pounds per trip, which means a minimum of five trips a day.

The weight of the fuel that must be carried varies by type of fuel. Firewood is one of the heaviest fuels and is commonly used in many parts of Latin America and Africa. Other common fuels are cow dung, plant residues, and charcoal. Not only are sufficient amounts of these fuels often heavy, but also collecting them involves bending, stooping, and walking over rough terrain, all of which are more difficult during pregnancy.

The amount of time women in developing countries spent in gathering water and fuel and in processing food has been shown in several studies to exceed 2–3 hours each day. These activities have also been classified in several studies as moderate to heavy in terms of energy expenditure (Bleiberg et al., 1980; Roberts et al., 1984). Many women in developing countries are involved in agricultural activities that have higher energy costs. The overall energy expenditure among women in Burkina Faso (formerly Upper Volta) increased by more than 500 kcal/day when they worked in agricultural activities, bringing their energy expenditure to 2,900 kcal/day during the busiest farming season (Bleiberg et at., 1980). Among women in The Gambia, the amount of time spent performing moderate or heavy activities varied between 45 and 65 percent of the working day.

A study of peasant households in the Sierra region of Peru found that mothers are responsible for 93 percent of the conversion of agricultural products to food and meal preparation, 78 percent of water collection, 58 percent of fuel gathering, and 62 percent of animal care (Deere, 1983). In a study in Tanzania, 91 percent of the weeding and harvesting, 64 percent of the ploughing, and 79 percent of the slashing of grasslands was by women (Tobisson, 1980). Direct observations of villagers in Burkina Faso illustrated that women carried out 64 percent of production and supply tasks, including food and cash crop production, food storage and processing, and water and fuel supply maintenance. They also performed 23 percent of crafts activities, 97 percent of household tasks (child care, cleaning, and cooking), and 23 percent of community obligations. Overall, women performed 56 percent of all work compared with 44 percent for men (McSweeney, 1979).

Women spend 1–3 hours daily processing agricultural products (e.g., threshing and grinding grain), 1–2 hours preparing food, 2–5 hours farming, up to 1 hour maintaining the fuel supply, and up to 4 hours caring for children. In total, rural women work 10–12 hours per day on both home and market production.

The amount of time spent in child care may seem surprisingly low. However, this figure reflects a pattern of child care in which small children and infants are rarely separated from their mothers, so that it is often not feasible to distinguish between the time spent doing child care and the time spent marketing or food processing. Typically, a child is with the mother and receives attention while she is engaged in other tasks.

Census figures show that women's participation in agricultural activities is much lower in Latin America (excluding the English-speaking Caribbean) than in Africa or Asia. Although it is well known that national census efforts consistently, and sometimes grossly, underestimate the female agricultural labor force (Rechinni de Lattes and Weinerman, 1979), it appears that women are not the principal source of agricultural field labor in rural Latin America, in contrast to the situation in rural Africa.

Income From Agricultural Labor

Buvinic (1982) conducted a case study of the amount of pay women receive for agricultural work in the coffee and tobacco plantations of Honduras and compared these figures with those of a national census conducted 3 years earlier for the same geographical region. Based on plantation production and salary records, Buvinic estimated the extent of female participation in the paid agricultural labor force for the previous harvest season. When compared with the case study figures, it was found that census figures had underestimated women's participation in the agricultural labor force by between 30 and 40 percent. Women in Honduras make up almost 90 percent of the paid labor force in coffee production. Similar evidence of census under-reporting is available for Chile, Paraguay, Bolivia, and the Dominican Republic (Rechinni de Lattes and Weinerman, 1979).

Guatemalan women also work in large plantations, either seasonally or year round, in the field and at tasks ancillary to agricultural activities, such as cleaning and classifying produce, cooking and washing clothes for the seasonal work force, and tending livestock (Bossen, 1984). An in-depth study of a sugarcane plantation in southeastern Guatemala found that among the 80 households permanently attached to the plantation (there was also a seasonal work force of about 400) 50 percent of the women performed subsistence agricultural work and service work, compared with 88 percent of the men. Bossen described their circumstances as follows:

> Working conditions of them women are unenviable. They rise at 3 a.m. to begin making tortillas, and their work finishes at 7 p.m. If they have free moments during the day, there are clothes to wash by hand. The Labor of making tortillas while standing over hot wood fires is extremely intensive. Poor ventilation of the smoke from numerous fires produces burning, tearing eyes and probably respiratory problems among the women. (Bossen, 1984, pp. 145–146).

Another study conducted in the same coastal plantation belt region provides additional insights and measures of women's physical activities. McGuire (1979) conducted a longitudinal prospective study of energy intake, energy expenditure, and work. The women in this sample worked as unpaid family workers in subsistence crop production and as coffee pickers for a local cooperative. This work varied seasonally.

Daily intake of energy, protein, and iron, by physiological status, for these women are presented in Table 2-8. McGuire (1979) found that dietary intake was low but within the range of recommended values and that there were no modifications in intake by physiological status or season. Energy expenditure was measured for different activities by using a "Bolfi bag," a modification of the Douglas bag, and a respirometer.

Daily energy expenditure averaged about 2,000 kcal/24-hour period or 41 kcal/kg/day. McGuire found no seasonal effects on energy expenditure. Pregnant women expended significantly more energy per day than lactating women—2,044 ± 158 kcal/24 hours and 1,821 ± 120 kcal/24 hours, respectively; ($P < 0.01$)—but these differences disappeared when data were corrected for body weight. The energy losses in breast milk are not included in these figures. When women worked outside the home, however, they expended more energy than when they worked at home—2,085 ± 273 kcal/24 hours compared with 1,970 ± 238 kcal/24 hours, respectively. This difference was significant at the $P < 0.01$ level. Women work on their feet markedly more on days when they work outside the home. Understandably, they also spend more time and energy walking. When the proportion of workday time spent off their feet was compared between pregnant and lactating women, no discernible differences were found. However, when women worked outside the home, they spent significantly less time ($P < 0.05$) off their feet. These data are summarized in Table 2-9.

TABLE 2-8 Daily Intake of Energy, Protein, and Iron Among Rural Women in Southeastern Guatemala, 1977–1978

Physiological Status	N	Kilocalories	Protein (g)	Iron (mg)
Pregnant	12	1,678 ± 558	51.8 ± 22.6	19.1 ± 8.1
Lactating	28	1,845 ± 483	54.6 ± 17.2	18.3 ± 6.3
Nonpregnant, nonlactating	10	1,682 ± 377	54.4 ± 17.5	17.5 ± 8.0
TOTAL	50	1,792 ± 492	53.9 ± 18.1	19.1 ± 6.2

SOURCE: McGuire, 1979.

Weight gains were recorded during the second and third trimesters for seven of the pregnant women in the study. During the second trimester, the average weight gain was 0.04 ± 0.02 kg/day; or 3.6 kg/trimester. Identical figures were obtained for the same group of women in the last trimester.

In summary, the available evidence seems to indicate that women increase their participation as agricultural field workers in Latin America as the transition to cash cropping occurs. Nonetheless, women's involvement in agriculture in the region probably will not approximate that of African women.

Seasonality

Results of the above studies indicate the large amount of time spent on home production activities as well as on agricultural production. Both types of activities often necessitate substantial energy expenditures. Using the data from The Gambia, the amount of time pregnant women spend in light, moderate, and heavy work can be estimated, including the amount of energy expended on these activities. During the beginning of the rainy season, farming takes up a major part of women's overall activities, and pregnant women spend the largest proportion of their time throughout the year in heavy activities. Taking the month of June as an example, pregnant women spent 738 minutes out of a 15-hour workday in activities other than resting and unaccounted light activities, with about 25 percent of the day spent in hard work, 35 percent spent in moderate work, and 20 percent spent in light work. During the least active time (April), only 436 minutes out of a 15-hour workday were spent in activities other than resting or not otherwise specified light activities, with about 3 percent spent in hard work, 32 percent in moderate work, and 15 percent spent in light work, with the rest of the time spent resting. Using data from the same studies, an estimate of energy expenditure can be made (Table 2-10).

TABLE 2-9 Proportion of Woman's Workday Spent Off Her Feet (percentage of workday time), Guatemala, 1977–1978

	N	Total Sample (%)	N	Selected Subsample (%)
Physiological status				
Pregnant	08	28.4 ± 7.5	7	29.4 ± 7.5
Lactating	15	23.1 ± 8.0	7	24.2 ± 8.8
Nonpregnant, Nonlactating	05	29.0 ± 9.0		
Worked performed				
At home	16	26.8 ± 7.7	8	30.9 ± 6.4
Away from home	10	20.9 ± 9.0	8	21.6 ± 8.6[a]

[a] $p < 0.05$.
NOTE: The total sample and selected subsamples were selected for paired ± tests.
SOURCE. McGuire, 1979.

The estimates used in Table 2-10 are those observed for women in the second and third trimesters of pregnancy. While the data on energy expenditure for light and moderate work were similar for tasks categorized as light and moderate, expenditure for hard activities varied, thus the three estimates were used. Light activities with an estimated energy expenditure rate of 1.25 kcal/minute included sitting, most food preparation, and standing with a child. Moderate activities were estimated at levels of 2.09 kcal/minute for harvesting rice and 3.28 kcal/minute for walking while carrying a load such as fuel or items from the market place at 4.4 kph. Other activities within this range were beating groundnuts, washing clothes, and drawing water. Heavy activities included harvesting groundnuts (3.74 kcal/minute), digging while standing (4.59 kcal/minute), and pounding grain (4.81 kcal/minute). Carrying heavy loads, for example, chopping wood, clearing land, planting seeds, and digging and weeding groundnuts were also classified as heavy activities.

These estimates were based on 24-hour recall and observations of activity patterns and energy expenditures by using oxygen consumption for specific activities. The total estimated calories expended are substantially greater than the intakes recorded based on food weights. This may reflect an error in measurement of intake data similar to the Guatemalan study. The data on activities probably do not include the amount of time spent not active in each of the activities, such as the time spent resting while chopping wood or carrying loads. However, Table 2-10 can be used for illustrative purposes to indicate the large seasonal differences that are evident, the associated increases in energy expenditure related to field work, and the other home maintenance duties that women are responsible for on a daily basis.

TABLE 2-10 Estimated Energy Expenditure Level Among Pregnant Women in The Gambia

Month, Activity, and Time (min) Spent in Activities	Rate of Energy Expenditure (kcal/min)	Total Energy Expenditure (kcal/task)	Total Energy Expenditure (kcal/day)
June			
Sleeping 9 h x 60 min = 540 min	0.97	524	
Resting 3 h x 60 min = 180 min	1.25	225	
Light 3 h x 60 min = 180 min	1.16	227	
Moderate 5.25 h x 60 min = 315 min	2.09	658	
Hard 3.75 h x 60 min = 225 min	3.74	842	
Total in 24 h			2,476
			3,091
April			
Sleeping 9 h x 60 min = 540 min	0.97	524	
Resting 7.5 h x 60 min = 540 min	1.25	563	
Light 2.25 h x 60 min = 135 min	1.26	170	
Moderate 4.8 h x 60 min = 288 min	2.09	602	
Hard 0.45 h x 60 min = 27 min	3.74	101	
	4.59	124	
	4.81	130	
Total in 24 h			2,214
			2,332

NOTE: Using the lowest and highest estimates for the amount of energy expenditure for moderate and hard work.
SOURCE: Lawrence et al., 1985; Roberts et al., 1982.

Activity Patterns of Women in Urban Areas

Low-income women living in urban areas in developing countries are often as active as those living in rural areas, although the activities they perform are probably not as energy intensive. Urban women are also doubly burdened by home production and market work, and the poorer the household in which a woman lives, the more important her economic contribution becomes (Safilios-Rothschild, 1980). In cities where electricity and potable water systems are widely available, low-income women may not necessarily be relieved of the tasks described above for rural women. In general, poor urban women do not participate in the three most strenuous physical activities: gathering fuel, drawing water, and doing agricultural work. However, in most shanty towns and slums in large cities in developing countries, piped water is not available to the entire urban population, so carrying water is a job performed by women and children. Transportation to and from work, to buy and carry essential household goods, including food, or to attend health care facilities (for the children or herself) also require considerable amounts of energy, especially when public transport is expensive and unreliable. With increased rural-urban migration in Latin America, an increasing pattern of seasonal work in the agricultural sector for urban women has been described. In fact, in most Central American countries, seasonal employment of urban and rural women in the coffee-picking activities has long been known. This seasonal involvement of urban dwellers in cash crop agricultural activities is increasing in Brazil (coffee harvest) and Chile (fruit harvesting and packing) (UN-ECLAC, 1988).

The physical activity involved in market work (income-generating work integrated into the market, money-oriented economy) may or may not make up for the differences between rural and urban women noted above, depending on whether the work is sedentary or whether it involves standing, walking, or lifting objects. The opportunities for income-generating work are diverse in urban settings and range from petty trading on the streets and domestic service to formal employment in the modern industrial and service sectors. Overall, women in cities in developing countries are mostly represented in the service sector. In the mid-1960s, approximately 90 percent of domestic employees in Chile were women; in Colombia the figure was 80 percent, and in Mexico it was 68 percent (ICRW, 1980). The participation of women in manufacturing is mostly circumscribed to lighter industries, such as electronic assembly plants, textile or garment factories, and pharmaceutical industries. Table 2-11 presents the proportion of the economically active population engaged in industrial and service work in selected countries by sex. It should be noted, however, that the figures for the Middle East may not be comparable since Muslim women (in purdah) presumably perform tasks very different from those of women in other areas.

TABLE 2-11 Proportion of Economically Active Population in the Nonagricultural Labor Force for Selected Developing Countries, by World Region and Sex

Middle East		Latin America		Asia	
Iran		*Bolivia*		*South Korea*	
Male	0.61	Male	0.48	Male	0.67
Female	0.70	Female	0.74	Female	0.37
Libya		*Brazil*		*Philippines*	
Male	0.79	Male	0.60	Male	0.40
Female	0.62	Female	0.73	Female	0.65
		Chile		*Thailand*	
		Male	0.73	Male	0.36
		Female	0.97	Female	0.417
		Honduras			
		Male	0.30		
		Female	0.41		
		Venezuela			
		Male	0.78		
		Female	0.96		

NOTE: Male indicates male labor force, and female indicates female labor force.
SOURCE: ICRW, 1980a.

Most developing countries subscribe to International Labor Organization conventions that are designed to protect women from heavy work or work that may endanger a woman or her fetus. This protective legislation sometimes prohibits women from working in the mining sector or working at night. Although few of these labor codes are ever enforced, they have contributed to the maintenance of a sex-stratified labor force in developing countries in both rural and urban areas (ICRW, 1980b). There are several exceptions, however, especially in some cities. These changes in women's work roles may not have reached large numbers of women, but may be indicative of future trends. For example, in Jamaica, women are moving into truck driving and the operation of other medium and large vehicles in the transportation and industrial sectors (Powell and Olafson, 1982). In Bahia, Brazil, metalwork is an activity that is opening up to women as vocational schools introduce nontraditional training for young adult females (Crandon and Shepard, 1984). In Chile, the government accepted the participation of women in public road maintenance and street-cleaning programs as part of its efforts to lower unemployment. A survey of 10,000 workers in these programs showed that 52.4 percent were women working up to 8 hours a day. Seventy percent of these women were 18–40 years of age (Buvinic and Mellencamp, 1983). It is not known how this change in women's work roles will affect the outcome of pregnancy.

By and large, women are not represented in great numbers in the industrial or manufacturing sector. They tend to concentrate in the lower levels of the tertiary or service sector and in the informal sector of the labor market (ICRW, 1980b). In Latin America and Asia, women make up more than one-third of the labor force in the service sector, most of it in urban areas. These figures include middle-and upper-class women engaged in professional work.

Informal Sector Activity

Informal is the term used to refer to that growing sector of the economy characterized by microenterprises that are usually family based and employ one to five workers, have little capital and less than optimal technology, and buy work that is piecemeal. It is often performed at home or in the street and is unregulated, untaxed, and sometimes illegal. It is generally outside the realm of what labor codes define as adequate both in terms of remuneration and in working conditions. In cities like Bombay, Jakarta, and Lima, the informal sector absorbs 53–69 percent of all urban workers. The informal sector of the labor market receives the oversupply of workers from the formal service sector. In the informal sector of urban economies, women workers proliferate (Buvinic et al., 1983). Market vending, street food vending, and domestic service are examples of informal sector work dominated by women in Latin America, the Caribbean, Africa, and parts of Asia. In Belo Horizonte, Brazil, in the mid-1970s, for example, 54 percent of the informal sector workers were women. When domestic servants were excluded from this population, 40 percent of informal sector workers were still women. Sixty percent of the self-employed within the informal sector were women (Merrick, 1976). In urban India in the mid-1970s, 40–50 percent of women workers were in the informal urban labor market, whereas only 15–17 percent of the male labor force was engaged in informal work (ICRW, 1980). There is no reason to expect that this trend has reversed in a decade. On the contrary, evidence from the current economic crisis indicates that it has become more marked (UNICEF, 1987).

Case studies of Indian women provide evidence that they are working in heavy informal work: collecting garbage, cutting stone, carrying bricks and other construction materials, and doing construction work. Although no figures are available on the involvement of women in construction work, in New Delhi and Bombay, there are now mobile creches that provide care for approximately 5,000 of these women's children (Mahavedan, 1977; Huffman, 1985).

Market and street vending is another urban occupation in which women predominate or are well represented in all but the Muslim regions, where purdah is still observed. Market and street vending requires women to be on the streets or in the market for long hours during the day, sometimes even during the night. There is a lack of studies of time use or activity patterns of market vendors and domestic workers, but several intensive life histories of some of these women recently have been published as composite profiles (Bunster and Chaney, 1985). Market and street vendors have, on average, 3.4 children each, and nearly half of these women are the main economic support for their households. The workday may begin as early as 3 or 4 a.m., and some women work from 8 a.m. to 7 p.m. and then perform their own housework, including washing clothes by hand. The total workday may be up to 18 hours long, 6 or 7 days a week. Commuting to the workplace is a major effort, because the women have to carry produce and, sometimes, children, and public transportation systems are often inadequate.

Traders and peddlers alternate street or market work with employment as domestic service workers. Domestic service work often requires that women work 14–16 hours a day, most of the time while standing or bending, and is considered highly demanding work by the women themselves (Bunster and Chaney, 1985). Washing clothes by hand is part of domestic service. This activity requires women to adopt uncomfortable positions and to exert themselves as they pound or rub the wet clothes against a hard, rough surface, such as river stones or cement washboards, and then rinse and force the water out, squeezing the pieces one by one. Furthermore, it is a domestic task that must be undertaken frequently. It may take from 1 to 3 hours a day twice a week for a family of five (two adults and three children); when there are diapers to be washed, it can take up to 4 hours a day (Nieves, 1986). A study of domestics and petty traders revealed that washing and ironing clothes was considered by domestic servants to be the hardest and most unpleasant work (Bunster and Chaney, 1985).

In the Lima study mentioned earlier, the median amount of time domestic servants worked was 11.5 hours a day. Some women in a sample of 50 servants worked up to 17 or 18 hours a day. They reported that most of the time they were standing, walking, or climbing stairs (Bunster and Chaney, 1985). Domestics work more hours per day than do their male counterparts in blue-collar jobs, and they earn about 60 percent of what other informal sector workers do (ICRW, 1980a).

While domestic servants begin their working lives when they are still very young (12–15 years old in Latin America), they work intermittently as domestic servants throughout their adult lives. The work histories collected by Bunster and Chaney (1985) showed that the first pregnancy usually occurs while the woman is employed. If she is not dismissed immediately, she will continue working as a servant, with no diminished responsibilities, until she is dismissed later in the course of the pregnancy or leaves voluntarily. No quantitative data are available on how many women work in domestic service through the second or third trimesters of pregnancy.

The involvement of women in informal sector work in developing countries is a subject that social scientists are studying intensively. As more data become available, types of work that poor urban women perform will be better identified. More attention needs to be given to documenting the conditions of work and the physical activity involved, as well as the economics and the sociology of work. Physical mobility and the ability to transport themselves and their children from one point in the city to another already have been identified as key aspects of poor women's survival needs in urban areas in Latin America. The identification of other physical demands of urban life and urban work for low-income women, and low-income mothers specifically, deserves more attention.

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3

Physiology of Normal Pregnancy and the Effects of Undernutrition

The physiology of pregnancy presents well-defined challenges to the maternal organism that are unparalleled in the physiology of nonpregnant women. The fetus develops and grows at a rapid rate unequalled to that in postnatal life, and the mechanisms by which this growth occurs and the demands on the maternal organism imposed by this growth are only beginning to be understood. While a detailed review of maternal, placental, and fetal physiology and metabolism is beyond the scope of this report, the following presents a brief synopsis of the physiology of normal pregnancy, with emphasis on physical activity and diet, and in particular, undernutrition.

BODY WEIGHT AND COMPOSITION

The magnitude and pattern of weight gain during pregnancy is quite variable (Pitkin and Spellacy, 1978). Some of this variance is due to the manipulation of weight gain by restriction of food intake; the influence of age, parity, and pregravid body weight, and the presence or absence of excessive water retention. Total weight gain in healthy women who eat to fulfill their appetite probably averages between 10 and 12 kg (Pitkin and Spellacy, 1978). In developing countries, however, where less favorable conditions regarding food intake prevail, weight gains during pregnancy as low as 5 kg have been reported (Lawrence et al., 1985). Maternal weight gain during the first trimester may be minimal; at the end of the first trimester, weight begins to accumulate, and the rate of maternal weight gain is essentially linear throughout the second and third trimesters, at 350 to 400 g/week (Pitkin and Spellacy, 1978) (Figure 3-1).

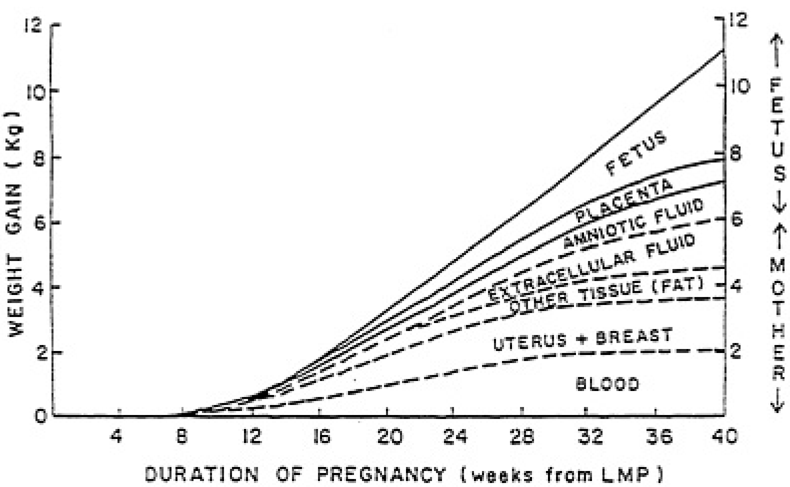

Figure 3-1 Pattern and components of maternal weight gain during pregnancy. Source. Pitkin, 1976.

Accumulation of maternal tissue (i.e., blood, uterine, and breast tissues and tissue stores) occurs primarily during the second trimester as does growth of the placenta, while growth of the fetus and increases in the amount of amniotic fluid occur most rapidly in the third trimester. Of an average 11 kg of total weight gain, the maternal compartment represents about 6 kg and the conceptus (fetus, placenta, and amniotic fluid) represents about 5 kg.

The composition of the weight gain also varies, but an 11-kg gain includes, on the average, about 7 kg of water, 3 kg of fat, and nearly 1 kg of protein (Hytten, 1980b). Of the total 7 kg of water gain, about 2–3 kg consist of maternal extracellular fluid. Pregnant women with edema, particularly generalized edema, may gain substantially more water. Sodium and other minerals also accumulate during pregnancy, but their direct contribution to the total weight gain is minimal.

Fat metabolism is affected substantially by pregnancy. Starting early in human pregnancy, women begin to store large amounts of fat, with sustained fat deposition occurring through the first two trimesters. Fat accumulation averages 3 kg, or approximately 15–25 percent of the prepregnant fat content (Hytten, 1980a). The rapid rate of maternal fat deposition occurs in many species (Widdowson and Spray, 1950), including the rabbit (Elphick et al., 1978), guinea pig, and sheep (Vernon et al., 1981), and the maternal total body fat content in these animals may increase by as much as 50 percent (Widdowson and Spray, 1950).

This rapid deposition of fat represents an efficient form of storage for large amounts of energy. Such fat deposition requires that energy intake go beyond basal needs, and this may result from spontaneous increases in energy intake, endocrine changes promoting fat deposition, and decreases in energy expenditure, including resting metabolic rate (RMR). In humans, the rate of fat deposition slows and may decline slightly during the third trimester. The human fetus normally accumulates up to 16 percent of its body weight as fat. This rapid accumulation of fat by the human fetus is unusual among mammals (Sparks, 1984; Widdowson and Spray, 1950) and is related to slow growth and long gestation.

In contrast to body fat, lean body mass appears to change relatively little in women during the course of pregnancy. While some individual organs, particularly the breast and uterus, increase in size substantially during pregnancy, the overall change in lean body mass appears to be of a smaller magnitude and more difficult to detect. Nitrogen balance studies in humans have shown only minimal changes, on average, in lean body mass (Johnstone et al., 1981). Carbohydrates are stored as glycogen in the liver and in muscle tissue.

Maternal Energy Expenditure and Energy Balance

Studies from The Gambia suggest that the nutritional state of the mother may influence the change in resting metabolism. At term, the cumulative change in RMR totaled 13,000 kcal in supplemented women, whereas RMR increased by only 1,000 kcal in unsupplemented women. In studies done in the Philippines (Tuazon et al., 1987) and Thailand (Thongprasert et al., 1987); where the maternal energy supply was not as limited as that in The Gambia, the cumulative increase in RMR totaled 23,900 and 18,900 kcal, respectively. It appears that prepregnancy undernutrition and/or underfeeding during pregnancy limit the increase in resting metabolism that occurs during pregnancy. This is consistent with the response to semistarvation in adult men. Grande et al. (1958) found that a 50 percent reduction in energy intake caused RMR to fall about 20 percent after 13 days. This rapid initial decline in RMR with undereating is associated with a fall in circulating levels of active thyroid hormones and the urinary excretion of catecholamine metabolites (Jung et al., 1980). A reduction in lean, or actively metabolizing, tissue among the underfed women also accounted for a reduction in their RMR. However, based on measurements of total body water, Gambian women have about the same amount of lean tissue as the

Cambridge, England, women, (43 and 41 kg, respectively) (Prentice, 1984). If there were no differences in the amount of active lean tissue, the lower RMR of the Gambian women must have been due to a reduced rate of metabolism per gram of lean tissue.

Women living in some developing countries may be exposed to an annual cycle of food shortages and the seasonal energy demands of subsistence farming (Roberts et al., 1982). Maternal weight gain is affected by this cycle. After adjustment for seasonal effects, Gambian women gained on average 6.3 kg by 35 weeks; those women receiving a food supplement that increased their total energy intake by about 430 kcal/day gained, on average, 7.9 kg (Lawrence et al., 1987). Approximately 10.7 kg are gained by well-nourished women at the same time of gestation. The mean total weight gain of Taiwanese pregnant women is 7.6 kg (Adair, 1983). Colombian and Guatemalan pregnant women gain about 7 kg (Lechtig et al., 1975; Mora et al., 1979), and Filipino and Thai women gain about 8.5 kg (Thongprasert et al., 1987; Tuazon et al., 1987). In general, it appears that women who live in developing countries gain 2.5 to 4.5 kg less than do well-fed women who live in developed countries. There is some evidence that a reduction in maternal weight gain is associated with a reduction in fat gain. For example, the Filipino and Thai pregnant women who gained about 8.5 kg overall gained only 1.3 kg of fat in comparison with the 3.3 kg of fat gained by well-fed women who live in developed countries. The measurements of change in fat mass during pregnancy are fraught with methodological limitations. Furthermore, there is a possibility that average gains in developed countries are higher than needed (Thongprasert et al., 1987; Tuazon et al., 1987).

Lawrence et al. (1987) also evaluated the effect of food supplementation and seasonal energy demands on total fat gain during gestation in Gambian women. In unsupplemented women, there was no gain in body fat, as estimated from changes in total body water, throughout pregnancy. In supplemented women, approximately 2.5 kg of fat were gained by the end of the second trimester, of which 0.5 kg was subsequently mobilized during the third trimester. There were marked seasonal influences, however, on tissue fat changes in both groups. In unsupplemented women whose second and third trimesters coincided with the worst time of the year (from the point of view of food availability and workload), total weight gain averaged 2.3 kg, and there was an overall fat loss of 4.7 kg. During the best time of the year, the unsupplemented women gained up to 11.2 kg and had a maximal net fat gain of 3 kg. In supplemented women, total weight and fat gain were greater than in their unsupplemented counterparts at the worst and best times of the year, but the seasonal differences in their weight gain were narrower than in the unsupplemented ones. Thus, during periods of limited energy intake, pregnant women conserve energy for fetal growth by mobilizing maternal stores to the maximum extent possible. Because weight gains were the greatest among women with the most depleted reserves (Lawrence, 1997), these stores seem to be repleted when the energy supply improves.

Potential Energy-Sparing Mechanisms

Besides the already indicated changes in RMR among the less nourished groups, savings in energy expenditure seem to occur also through a reduction in physical activity. Two types of reductions are most likely: a reduction in the number and duration of activities or a change in the efficiency with which various physical activities are accomplished. There is some evidence that underfed pregnant women adjust both the amount of physical activity as well as the intensity of that activity. Studies of the activity patterns of women in developing countries show that they perform the same tasks whether or not they are pregnant. If any changes occur, they are in the duration and intensity of work and not in the type of work. Activity diaries of pregnant Gambian women (Roberts et al., 1982) showed that they reduced their energy expenditure to 75 percent of that of nonpregnant women in the last month of pregnancy by reducing the amount of housework and heavy farm work. The total time spent farming was unchanged, however.

The response to food supplementation is also of interest. A net increase of 723 kcal/day during lactation did not affect breast milk volume or milk energy content (Prentice, 1984). There was a slight increase in maternal body weight during the first 2 months after initiation of the supplement, but thereafter, weight change patterns were similar to those in unsupplemented women. Those changes in body weight accounted for only 7 percent of the supplemental energy. It is unclear what happened to the remaining energy. The women reported reduced fatigue and an increased feeling of well-being, but it is unlikely that changes in physical activity could account for an additional 700 kcal/day, as this would require that they double their physical activity (Prentice, 1984). Hormonal and energy substrate levels in the blood suggested that overall metabolic efficiency was reduced.

It is possible that adaptations in metabolism allow underfed women to achieve an energy balance when consuming energy-limited diets. With improved intakes, this efficiency is not maintained, and the additional energy is expended without a sufficient weight gain.

The energy costs of various activities have been measured in pregnant and nonpregnant women to determine whether the activity is performed in a more economical, energy-conserving manner. The energy costs of 40 domestic and agricultural activities were assessed recently in 142 nonpreg nant, pregnant, and lactating Gambian women (Lawrence et al., 1985). Since the energy expenditures of nonpregnant and nonlactating women, pregnant women in the first trimester, and lactating women did not differ, these women were grouped and compared with pregnant women in their second and third trimesters. With one exception, there was no significant change in the energy cost for activities with advancing gestation. The exception was for bending and digging, for which the total energy cost *decreased* during late pregnancy. When the data are expressed per unit of body mass, the energy expenditure of pregnant women was significantly less than that of nonpregnant women. This is because the pregnant women weighed 5 kg more than the nonpregnant women. Since RMR increased about 0.1 kcal/minute during weeks 20–33 of gestation, the net energy cost for all of these activities would have decreased in the second and third trimesters. This reduction in the net cost for activity in late pregnancy suggests that the intensity of work declined, particularly for bending and digging activities. The energy cost of physical activity did not increase with food supplementation (Lawrence et al., 1985). It is possible that all pregnant women, regardless of nutritional state, reduce their work intensity. However, studies of East Javanese peasant farmers showed that energy-deficient people perform work more efficiently (Edmundson, 1977).

Because women in developing countries weigh about 6 percent less than women from developed countries, the energy cost for weight-bearing activities should be reduced accordingly. This is evident from measurement of energy expenditure for walking during pregnancy. Reductions in nonshivering thermogenesis may contribute to energy balance in underfed people (Prentice, 1984). This hypothesis is supported by the fact that adult Kalahari (African) Bushmen and Australian Aborigines have a reduced response to the cold and that they allow their core body temperatures to fall during the night, thus reducing the temperature gradient and the heat loss (Prentice, 1984). Nonshivering thermogenesis may result from futile cycles in the muscle or from the uncoupling of adenosine triphosphate (ATP) synthesis in brown adipose tissue. The role of these cycles in energy balance in humans is uncertain. Recent work in mice shows that energy can be conserved very efficiently during pregnancy and lactation by the uncoupling of ATP synthesis in brown adipose tissue (Trayhurn et al., 1982). The additional heat resulting from fetal growth and milk production may obviate the need for thermoregulatory heat production, or there may be a physiologic adaptation in energy metabolism mediated by a hormone such as prolactin (Prentice, 1984). Prolactin levels in pregnant and lactating women in developing countries tend to be higher than those in women in developed countries. It is uncertain, however, whether this hormonal change mediates an adaptation to thermogenesis in humans.

Blood Volume and Composition

Blood volume and composition change profoundly in pregnant women. Plasma volume increases in healthy, pregnant women by at least 1,250 ml, or about 48 percent above the usual volume of 2,600 ml in nonpregnant women (Hytten and Lind, 1973). The increase in plasma volume follows a sigmoid pattern with little change during the first 10 weeks, but it increases linearly during the second and the early part of the third trimesters until a plateau is reached at about 30–34 weeks of gestation. In general, the larger the increase in plasma volume, the larger the fetus. Erythrocyte volume also increases, but to a smaller extent than the plasma volume. In a healthy, pregnant woman who is not receiving iron supplements, the erythrocyte volume increases about 18 percent (250 ml) above that of a nonpregnant woman (1,400–1,650 ml). With iron supplementation, hemopoiesis is more rapid, and the erythrocyte volume increases about 30 percent through the end of gestation (an increase of from 400 to 450 ml). Erythrocyte volume also begins to expand at about 10 weeks of gestation, but unlike the plasma volume, it continues to expand until the end of gestation. Without iron supplementation, the erythrocyte count, hemoglobin concentration, and hematocrit fall during pregnancy, reaching a nadir at 28–32 weeks of gestation.

Total serum lipids increase progressively throughout pregnancy, reaching a level about 0.4 g/dl higher than that in nonpregnant women at the end of gestation (Hytten and Lind, 1973). The concentrations of triglycerides, cholesterol, and phospholipids increase, with the concentrations of phospholipids and triglycerides tending to level off in the third trimester and the cholesterol concentration continuing to rise (Knopp et al., 1978).

Undernutrition, Blood Volume Expansion, and Placental Blood Flow in Animal Models

Acute food restriction in pregnant rats limits the expansion of blood volume (Rosso and Streeter, 1979), and this, in turn, limits the increase in uterine blood flow (Rosso and Kava, 1980). An alternative explanation is that undernutrition reduces uteroplacental metabolism and then uterine blood flow, which leads to accommodating adjustments in central cardiovascular functions, including blood volume. In a comparison of chronically and acutely malnourished pregnant rats, the percent absolute increase in maternal plasma volume expansion in chronically malnourished animals was nearly twice that seen in the acutely malnourished ones (Fellows, 1985).

Adjustment to chronic undernutrition before conception may improve the rats' adaptation to pregnancy.

The timing of food restriction during pregnancy alters the distribution of the cardiac output to the uteroplacental unit in rats (Ahokas et al., 1983a). When food restriction was initiated late in gestation (day 14 of 22 days), cardiac output and uteroplacental blood flow were equally reduced, showing that the distribution of the cardiac output to the uterus was maintained. Restriction early in gestation (up to day 5), however, showed that uteroplacental blood flow was, at term, reduced more than the cardiac output was, suggesting that the cardiac output is redistributed away from the conceptus. Restriction during midpregnancy only (days 5–14) caused a redistribution of the cardiac output toward the conceptus at term. The timing of the onset of maternal food restriction can have different effects on uteroplacental blood flow, depending on the distribution of the cardiac output.

It is unclear whether a reduction in placental blood flow caused by food restriction significantly reduces nutrient transfer to the fetus. Measurements of placental nutrient clearance in sheep show that the clearance of substances such as ethanol is asymptotic; that is, there is little change in clearance with changes in blood flow at high rates of flow (Wilkening et al., 1985). Thus, a 50-percent reduction in placental blood flow caused only a 20-percent decrease in the clearance of ethanol. In rats, malnutrition reduced placental blood flow by 43 percent (Rosso and Kava, 1980); the associated reduction in nutrient clearance may be much less—possibly less than 20 percent. Assumptions about fetal nutrient supply cannot be made from measurements of uteroplacental blood flow without information about nutrient clearance since the two are not linearly related. For a discussion of the effects of maternal undernutrition on fetal and maternal outcomes in animal models, the reader is referred to Rosso and Lederman, 1983.

GESTATIONAL EFFECTS ON ORGAN SYSTEMS IN PREGNANT WOMEN

Renal plasma flow is continuously increased throughout pregnancy from about 200 to 250 ml/minute (Hytten and Lind, 1973). The glomerular filtration rate (GFR) similarly increases by about 50 percent during the last two trimesters, and a small fall in GFR may occur during the last 4 weeks of pregnancy. The rise in GFR may merely be the result of the increased renal plasma flow; it does not appear to be regulated hormonally during pregnancy.

The general tone and motility of the stomach and the small and large intestines are reduced during pregnancy because of smooth muscle relaxation by progesterone (Hytten and Lind, 1973). Consequently, gastric emptying time and intestinal transit time are prolonged. This relaxation of muscle tone may explain the nausea that occurs during pregnancy; constipation is also a common complaint. It is not known whether this prolonged intestinal transit time contributes to improved nutrient absorption.

Pregnancy-Related Changes in Maternal Metabolism

Maternal metabolism meets two important goals: maintaining concentrations of key substrates in blood within a certain range and dynamically producing and consuming sufficient substrate quantities to meet ongoing tissue needs. The dynamic disappearance of glucose to meet tissue energy and carbon requirements balances the dynamic appearance of glucose from endogenous and exogenous sources, maintaining blood glucose within a relatively narrow range.

Metabolic Adaptations

When women fast during pregnancy, placental steroid secretion is altered. The human placental lactogen (hPL), a lipolytic hormone that mobilizes maternal fatty acids and thus spares glucose for the fetus and placenta (Kitzmiller, 1980), is increased in fasting pregnant women (Kim and Felig, 1971). This is associated with a rapid rise in maternal fatty acid and ketone levels (Schreiner et al., 1980). Placental hPL levels also increase when the maternal blood glucose level is low (Prieto et al., 1976). Placental estrogen and progesterone secretion alter maternal insulin levels, fat deposition, and plasma and red blood cell volume expansion (Kitzmiller, 1980). Maternal malnutrition may also alter the synthesis of these placental hormones. Chronic undernutrition in rats decreased estradiol levels on day 18 of gestation, but there was no change in the progesterone level (Alexander et al., 1988). Indian women of low socioeconomic status have decreased levels of urinary estrogen (Iyengar, 1968) and progesterone (Rosso, 1980). Thus, undernutrition may alter the mother's ability to accumulate nutrient stores early in pregnancy and, subsequently, to deliver them to the fetus late in gestation (Jones and Crnic, 1986). This is supported by the fact that impaired fat deposition in women during the second trimester is predictive of poor fetal growth (Viegas et al., 1987). Also, interpregnancy supplementation from the special Supplemental Food Program for Women, Infants, and

Children of the U.S. Department of Agriculture and, therefore, an assumed increase in maternal stores at conception, improves birth weight significantly more than supplementation only during pregnancy (Caan et al., 1987).

Pregnancy imposes significant alterations on substrate metabolism, resulting in considerable changes in the dynamic rates of metabolism and lesser changes in substrate concentrations in the basal state. From the point of view of physical activity and diet, these changes in metabolism are particularly important for glucose, lactic acid, and oxygen and non-esterified fatty acids.

Oxygen

While oxygen is not typically considered to be a nutrient, energy production to perform metabolic and physical work requires oxygen consumption. The relationship of oxygen consumption to work is basic to nutritional studies and provides a foundation for indirect calorimetry. Like that of glucose, the concentration of oxygen does not appear to change greatly during pregnancy. Oxygen consumption, analogous to the disposal of carbon substrates, appears to increase gradually throughout pregnancy. In resting women during late gestation, oxygen consumption is 16–32 percent greater than that of nonpregnant controls, apparently because of the effects of the conceptus, rather than a large increase in the oxidation rate of nonuterine tissues (kidneys, heart, liver, and gut) (Lotgering et al., 1985). This increase in the level of absolute oxygen consumption while resting is consistent among species, and it appears reasonable in view of not only the continued growth of the metabolically active conceptus but also the high cost of the extra maternal cardiac and respiratory work and the considerable cost of reasborbing the extra sodium filtered by the raised glomerular filtration rate (Block et al., 1985; Gilbert et al., 1982). Resting oxygen consumption in early and mid-gestation appears to be highly variable, being lowered or increased depending on previous maternal nutritional status and energy intake.

Glucose

Glucose is a major fuel for the maternal organism and is required for the proper functioning of vital maternal organs, particularly the brain. Pregnancy alters glucose concentration in the fed state only minimally, resulting in small and gradual, but real, decreases in the glucose concentration in blood throughout pregnancy. In the starved state, changes are rapid and dramatic, giving rise to the concept of accelerated starvation, which is discussed later in this chapter. Such changes have been described in several species, including human, rabbits, monkeys, sheep, and guinea pig (Lotgering et al., 1985).

In contrast to the relatively small changes in the glucose concentration in blood during pregnancy, relatively large changes in glucose kinetics do occur. The brain, which is relatively insensitive to insulin, accounts for a major portion of glucose disposal in nonpregnant animals. Glucose use by other tissues such as muscle and adipose tissue is quantitatively less important, but it is more variable in time and is subject to insulin regulation. Tracer studies in unstressed guinea pigs, rabbits, and sheep have shown that substantial changes in the disposal rate of glucose occur in the pregnant animals, and more limited stable isotope studies have demonstrated that considerable increases in glucose turnover occur in pregnant women as well. In guinea pigs, animals that typically have a larger fetal mass per body weight, the absolute turnover of glucose during pregnancy approximately doubles (Gilbert et al., 1982); there are lesser effects in other species. Recent studies in guinea pigs have related the increase in glucose turnover directly to fetal number and mass (Lotgering et al., 1985). Studies in sheep with one and two fetuses (Bergman, 1974; Hay et al., 1983) support the concept that most of the increase in glucose turnover during pregnancy is a direct result of the increasing mass of the metabolically active conceptus that is being supported by the mother and increased feed intake (Steel and Leng, 1973).

In view of the complex endocrine changes that occur during pregnancy, the question of possible alterations in glucose appearance and disposal of nonreproductive maternal tissues is of great interest but remains largely unresolved. Increases in cortisol, hPL, human chorionic gonadotropin (hCG), estrogens and progesterone during pregnancy alter maternal glucose metabolism. Cortisol increases gluconeogenesis and glucose release, but its effects may be offset by the effects of increased progesterone and its metabolites. Estrogen may also increase gluconeogenesis and glucose turnover. While under nonstressed conditions, pregnant women maintain glucose concentrations near the levels found in nonpregnant women. The altered endocrine milieu appears to predispose women toward having difficulties in handling metabolic stress during pregnancy.

Insulin and glucagon are major regulators of glucose metabolism in nonpregnant animals. In pregnant animals, glucagon appears to play a minor role in metabolic adaptation to pregnancy (Knopp, 1981). In contrast, considerable interest has been paid to the concept of insulin resistance in which, despite increased levels during pregnancy, insulin appears to be less effective in maintaining glucose homeostasis. Insulin resistance appears to develop early in pregnancy, and a variety of hypotheses have been proposed to explain it. It has been suggested that there may be an increased gluconeogenic set point induced by other hormones during pregnancy and that there is an alteration in insulin receptor function and number. More recently, new methodologies such as the glucose clamp have helped investigators assess glucose homeostasis. (In the glucose clamp, the glucose concentration is maintained within very narrow boundaries by careful intravenous infusion of glucose with frequent monitoring; concentrations of insulin, glucagon, somatostatin, and other hormones are altered experimentally. The effect of the alteration can then be quantitated by determining the change in the glucose infusion rate required to maintain the glucose concentration within the desired range.) Newer glucose clamp techniques are beginning to elucidate further the phenomenon of insulin resistance during pregnancy (Leturque et al., 1984; Ryan, et al., 1985).

Lactic Acid

Lactic acid metabolism during pregnancy deserves particular attention in view of its importance during acute exercise and conditioning. Lactic acid is produced by the reduction of pyruvate and is an intermediate in many biological reactions. As such, it can be viewed as a central intermediary metabolite by a number of glycolytic tissues, including red cells, the placenta, and probably, muscle. Lactic acid production does not necessarily imply hypoxia or ischemia. Lactic acid is not normally ingested in significant amounts by adults, and therefore, its metabolism can be viewed primarily as the balanced endogenous production and endogenous consumption of lactic acid (Johnson et al., 1986; Kreisberg, 1980). Ordinarily, the rates of both consumption and production of lactic acid are rapid and balanced. Carbon cycling among organs in the form of lactic acid and other compounds may be important in the internal economy of the organism, but it need not have caloric implications for the economy of the whole organism, as both lactic acid production and consumption are endogenous within the organism.

When the body is at rest, lactic acid concentration remains relatively constant over time because rapid production of lactic acid is balanced by rapid consumption. During periods of short-term activity as well as strenuous activity, increased lactic acid production from muscular tissues may lead to significant, but transient, increases in the lactic acid concentration, which is then cleared to normal levels as activity is reduced. In pregnant women in labor, lactic acid concentration normally increases in relation to muscular work with each contraction.

Little is known about the specific factors regulating the production and consumption of lactic acid in nonpregnant or pregnant animals. However, net production of lactic acid in large amounts by the gravid uterus appears to be a general property of pregnancy in a number of species, including humans, sheep, rabbits, and guinea pigs (Block et al., 1985; Johnson et al., 1986; Sparks et al., 1982). The effect of this large load of lactic acid on either normal maternal metabolism or maternal exercise physiology remains to be determined.

Other Substrates

Basal concentrations of amino acids, free fatty acids, and keto acids do not appear to change substantially during pregnancy in well-fed humans or experimental animals (Gilbert et al., 1984; Lotgering et al., 1985; Sparks et al., 1982).

Undernutrition in Pregnancy: "Accelerated Starvation"

While the basal circulating concentrations of major substrates appear to change over a relatively narrow range during pregnancy when food intake is adequate, the combination of increased absolute rates of fuel consumption and the endocrine changes associated with pregnancy appear to predispose pregnant animals toward intolerance of brief fasts that nonpregnant animals would easily accommodate. During pregnancy, the normal metabolic responses to a fast appear exaggerated in both time and quantity. This exaggerated response has been described as *accelerated starvation*. Studies in humans have demonstrated that even a brief fast is associated with rapid changes of large magnitude in gluconeogenic amino acids, keto acids, and free fatty acids, confirming a series of previous studies in experimental animals that document similar exaggerated responses to even brief periods of starvation (Metzger, 1982; Freinkel et al., 1972). Recently, these studies have been repeated in guinea pigs along with studies of glucose kinetics and substrate levels. Guinea pigs are notable because of their extremely large fetal mass, and starvation for as short as 2 hours results in significant decreases in glucose turnover, as well as a rapid elevation of keto acids levels. In particular, the magnitude of the changes in glucose concentration and turnover directly relate to the fetal mass (Gilbert et al., 1985).

METABOLIC AND TRANSPORT FUNCTION OF THE PLACENTA

While the roles of the placenta in hormone synthesis and substrate transport are well known, the metabolic processes that fuel these roles are considered less often and are considerably less well understood. Generalizations about placental function and structure are somewhat difficult in view of the surprising diversity among species in placental types and perfusion patterns (Meschia, 1983). Placental tissues generally are rich in mitochondria, and recent *in vivo* studies of sheep placenta demonstrate surprisingly high weight-specific oxygen consumption, almost as high as that for brain tissue. In ruminants, glucose appears to be a major placental substrate, with the concomitant net placental production of lactate distributed into both the fetus and the mother. Placental tissue from many species consumes glucose and produces lactate *in vitro*.

This rapid placental metabolic rate may have significant consequence in considerations of placental nutrient flux. In sheep, the placenta normally consumes 50 percent of the oxygen and 75 percent of the glucose that leaves the uterine circulation (Meschia, 1983). Far from being a simple membrane diffusion system, the placenta appears to be actively involved in the metabolism of major substrates, and this has added considerable mathematical and practical complexity to metabolic studies that attempt to characterize and compare maternal and fetal rates of substrate metabolism in experimental animals (Hay et at., 1981; Sparks et al., 1982).

From the point of view of transport, the properties governing nutrient flux across the placenta also are receiving considerable attention. In general, nutrient transport can be considered to be limited by diffusion on the one hand and by blood flow on the other. More recent work has documented that the flux of actual nutrients appears to be more complicated and varies from simple diffusion as for water; facilitated diffusion, as for glucose; or active transport, as for some amino acids and calcium. Fluxes of some substrates, such as ethanol, appear to be directly related to placental blood flow, while fluxes of others, such as glucose and oxygen, are relatively independent of flow until it is markedly diminished (Wilkening and Meschia, 1985; Wilkening et al., 1985). The effect of alterations in uterine blood flow on actively transported substrates is unknown. Because substrates appear to be affected differently by changes in uterine blood flow and maternal substrate concentration, alterations in blood flow may affect the transport of some substrates more than others. Thus, there is a possibility that alterations in flow or concentration, such as those that occur with exercise or dietary interventions, may produce not only differences in nutrient flux but also some redistribution in the types of caloric sources available to the fetus.

The nonlinearity of nutrient flux to blood flow (e.g., glucose and oxygen) (Wilkening and Meschia, 1985; Wilkening et al., 1985) and to concentration (e.g., glucose) (Simons et al., 1979) significantly complicates the prediction of nutrient flux across the placenta from mother to fetus. The amounts of glucose and oxygen crossing the placenta do not change substantially with a change in blood flow until there is a marked reduction of flow, but they decrease rapidly with a further reduction in blood flow. Similarly, many substrates, including glucose, amino acids, and minerals, cross the placenta by carrier-mediated or active transport systems. Thus, changes in blood flow or nutrient concentration may have minimal or dramatic effects, depending on the precise nature of the transport system and the particular circumstances under study. Studies in chronically prepared sheep, discussed later in this report, suggest that exercise may result in decreases in uterine and umbilical blood flow unaccompanied by decreases in nutrient flux.

Placental Transport in Malnourished Women and Animals

The placentas of women from lower socioeconomic groups weigh less, have disproportionately large deficits in trophoblastic mass, and have reductions in the surface area of villi. The surface area of the villi of fetal capillaries is also reduced as compared with that of fetuses developing in women from higher socioeconomic groups (Laga et al., 1972). Reduced amounts of placental DNA also have been measured (Dayton et al., 1969). It is uncertain whether these placental defects alter fetal nutrition. It is thought that the fetal demand for nutrients is far less than the placental functional capacity for transport. For example, when rats were malnourished in early gestation and returned to *ad libitum* feeding on day 14, pup birth weight recovered to control levels, whereas placental weight did not (Ahokas et al., 1983a). In sheep, reduction in placental size due to chronic undernutrition is highly correlated with reduced fetal growth rate during late gestation (Mellor, 1983). In humans, degenerative placental changes are not associated with a reduction in birth weight (Shah et al., 1979). It seems that morphological changes in the placenta due to malnutrition may not necessarily impair transport capacity sufficiently to alter fetal nutrition (Jones and Crnic, 1986).

Effect on Nutrient Flux

In animals, chronic protein-energy malnutrition may significantly affect both the circulating nutrient concentration and maternal hemodynamics. As noted earlier, numerous studies in sheep, rats, rabbits, and guinea pigs have demonstrated that there are decreases in blood glucose associated with elevations in keto acids and fatty acids.

The relationship of nutrient flux to either blood flow or maternal nutrient concentration appears to be nonlinear and is possibly saturable for nutrients whose transport is either carrier-mediated or actively transported (Wilkening and Meschia, 1985; Wilkening et al., 1985). However, the combination of diminished uterine blood flow and altered substrate concentration suggests that chronic fasting may diminish the flux of nutrients available to the fetus. Such data are limited, but direct measurements in sheep suggest that glucose flux may be substantially diminished during prolonged fasting: The decreases for lactic acid are less. Given the limited permeability of the cell to keto acids and fatty acids, the net result suggests that there is diminished total nutrient entry to the conceptus during fasting. Similarly, studies in small animals demonstrate the altered transport of nutrient analogs consistent with the hypothesis of diminished nutrient flux when the mother is undernourished.

Maternal protein-calorie malnutrition in rats can also limit the normal expansion in circulating blood volume and can result in diminished uterine blood flow (Rosso, 1981). Decreased uterine blood flow and decreased substrate concentration in combination result in diminished nutrient delivery consistent with diminished nutrient flux from mother to fetus.

FETAL METABOLISM AND NUTRITION

Studies of fetal body composition during pregnancy have established ranges for fetal nutrient requirements. Measurements of fetal body composition are available for several species, including rats (Lederman and Rosso, 1981), sheep (Rattray et al., 1974), guinea pigs (Sparks et al., 1985) and humans (Sparks, 1984; Widdowson and Spray, 1950). There are significant interspecies differences in nutritional requirements for fetal growth. For these reasons, one must be cautious in interpreting fetal growth data between human and nonhuman species.

Surprisingly, the more extensive data on fetal body composition are available for humans than for other species, and these cross-sectional data provide chemical analyses of body composition in a large number of fetuses over a range of gestational ages. These data, which have been reviewed extensively (Sparks, 1984; Widdowson and Spray, 1950; Ziegler et al., 1976), provide estimates of the net rate of accretion of calories and major macronutrients in the human fetus, although the data provide only minimal requirements for those nutrients. Growth of the human fetus in the third trimester represents accretion rates of approximately 40 kcal/kg of fetal weight per day, of which approximately 80 percent is accounted for by fat accretion. Rates of nitrogen, nonfat (lean weight), and mineral accretion have also been calculated.

Data describing the diet available to the fetus for oxidative metabolism and tissue accretion are considerably more limited. Unstressed measurements of substrate uptake are available only in the ruminant. In summary, during normal pregnancy, the fetal lamb grows a lean fetus at approximately 6 percent per day on a diet consisting of glucose (35 percent), lactic acid (15 percent), and amino acids (50 percent). The placenta of the fetal lamb is somewhat impermeable to fatty acids, keto acids, and acetate, and these substrates appear to contribute minimally to oxidative metabolism and tissue growth in the fetal lamb.

For the human, the fetal diet is likely to differ somewhat from that of the lamb. Glucose appears to provide a larger share of the fetal diet, as high as 50 percent. In addition, the human placenta appears to be more permeable to fat, and placentally transferred fat may provide a meaningful portion of total fetal intake of calories and carbon.

The role of lactic acid as an exogenous fetal macronutrient in humans is less clear (Soothill et al., 1986), although for unstressed human fetuses, the data support the fact that lactic acid is a fetal nutrient (Stembera and Hodr, 1966). From the point of view of normal fetal nutrition, lactic acid appears to be produced by the placenta (derived from the glycolysis of fetal glucose) and consumed by the fetus, providing a major source of energy and carbon. As it was mentioned earlier in contrast, lactic acid accumulation in the fetus is regarded clinically as an indicator of the degree of fetal distress, as caused by asphyxia or hypoxia. In humans, lactic acid is produced by intensive exercise and is widely used as an indicator of exercise conditioning and fitness. These very different roles of lactic acid have not been reconciled, and the consequences of maternal lactic acidemia from vigorous maternal physical work on a fetus already consuming large amounts of lactic acid has, thus far, received only minimal scientific attention. However, Chandler et al. (1985) showed that in sheep, despite increased maternal and fetal blood concentration, fetal lactate metabolism is not grossly disturbed by moderate maternal exercise. This study also examined fetal responses to combined maternal under-nutrition and exercise.

Iron Status and Work Performance

Iron is an essential component of hemoglobin, which is responsible for transporting oxygen to the tissues. Iron deficiency can lead to reductions in hemoglobin synthesis and impairment of oxygen transport to the tissues. Iron deficiency can also cause a reduction in the synthesis of cytochrome C, which is involved in transporting electrons and forming ATP during oxidative metabolism in the mitochondria. Iron deficiency may also reduce myoglobin synthesis, which is essential for storing oxygen in the muscles for use during work. If cytochrome C and myoglobin levels are low, the working muscle must rely primarily on anaerobic metabolism, which results in lactic acid production. As earlier discussed in this chapter, lactate accumulation during physical activity contributes to fatigue and impairs work performance (O'Neil et al., 1986). These reductions in hemoglobin, cytochrome C, and myoglobin caused by iron deficiency were hypothesized to have a negative effect on work performance.

The impairment of physical performance under conditions of iron deficiency is evident from a reduction in total exercise time, increased heart rate, decreased oxygen uptake (decreased maximal oxygen consumption), and increased lactate levels in blood (Gardner et al., 1977; O'Neil et al., 1986).

Severe iron deficiency markedly alters the metabolism of biogenic amines and the production of triiodothyronine (T3). Increases in the circulating levels and urinary excretion of norepinephrine and reductions in T3 production rates have been documented, together with diminished receptor sites in the brain for dopamine and serotonin. These changes are considered to be responsible for behavioral modifications, and for increased heartbeat loss and impaired temperature regulation in people with iron deficiency and anemia (Beard et al., 1984; Dallman, 1986).

The end result of iron deficiency on energy metabolism is a marked diminution of the efficiency of energy use and conservation. These consequences of iron deficiency and anemia may exaggerate the undesirable effects of energy deficiency during pregnancy and lactation on work performance and the outcome of pregnancy. These are areas in which research is needed.

Workers' productivity may also be negatively affected by iron deficiency. Iron supplementation for 2 months significantly improved the amount of tea female workers picked on a tea plantation in Sri Lanka (Edgerton et al., 1979). The degree of improvement was greater in more anemic women (those with hemoglobin concentrations were between 6.0 and 9.0 g/dl). Work tolerance, as estimated by changes in heart rate or actual work performance, was 20 percent lower in women with hemoglobin concentrations between 11.0 and 11.9 g/dl than it was in women with hemoglobin concentrations greater than 13.0 g/dl (Gardner et al., 1977). No data are available on the effect of moderate or severe iron deficiency and anemia in exercise performance or in physical work productivity during pregnancy and lactation.

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4

Nutrient Metabolism and Physical Activity

ENERGY

Energy is the primary dietary requirement. If the overall intake of energy is inadequate, dietary protein, vitamins, and minerals will not be used effectively for their various metabolic functions. Durnin (1987) estimated that the energy cost of pregnancy is about 60,000 kcal among well-fed women. Based on the composition of the average weight gain and the cost of its accretion and maintenance, Hytten (1980b) estimated that the energy requirement for pregnant women who have an adequate prepregnancy nutritional status totals 85,000 kcal, or 300 additional kcal/day if the need is distributed equally over the 280 days of gestation. Of the 85,000 kcal, about 41,000 kcal are deposited as the accretion of fat and lean tissue, and about 36,000 kcal are required for the increased metabolism rate (Table 4-1). An additional 8,000 kcal are needed to convert dietary energy to metabolizable energy. It is thought that the energy demand is distributed equally throughout the last 10 weeks of the pregnancy. Deposition of about 3.5 kg of fat in the maternal compartment accounts for two-thirds of the total energy need during the second and third quarters of pregnancy. Fetal growth needs are maximal in the fourth quarter.

Resting or Basal Energy Requirements

Many investigators have attempted to confirm the estimated energy requirement for pregnancy by measuring the two major components of energy expenditure: resting metabolism and energy expenditure during periods of activities. These two aspects may account for 90 percent or more of the total energy expenditure.

TABLE 4-1 Cumulative Energy Cost of Pregnancy Computed from the Energy Equivalents of Protein and Fat Increments and the Energy Cost of Maintaining the Fetus and Added Maternal Tissues

	Equivalent (kcal/day)[a] at the Following Weeks of Pregnancy				Cumulative Total
	0–10	10–20	20–30	30–40	(kcal)
Protein	3.6	10.3	26.7	34.2	5,186
Fat	55.6	235.6	207.6	31.3	36,329
Oxygen consumption	44.8	99.0	148.2	227.2	35,717
Total net energy	104	344.9	382.5	292.7	77,234
Metabolizable[b]	114	379	421	322	84,957

[a] Taken as 5.6 kcal/g for protein and 9.5 kcal/g for fat.

[b] Metabolizable energy = total net energy + 10%.

NOTE. For the first 10-week; period, the total increment is divided by 56 because pregnancy is dated from the last menstrual period.

SOURCE: From Hytten, 1980 (with permission).

Measurements of energy expenditure for metabolism (i.e., basal (BMR) or resting (RMR) metabolic rate) from several groups of pregnant women are given in Table 4-2 (Blackburn and Calloway, 1976; Durnin et al., 1985; Forsum et al., 1985; Lawrence et al., 1984, Nagy and King, 1983). For comparison, the estimated RMR during pregnancy and its total energy cost (Hytten, 1980a) are also presented. The additional amount of energy used for RMR should be comparable with the estimated need for metabolism, that is, 36,000 kcal/pregnancy (Hytten, 1980a). Resting energy metabolism increased in all the groups of women studied, but the incremental increase varied greatly among the groups. The biggest net change in resting metabolism was seen in Swedish women (46,500 kcal), whereas the unsupplemented women in The Gambia (see Chapter 3) had the lowest change (1,000 kcal).

Studies from The Gambia suggest that maternal nutritional status influences the level of change in resting metabolism during gestation. The unsupplemented women, who consumed only 1,500 kcal/day, had lower RMRs in the second and third trimesters than did the women who received supplements and consumed about 1,950 kcal/day (Lawrence et al., 1984; Prentice et al., 1983). The supplemented women required an additional 13,000 kcal for resting metabolism; only 1,000 kcal were required by the unsupplemented women (Table 4-1).

Conventional formulas make no allowance for the increased energy costs required to move a heavier body because it is assumed that pregnant women compensate for the increased energy need for physical activity by becoming more sedentary or by performing tasks in a more relaxed or energy-efficient manner (Banerjee et al., 1971; Emerson et al., 1972, Hytten, 1980a).

However, physical activity and exercise recently have become more popular among women living in industrialized societies, and the effects of such programs on the energy requirements during gestation depend on the frequency, intensity, and duration of exercise. Although studies of the energy expenditure of pregnant women who regularly take part in recreational activities have not been done, one group of investigators reported that the energy intakes of women who jog throughout their pregnancies are similar to those reported by sedentary pregnant women studied previously (Slavin et al., 1985). There is some evidence that physical activity improves the efficiency of energy use in nonpregnant women (King and Butterfield, 1986). If this is also true in pregnant women, the net energy cost for physical activity among fit pregnant women may be less than expected.

Energy Requirements for Activity

The amount of energy expended during physical activity fluctuates with the intensity, duration, and type of exercise, as well as body weight. Tables are available for estimating energy expenditure for a variety of activities based on the individual's body weight. Because of weight gain during pregnancy, the energy required for weightbearing activity should increase gradually with advancing gestation. The energy expenditure for nonweightbearing activity may also be higher in pregnant women as a result of the increased basal metabolic rate, especially during the second half of pregnancy. The efficiency of a person's movements also influences the total energy expenditure for activity. Runners who have smooth, comfortable gaits expend fewer calories than those who struggle all the way. It has been stated that pregnant women move in a more economical manner (Hytten, 1980a). If movements become more efficient during pregnancy, the energy cost for activity during pregnancy may be lower than that in the nonpregnant state. Separate tables for physically active pregnant women may be useful to adjust the energy expenditure for changes in basal metabolism and efficiency of movements (Table 4-3).

The amount of energy required for quiet or light activities that do not involve body movement is reflected in the change in resting metabolism. The energy requirements for activities involving body movement reflect the amount of weight gain as well as the change in resting metabolism.

TABLE 4-2 Energy Expenditures of Pregnant Women at Rest

		Resting Metabolic Rate (RMR) of Women (kcal/min)				
			Pregnant (trimester)			Total Increment in RMR (kcal)
Reference	Population[a]	Nonpregnant (kcal/min)	1st	2nd	3rd	
Theoretical						
Hytten and Chamberlain, 1980[b]		1.07	+0.103	+0.103	+0.16	36,000
Developed Countries						
Forsum et at., 1985[c]	Sweden (n = 19)	0.93	0.97	1.13	1.22	46,500
Durnin et al., 1985[d]	Glasgow, Scotland (n = 67)	0.94	0.91	0.95	1.01	7,000
Nagy and King, 1983[e]	United States	0.86	—	1.01	1.15	—
Blackburn and Calloway, 1976[f]	United States	0.79	—	0.96	1.10	—
Less Developed Countries						
Lawrence et al., 1984[g]	The Gambia Unsupplemented (n = 10)	0.97	0.94	0.94	1.05	1,000
	Supplemented (n = 12)	0.94	0.94	0.97	1.10	13,000

[a] *n* indicates the number of women studied.
[b] First, second, and third trimester changes in RMR were derived from oxygen consumption data.
[c] RMR data calculated from figures.
[d] Values listed represent basal metabolic rate (BMR) data and not RMR data. BMR data are generally about 10 percent lower than RMR data.
[e] The nonpregnant ($n = 6$) data were derived from a different subject population. A population of pregnant women was studied at 15–25 and 35–40 weeks ($n = 5$).
[f] Values listed represent BMR data, not RMR data. Pregravid data are actually a postpartum measurement of lactating and nonlactating women ($n = 16$). These values were grouped, as no significant differences were observed. Eleven and six women were studied at 20–28 and 37–40 weeks, respectively.
[g] Of the Gambian women studied, 12 received a daily food supplement, and 10 received no supplement.

Comparisons of the energy expenditures for common household tasks in pregnant and nonpregnant women (Banerjee et al., 1971) showed that pregnant women expend more total energy for a given task, but the net increase in energy expenditure above the resting expenditure is lower in pregnant than in nonpregnant women. This suggests that the pregnant women performed the tasks in a more relaxed or economical fashion, that is, they reduced their work intensity. A similar decrease in work intensity was seen in the second and third trimesters of pregnancy among women in The Gambia (Lawrence et al., 1985). Energy expenditures above the resting metabolism were less in pregnant than in nonpregnant women for activities such as weeding, hoeing, pounding grain, and washing clothes.

TABLE 4-3 Energy Cost of Activities During Pregnancy

	Total Cost (kcal/min)			Net Increase Above RMR (kcal/min)			Total Cost (cal/kg/min)		
Activity	NP	Tr2	Tr3	NP	Tr2	Tr3	NP	Tr2	Tr3
Sitting	0.95	1.07	1.25	0.16	0.11	0.15	15	17	17
Standing	1.14	1.20	1.42	0.35	0.24	0.32	18	19	19
Biking (30 mph)[a]	3.98	3.88	4.82	3.19	2.92	3.72	61	61	62
Walking (3 mph)[a] U.S. women treadmill	3.98	4.12	4.90	3.19	3.16	3.80	60	62	64
Walking (3 mph)[c] U.S. women self-paced	—	4.61	5.13	—	3.60	3.98	—	71	66
Walking (3 mph)[d] Gambian women self-paced	3.03	—	3.28	1.79	—	2.03	59	—	57

NOTE: NP, Nonpregnant; Tr2, Second Trimester; Tr3, Third Trimester.
[a] From Blackburn and Calloway, 1976.
[b] From Blackburn and Calloway, 1974.
[c] From Lawrence et al., 1985.
[d] From Nagy and King, 1983.

Among agricultural workers in developing countries, there are seasonal changes in the food supply and physical work. In The Gambia during the wet season, when more people go hungry, agricultural work is greater than during the dry season, when people usually have adequate food supplies. Changes in body weight indicate that pregnant and lactating women are in a negative energy balance during the wet-hungry season and in a positive energy balance during the dry-fed season (Prentice, 1984). Thus, their body weights are relatively constant from year to year and are considered to be in long-term energy balance. Calculations of the energy available from either diet or maternal fat stores for resting metabolism and activity in pregnant and lactating women during the wet and dry seasons show that the amount of energy available is similar during both seasons, even though the energy intake is about 200 to 250 kcal less per day in the wet season. (Note: These values may be questionable as women are less likely to admit that they had sufficient food in the wet season).

The increase in the amount of energy required for walking during gestation is proportional to the maternal weight gain. The energy expended for walking (4.4 kph) in women who were in late gestation was about 0.25 kcal/minute higher than it was in nonpregnant or early-gestation women in The Gambia; the late-gestation women weighed about 5 kg more than the nonpregnant or early-gestation pregnant women (Lawrence et al., 1985). In comparison, the energy required for walking (4. 8 kph) among North American women who gained about 10 kg during pregnancy was twice as high (0.5 kcal/minute) (Nagy and King, 1983). These data suggest that the energy need for walking increases about 0.05 kcal/minute/kg of weight gain during gestation. Women who spend a significant amount of time each day walking have an additional need for energy that currently is not included in recommended energy intake for pregnant women (NRC, 1980).

Sources of Energy

The source of energy in the diet, that is, carbohydrates, protein, or fat, may be more important for physically active than for sedentary pregnant women. Glucose is the preferred fuel for the fetus, and glucose is transported across the placenta by facilitated diffusion. An adequate glucose supply for the fetus is favored by maternal increase in lipolysis during the third trimester. Glucose is also the fuel of choice for short-duration, high-intensity exercise; however, because glycogen stores are limited, fat is always an important fuel for endurance activities. Since tissue use of glucose is increased during exercise, maternal glucose levels in blood fall and may thereby limit the fetal glucose supply. In late pregnancy, glucose concentrations in blood fall with short-term exercise of moderate intensity (Gorski, 1985), suggesting that in spite of increased fat use, glucose production does not keep pace with accelerated glucose use during exercise. Changes in lactate metabolism may play a key role in these events. There may be an interspecies difference in the blood glucose response to exercise; the glucose concentration in blood was found to increase in pregnant ewes after prolonged exercise (Gorski, 1985). Studies of uterine glucose uptake are needed to determine whether a fall in the maternal glucose concentration in blood during exercise is associated with a reduction in the fetal glucose supply. Those studies may not be feasible in human, however.

To ensure the replacement of maternal glycogen stores, it may be prudent for physically active pregnant women to consume a diet high in complex carbohydrates following a period of exercise. This would allow an adequate supply of glycogen for the maintenance of maternal glucose levels in blood and the fetal glucose supply during short-term or overnight fasts.

PROTEIN

Pregnant women retain about 6–8 g of protein (1–1.3 g of nitrogen) per day during the last half of their pregnancy. A reduction in urea synthesis and urinary urea nitrogen excretion occurs during pregnancy so that the proportion of dietary protein retained as tissue protein is higher. Since it would require that insufficient levels of protein be consumed, the efficiency of protein use in pregnant women has not been quantified. The National Research Council (1989) recommends that pregnant women consume an additional 10 g of protein per day throughout pregnancy.

IRON

Iron deficiency anemia is one of the most common nutritional problems among pregnant women. Although menstrual iron losses cease during gestation, pregnant women still require more iron than nonpregnant women do. This increased iron need, coupled with an intake of poorly absorbed iron (i.e., vegetable sources) and low maternal iron stores, accounts for the high prevalence of iron deficiency during pregnancy.

If dietary stored iron is not limiting, 800 mg of iron are deposited in maternal and fetal tissue (Bothwell et al., 1979). Of the 800 mg of iron gained, 45 percent is deposited in the conceptus and 55 percent is deposited in the expanded maternal red blood cell (RBC) mass. Blood loss at delivery and daily basal iron losses result in additional iron losses that must be provided for during pregnancy, bringing the total iron need to 1,200 mg. Since most of the expanded RBC iron is returned to the maternal stores following delivery, the net iron need during pregnancy is about 1,040 mg. The most variable of these needs is the amount required for expansion of the RBC mass, which varies with maternal iron status. In women with an unlimited iron supply, the RBC mass increases by about 35 percent; if iron is limited, the RBC mass can only expand about 18 percent (Bothwell et al., 1979).

Serum ferritin levels tend to rise postpartum, presumably due to a shift in RBC iron to the storage pool (Taylor et al., 1982). Increases in serum ferritin are greater in supplemented than in unsupplemented women, suggesting that the RBC mass expands more in the supplemented woman during gestation. Increased maternal serum ferritin levels are associated with higher serum ferritin levels in the newborn and in the 6-month-old infant, suggesting that maternal iron status does influence the amount of iron stored in the fetus (Puolakka, 1980).

To prevent depletion of maternal iron stores and to provide the needs for pregnancy, the Institute of Medicine (1990) recommends that all women take 30 mg of supplemental iron daily throughout pregnancy. Serum ferritin levels provide a rough measure of maternal iron stores during gestation. The adequacy of iron for hemoglobin formation can be estimated from erythrocyte volume measurements. A volume of less than 80 femtoliters is suggestive of iron deficiency anemia.

PREGNANCY AND OXYGEN CONSUMPTION

Under conditions of maximal exercise, maximal oxygen consumption (VO_2-max) provides an indicator of maximal sustainable energy expenditure, and there are varying reports about whether maximal oxygen consumption can be increased in pregnant women above the level found in nonpregnant women. Recent work with pregnant women in the third trimester during treadmill exercise suggests that oxygen consumption at basal and mild work levels is increased over that in nonpregnant controls, while oxygen consumption may be significantly decreased at moderate and maximal levels of exercise (Artal, 1986). Limited data from animals suggest that some increase in VO_2-Max is possible with physical training, particularly if the training begins before pregnancy.

Pregnancy also appears to increase the biological work necessary to accomplish physical work, through increases in both total mass and respiratory work. Upper body physical activity at the same work load in pregnant and nonpregnant women appears to increase the VO_2-max to similar degrees, while treadmill exercise involving the locomotion of gravid women appears to require more energy in pregnant than nonpregnant women, perhaps because of the larger mass carried by pregnant women.

The combination of increased resting oxygen consumption and decreased VO_2-max suggests that there is a decreased tolerance to exercise during the later part of pregnancy. The effect of conditioning before or early in pregnancy remains to be determined.

PREGNANCY, WORK, AND SUBSTRATE METABOLISM

The immediate effects of maternal physical activity on glucose metabolism are unclear. Reports of studies done in humans demonstrate increased, unchanged, or decreased serum glucose concentrations in response to maternal physical activity. Glucose turnover has not been measured in exercising, pregnant women, but the increasing respiratory quotient observed in exercising, pregnant women could be consistent with the increasing use of carbohydrates during exercise (Artal, 1981). In pregnant sheep, the maternal glucose level appears to increase with exercise (Bell et al., 1983, 1986; Lotgering et al., 1985). It is about double during treadmill exercise at about 2–3 times the RMR (Levry et al., 1982).

Hormonal Changes

Maternal hormonal responses to physical activity have received comparatively little attention, but in general, they appear to resemble the changes observed with acute stress. Mild exercise in pregnant women causes minimal hormonal changes, with a small increase in norepinephrine (Artal, 1981). More intense exercise appears to be associated with elevated epinephrine and norepinephrine, but with nonsignificant changes in plasma cortisol levels. Glucagon levels also are elevated with moderate exercise, presumably increasing hepatic glucose concentrations. Prolactin levels also increase with moderate exercise (Rauramo, 1982).

Temperature

As might be expected, maternal temperature appears to increase during physical activity. Studies in chronically catheterized sheep demonstrated small elevations in core temperature with sustained physical activity (Bell, 1986; Lotgering et al., 1985). Studies in humans suggest that the rise in core body temperature with physical activity is similar in pregnant and nonpregnant women. In pregnant as in nonpregnant animals and probably humans, exercise-induced increases in body temperature are exacerbated if ambient temperature is high. This may be an important consideration where women have to work in hot climates, especially if humidity is high, for example, wet season in The Gambia.

The placenta is an efficient exchanger of heat, as well as of gases and nutrients, and limited information suggests that physical activity-induced maternal hyperthermia appears to lead to fetal hyperthermia. Hyperthermia may, under other conditions, have effects on gas transport, metabolic rate, for teratogenicity; there also may be other effects. For example, chronic maternal hyperthermia during mid-and late gestation has profound negative effects on placental growth and transport function in sheep (Bell et al., 1987). The specific effects on the fetus of hyperthermia induced by physical activity remain unknown, however.

EFFECT OF MATERNAL UNDERNUTRITION OR PHYSICAL ACTIVITY ON THE FETUS

An acute 50-percent restriction in food intake during pregnancy in rats has a proportionately greater effect on fetal weight than on maternal weight (Lederman and Rosso, 1980). In comparison with those of pair-fed nonpregnant controls, maternal fat stores were unchanged at term, suggesting that the mothers failed to mobilize their available reserves to sustain fetal growth. Fellows and Rasmussen (1985) compared the partitioning of nutrients among acutely and chronically underfed pregnant rats. Acutely restricted dams devoted a greater proportion of the weight gain to their fetuses and had heavier litters than did chronically restricted dams. Chronically restricted dams gained both fat and protein during pregnancy, while acutely restricted dams lost fat while they maintained their protein stores at prerestricted levels. Although there is some difference in the responses of acutely versus chronically restricted dams, results of these two studies indicate that when food is restricted during gestation, a dam spares her own tissue at the cost of the fetus.

Only limited information is available regarding the effects of maternal physical activity on the fetus. For practical reasons, human data relating physical activity to fetal metabolic status are very restricted and are essentially limited to observations of the fetal heart rate.

As it has long been known, exercise induces a redistribution of blood flow that favors working muscles at the expense of splanchnic organs. A reduction of uterine blood flow of over 50 percent could potentially induce fetal asphyxia and hypoxia. Although it is believed that this happens very rarely in healthy women during mild and moderate exercise, it is possible that it may occur during strenuous and prolonged exercise (Artal et al., 1986). On the other hand, healthy fetuses may tolerate short periods of asphyxia, to which they will respond initially with an increased heart rate of 10–30 beats per minute over the normal basal rate of 140–155 beats per minute, depending on gestational age. Artal et al. (1986) have reported that in 37 pregnant women, the fetal heart rate remained significantly elevated immediately after and at 5 minutes after the end of exercise, regardless of the level of exercise; the fetal heart rate returned to the baseline 15 minutes after mild and moderate exercise, but remained elevated for at least 30 minutes after a strenuous period of exercise was stopped. Most measures of fetal responses have been taken after exercise because recording the fetal heart during exercise is technically very difficult. However, among 82 records of fetal heart rate responses during the mother's exercise, an incidence of fetal bradycardia of 8.5 percent has been reported (Artal et al., 1986). Limited information also is available on fetal breathing movements, which may increase or decrease in response to maternal physical activity, possibly in relation to maternal glucose and catecholamine responses (Platt et al., 1983).

More detailed metabolic information is available for chronically prepared sheep (Bell, 1983, 1986; Chandler, 1981, 1985; Clapp, 1980). Several observers have noted decreased uterine and, to a lesser extent, umbilical blood flow during physical activity, but oxygen uptake appears to be preserved. More recent studies have quantified the effects of physical activity on metabolism of the fetus and uteroplacenta. These studies in sheep have confirmed the observation of decreased uterine and umbilical blood flows and have documented the unchanged uterine and umbilical uptakes of oxygen, as well as the unchanged placental consumption of oxygen. Uterine glucose uptake increased, although no increase in umbilical glucose uptake was observed. Placental production of lactate showed considerable variation, while net umbilical lactate uptake appeared to decrease. These studies seem to indicate that changes in uterine blood flow need not imply that there are similar changes in nutrient flux to the placenta and fetus.

Unfortunately, no studies of the effects of maternal physical activity on fetal outcome in animals could be located.

EFFECTS OF UNDERNUTRITION ON PHYSICAL ACTIVITY

Physical activity influences nutritional status and the requirements for nutrients. Individuals who regularly perform strenuous work have a higher requirement for energy than do similar individuals doing sedentary work. Conversely, the nutritional status of an individual influences his or her capacity to do work. Individuals with a reduced weight-for-height often have a compromised muscle mass and a reduced capacity to perform certain types of physical work. Also, small stature, whether due to poor nutrition during the growing years or other causes, may reduce the capacity to perform certain types of physical work later in life. In developing countries, those populations with the lowest energy intake and the highest prevalence of undernutrition are also the ones engaged in the hardest work. The effect of chronic undernutrition among these individuals on productivity, discretionary physical activity, and physical work capacity (PWC) is discussed below.

Productivity

Productivity is a utilitarian concept that involves a product with a given value as a result of work. This is different from work performance, physical activity, or work capacity, which refer to parameters independent of the measurement of the product. Time-motion studies measure energy expenditure and the contribution of physical activity to it; they may or may not be coupled to measurements of productivity in which the type of task completed and the amount of time to complete a task are reported. These studies are generally done in individuals who perform agricultural or construction work. Although impaired productivity has been documented in chronically undernourished adult male and female populations (Edmundson, 1977; Viteri, 1971; Viteri and Torun, 1974; Wolgemuth, 1982), convincing evidence on the effect of mild to moderate chronic undernutrition on a reduction of productivity or, on the other hand, of energy supplementation on an increase in productivity is not available (Immink et al., 1984; Viteri et al., 1981). This may be due to the complex biologic-economic-social interactions that define productivity (Viteri et al., 1981). For example, maintenance of productivity may be due, in part, to the subjects' desire to please the investigators (Hawthorne effect) by expending energy in excess of their intakes (Viteri and Torun, 1974). Also, payment for work may be an incentive for individuals to work beyond their comfortable level of energy expenditure to provide for family needs. Another suggested explanation for the ability of undernourished individuals to maintain productivity is that they expend less energy while performing standard work tasks than well-fed individuals do because of a higher efficiency of work. Several studies (Ashworth, 1968; Keys et al., 1950; Poole and Henson, 1988), however, have failed to find convincing evidence of improved work efficiency in underfed individuals. A reduction in basal or maintenance energy expenditure also could reduce the overall energy expenditure needed to perform work in underfed individuals. Under conditions of severe energy restriction, there is a decrease in the resting metabolic rate per unit mass of lean tissue (Keys, 1950); this decrease is more marked in the early stages of energy restriction (deBoer, 1986). However, after correction for body weight and body composition differences, the basal metabolic rates of Indian men with different socioeconomic and nutritional states did not differ (McNeill et al., 1987). Thus, there is little evidence at present that underfed individuals expend significantly less energy while performing work than well-fed individuals do.

Discretionary Physical Activity

Although nutritional status seems to have little effect on productivity, there is some evidence that it does influence discretionary physical activity. In classical studies of semistarvation, Keys et al. (1950) noted that after a 24-week period of reduced food intake, the voluntary movement of the men studied was noticeably slower. Viteri and Torun (1974) also noted a relationship between food intake and discretionary activity in Guatemalan workers. Those workers who received a 250-kcal supplement daily used their *siesta* to work at home, walk around town, or play football, while the unsupplemented workers rested or slept. Both groups of workers took the same amount of time to get to work each morning, but the unsupplemented workers rested more frequently on their way home from work. In a group of healthy young men from a graduate theological seminary in California, a 500-kcal/day reduction in food intake was associated with a change in physical activity (Gorsky and Calloway, 1983). Obligatory activities were not affected, but the men spent significantly less time standing at leisure and walking and more time sitting at leisure. These data suggest that an early response to limited food intake is a reduction in discretionary activity, if time for discretionary activity exists. However, the data in Chapter 2 of this report indicate that rural Guatemalan women who perform agricultural work but who are also responsible for household work and child care spend only 25 percent, (6 hours) of their day *off* their feet. These women seem to have no discretionary time at all after allowing for sleep. The activity patterns of women given energy supplements during pregnancy and lactation have not been compared with those of unsupplemented women, but it has been observed that those women who receive energy supplements seem to have more energy for singing and talking while working in the fields (Prentice et al., 1983).

Physical Work Capacity (PWC)

PWC is quantitated by determining the maximal capacity to consume oxygen (VO_2-max) or the endurance time while performing standardized work: that is, the time it takes an individual to walk on a treadmill or ride a bicycle ergometer at a defined speed and grade. A restriction in food intake, either acute or chronic, seems to cause a significant depression in the

VO_2-max. A 580 or 1,010-kcal/day restriction for 24 days caused a 5–10 percent reduction in VO_2-max; this decrease was proportional to the decrease in body weight (Taylor, 1957). The VO_2-max of chronically malnourished adults in Guatemala and Colombia was depressed to the same degree as the depression of muscle cell mass (Spurr, 1984); more than 80 percent of the difference in VO_2-max between subjects with mild or severe malnutrition was accounted for by differences in muscle mass. While endurance time did not seem to be related to nutritional status among the subjects studied (Spurr, 1984), an unexplained reduction in the time required to become fatigued was seen in severely malnourished individuals after they had completed 2.5 months of dietary repletion. It is unclear why repletion with a nutritionally adequate diet caused a reduction in endurance time. There are very few studies of the effect of malnutrition on endurance time. More work is needed in this area.

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5

Effects of Diet and Physical Activity in Pregnant Human Populations

This chapter reviews the epidemiologic evidence concerning the effects of maternal energy intake and physical activity on pregnancy. Three different aspects of maternal energy balance are considered: nutrition during gestation, maternal physical activity, and the combined effects of nutrition and physical activity during gestation. Where available data permit, these three aspects will be examined with respect to the following fetal, infant, and maternal outcomes: fetal growth, gestational duration, spontaneous abortion (miscarriage), congenital anomalies, maternal mortality, and other pregnancy complications.

Far more studies have focused on fetal growth and gestational duration than on the other outcomes; consequently, these will receive more attention here. Fetal growth and gestational duration are the two determinants of birth weight, and from an international health perspective, birth weight is the most readily available index of pregnancy outcome. It is also a useful general indicator of women's health before and during pregnancy and of adverse influences on the developing fetus (See Table 2-3).

Much of the material in this chapter that bears on the determinants of fetal growth and gestational duration is taken from a recent review (Kramer, 1987) based on a methodologic assessment and synthesis of 895 articles in English and French published between 1970 and 1984. These papers described 43 factors that may act as determinants of intrauterine growth retardation or short gestation. A list of the studies examined in this review has been published (Kramer and Sasportas, 1985). The methodologic criteria used in evaluating studies bearing on maternal energy intake, physical activity, and gestational weight gain are shown in Tables 5-1a and 5-1b. For physical activity, the review has been updated (using the same criteria) to include studies published since 1984. In addition, other maternal and infant outcomes also have been considered.

TABLE 5-1a Methodologic: Standards Used To Assess Published Studies Bearing on Maternal Energy Intake, Physical Activity, and Gestational Weight Gain

	Gestational Weight Gain	Physical Activity	Energy Intake
Definition of Target Population and Study Sample	X	X	X
Description of Study Participation and Follow-Up Rates	X	X	X
Demonstration of Appropriate Temporal Sequence Between Factor and Outcome	X		X
Use of Experimental Design			X

TABLE 5-1b Confounding Variables Requiring Control Used To Assess Published Studies Bearing on Maternal Energy Intake, Physical Activity, and Gestational Weight Gain

Racial/Ethnic Origin	X		X
Maternal Height		X	X
Prepregnancy Weight	X	X	X
Maternal Age[a]	X	X	X
Socioeconomic Status	X	X	X
Energy Intake		X	
Physical Activity			X
Protein Intake			X
Cigarette Smoking	X	X	X
Alcohol Consumption	X	X	X

[a] Parity was accepted as a proxy control variable for maternal age.

EFFECT OF ENERGY INTAKE

Background

An important issue in studying energy intake is the difficulty in measuring it. Energy intake measurement requires either prolonged and careful observation, which may in itself influence energy intake, or adequate subject recall of dietary intake. Even if individual measurements are valid and reproducible, measurements must be made repeatedly during pregnancy to ensure that the entire gestational period is covered.

The susceptibility of energy intake to experimental intervention also deserves consideration. Random assignment of energy supplementation is feasible and provides the best methodologic approach for assessing the effects of energy intake, provided that caloric substitution and net caloric increase are also taken into account. Consequently, the best epidemiologic data available concerning the effects of energy intake are those based on supplementation trials or careful observational studies of several "natural" experiments involving severe caloric restriction (i.e., famines) in previously well-nourished women.

In the absence of a randomized experimental design, it is important to consider factors that may confound the relationship between energy intake and pregnancy outcome, that is, factors associated with energy intake and pregnancy outcome independent of energy intake. The potential confounding variables that should be controlled include racial or ethnic origin, socioeconomic status, age, parity, height, prepregnant nutritional and health status, and cigarette and alcohol consumption. In developing countries, a control for infectious morbidity during pregnancy is also important because it can be associated with both reduced energy intake and impaired fetal growth. Even chronic infestation with intestinal nematodes and protozoans may affect the efficiency of nutrient use and could act as an important confounding variable. Because women who consume more energy often burn more energy, a valid assessment of the effect of energy intake on pregnancy outcome requires careful monitoring of energy expenditure.

The length of gestation is itself an essential control variable because women who deliver their infants preterm will have consumed less total energy (an example of temporal precedence [reverse causality] bias). The effect of energy intake on gestational duration should, therefore, be based on the daily intake rather than overall intake. Effects on fetal growth either should be based on a similar measure (e.g., daily energy intake) or should control for gestational age.

In addition to its role as a potential confounding variable, prepregnant nutritional status, as reflected in prepregnancy weight, weight-for-height, or skinfold thickness, is also likely to modify the effect of energy intake on fetal growth. In other words, it might be expected that thin women would derive a greater increase in birth weight for a given intake of energy than would well-nourished or overnourished women. This hypothesis would predict that in women who begin pregnancy with large fat stores, energy intake would have little if any effect on fetal growth.

Gestational Duration

Few epidemiologic studies have examined the effects of energy intake on gestational duration. In fact, only two reports (Delgado et al., 1982; Villar et al., 1986) found a significant association, and those, though more recent and based on a larger sample, contradicted two previous reports of the same study of energy supplementation in Guatemala (Habicht et al., 1974; Lechtig et al., 1975). No effect on mean gestational age or rate of preterm delivery was reported in other energy supplementation trials (McDonald et al., 1981; Rush et al., 1980). Although historical evaluation of the effects of food supplements given to eligible women as part of the Special Supplemental Food Program for Women, Infants, and Children (WIC) program reported a significant increase in mean gestational age and a significant reduction in both preterm and very preterm (< 33 weeks) births, a concurrent (longitudinal) study found smaller, nonsignificant effects (Rush et al., 1988a and 1988b). Thus, although most of the available data suggest that maternal caloric intake does not have a large effect on gestational duration, a small effect cannot be excluded.

It is also important to understand that most studies bearing on gestational duration have based their assessment of gestational age on the mother's recollection of her last menstrual period. Compared with the "gold standard" of early ultrasonographic measurement of the biparietal diameter, low last menstrual period gestational age estimates tend systematically to underestimate true gestational age, whereas the reverse is true for high (i.e., postterm) last menstrual period estimates (Kramer et al., 1988). The end result will be some inevitable misclassification of growth-retarded infants as preterm (and vice versa).

Fetal Growth

Research on fetal growth reveals a different picture from that provided above. Examination of the evidence from the better designed and controlled epidemiologic studies (primarily the supplementation trials) reveals that there is an increase in the gestational age-adjusted birth weight of pregnant women given energy supplements (Blackwell et al., 1973; Herrera et al., 1980; McDonald et al., 1981; Mora et al., 1973; Prentice et al., 1983; Rush et al., 1980; Viegas et al., 1982). The only exception to this general pattern is the previously cited update of the Guatemala study (Villar et al., 1988), which found no reduction in risk of intrauterine growth retardation in energy supplemented women. The effect on fetal growth appears to be conditional on the women's nutritional status before pregnancy. In supplementation trials with demonstrably undernourished subjects, the effect of a given daily energy intake was greater than the effect in better nourished women. The data are somewhat mixed on the importance of the timing of the energy intake during pregnancy. Although most of the evidence regarding supplementation suggests that it is effective at any time during gestation (Habicht et al., 1974; Prentice et al., 1983), the Dutch famine study (Stein et al., 1975) showed that energy deprivation is important only in the third trimester. Hytten and Chambers (1980) have also found that energy requirements are considerably higher during the second and third trimesters than in the first trimester. Many of the participants in the supplementation studies did not begin supplementation until the second trimester, and it is unclear whether the reported effects of later supplementation would have had the same effects earlier in gestation.

Quantitative estimates of the effect of energy supplementation on fetal duration and fetal growth are summarized in Table 5-2.

TABLE 5-2 Effect of Energy Supplementation on Gestational Age, Preterm Birth, Birth Weight, and Intrauterine Growth Retardation

Outcome		Effect
Gestational Age		None
Preterm Birth		None
Birth Weight	In women poorly nourished before pregnancy	99.7 g/100 kcal/day supplemented throughout pregnancy[a]
	In women well-nourished before pregnancy	34.6 g/100 kcal/day supplemented throughout pregnancy[a]
Intrauterine Growth	In women poorly nourished before pregnancy	RR[b]: 0.47
Retardation	In women well-nourished before pregnancy	RR[b]: 0.82

[a] Throughout pregnancy indicates that the supplement is given for 280 days. Durations of supplementation shorter than 280 days would require proportionately more calories per day.
[b] RR: Relative risk of intrauterine growth retardation in women who receive 100 supplemented calories per day throughout pregnancy versus women who receive no caloric supplement.
SOURCE: Kramer, 1987.

Spontaneous Abortion

Epidemiologic studies of spontaneous abortion (miscarriage) are notoriously difficult, in particular because early miscarriages may not be recognized, and even if they are recognized, they may not come to the attention of a physician or other health care worker. The subcommittee identified few data relating spontaneous abortion and maternal nutrition.

In an early study of the effects of the Dutch famine, Smith (1947) noted an increased rate of "abortion and miscarriage" for Rotterdam women who conceived during the famine, but it is not clear whether the reported figures include induced abortions. Smith comments on the data presented by saying "there is no reason to assume they are accurate or that conclusions can be drawn from them."

A hospital-based study from New York City tried to identify relationships between prepregnant nutritional status and all forms of spontaneous abortions, including those of a particular chromosomal type. It found no associations (Stein, 1989). The hospital-based study from New York City found no association of spontaneous abortion with prepregnant nutritional status (Kline and Stein, 1987). A prospective study of pregnancies in Bangladesh reported that conception during the "lean period" (a period from June to October encompassing a phase of arduous work and reduced diet) was associated with pregnancy loss primarily in the third trimester, but before and during the second trimester as well (Pebley et al., 1985).

Congenital Anomalies

The subcommittee found no data relating gestational energy intake to the risk of congenital anomalies, in general, or of specific malformations. Deficiencies in specific nutrients have been linked to endemic goiter caused by iodine deficiency, and neural tube defects have been linked to lack of folate or B vitamins. Such specific deficiencies were considered to be outside the mandate of the subcommittee.

Maternal Mortality

In most developed countries, maternal mortality during pregnancy or childbirth is extremely rare, with rates generally below 10 per 100,000. The most common causes are pregnancy-related hypertension, pulmonary embolism, ectopic pregnancy, and hemorrhage (ante-and postpartum) (NCHS, 1987). In the United States, rates are 3–4 times higher for black women than for white women (Buehler et al., 1986). This discrepancy appears to be associated with poor prenatal care among black women (Sachs et al., 1987). Nutritional differences might also explain part of the racial discrepancy; but many other explanations are possible, and neither energy intake nor other nutritional factors have been investigated directly.

In sharp contrast, maternal mortality rates in developing countries are 10–50 times higher (in extreme cases, they may be up to 550 times higher)

(WHO, 1987), and the principal causes are hemorrhage, infection, and toxemia. Although none of these causes has been associated directly with maternal nutrition, one might speculate that women who were anemic on a nutritional basis would be more likely to the from hemorrhage before, during or after childbirth.

Finally, heart failure during and after childbirth can occasionally lead to maternal death. This has been observed principally but not exclusively among the poor in the United States, Africa, and elsewhere (Demakis and Rahimtoola, 1971). Although this observation could have a nutritional explanation, no direct evidence for this has been adduced (Homans, 1985).

Other Pregnancy Complications

No studies have produced convincing evidence directly linking maternal energy intake to either toxemia or dystocia (Davies and Dunlop, 1983; WHO, 1965). However, an observed reduction in eclampsia in Germany was temporally associated with food shortages during World War I (Anonymous, 1917; NRC, 1970). As discussed above, energy intake is associated with fetal growth. Thus low intake would be expected to reduce the risk of high birth weight (> 4,000 g) and the corresponding increased risk of dysfunctional labor, forceps delivery, birth trauma, and Caesarean section (Koff and Potter, 1979; Modanlou et al., 1980; Boyd et al., 1983), particularly in women with short stature or small pelvic size (Frame et al., 1985; Hughes et al., 1987). In general, undernutrition is associated with lower blood pressure, and as has been discussed above, gestational undernutrition impairs fetal growth. For example, the severe energy restriction that occurred during the Dutch famine was associated with a significant reduction in systolic blood pressure near the time of delivery (Riberiro et al., 1982). Although this might represent some reduction in the risk of toxemia, it could also be a mechanism for lowering uterine blood flow and thereby impairing fetal growth.

EFFECTS OF MATERNAL WORK AND PHYSICAL ACTIVITY

Background

As reviewed in Chapter 2, maternal energy expenditure in rural developing settings is of major interest because women in such countries often engage in strenuous activities, even during pregnancy, and because it is closely linked to adequate energy intake. Maternal work itself might also have an effect on pregnancy outcome quite separate from its effect on energy balance. For example, maternal physical activity or posture during work might diminish uterine blood flow and, consequently, hinder the fetal oxygen and nutrient supply (see Chapter 4). Moreover, there is some evidence that even quiet standing can provoke uterine contractions late in gestation (Schneider et al., 1985), which could theoretically increase the risk of preterm labor. Physical fatigue and psychological stress may be greater for women engaging in some types of work and may thereby affect pregnancy outcome. Exercise-induced hyperthermia could affect cellular differentiation and organogenesis during critical periods of development. Finally, exposure to toxic substances in the work environment may also affect pregnancy performance and outcome.

In examining the epidemiologic evidence, researchers should adapt the methodologies to the particular aspect of maternal physical activity under consideration. If the focus is on energy expenditure or strenuous physical labor, energy intake is an important potential confounding variable because the net balance of available energy depends on both energy intake and expenditure. When food supply is not a limiting factor, women who burn more energy also are likely to eat more, but failure to control energy intake may yield spurious results. Other factors that may confound the effect of energy expenditure include age, parity, height, prepregnancy weight, general health status, racial or ethnic origin, socioeconomic status, and smoking and alcohol consumption.

In considering the effects of posture, fatigue, stress, physical fitness, hyperthermia, or other aspects of maternal physical activity on pregnancy, energy intake need not be controlled; however, other potential confounding factors would be similar to those mentioned above. In assessing data from developed countries, it should be borne in mind that women who engage in leisure-time sports activities and exercise are likely to be younger, better nourished, and of higher socioeconomic status and are less likely to be members of a racial minority than those who do not. They are also much less likely to smoke or drink. And because intensive sport or exercise entails considerable energy expenditure, energy intake should also be controlled when assessing its effects.

In examining the available evidence from such studies in developed countries, it is often difficult to separate the effects of energy expenditure from non-energy-related work factors. Many of the reports from developed countries, for example, entailed studies of maternal work as a dichotomous variable, comparing pregnancy outcomes in women with paid employment with those in women without paid employment during pregnancy. Many of these reports have not distinguished different types of work in terms of physical exertion, posture, fatigue, or stress. By contrast, studies from developing countries make it apparent that maternal work often involves considerable energy expenditure in addition to any effects that are not energy related.

Gestational Duration

The evidence concerning physical activity and gestational age is conflicting. Two fairly well-controlled studies from a single data base in The Gambia found no significant effects of heavy agricultural labor on mean gestational age (Prentice, 1980; Prentice et al., 1981). A recently published study from Zaire (Manshande et al., 1987), on the other hand, reported significantly longer gestations in full-term (≥ 38 weeks) female infants born to hard-working multiparous women with longer durations of stay in a maternal rest village. No such effect was seen in male infants, however, and even the reported effect in females may reflect a temporal precedence (reverse causality) bias in that women who delivered earlier had less time to spend in the rest village.

The evidence from developed countries is more abundant but equally conflicting. A study of women in Boston found no effect of maternal employment in jobs requiring standing, even when the job was continued into the third trimester (Zuckerman et al., 1986). Although a variety of potentially confounding variables were controlled in the study, it is possible that women who continue to work are likely to be those without pregnancy difficulties, a factor that could explain the findings. By contrast, Clapp and Dickstein (1984) found that Vermont women who continued endurance-type exercise, including jogging, cross-country skiing, or aerobic dancing, during the third trimester of pregnancy had significantly shorter gestations than those who were either sedentary or stopped vigorous exercise of this kind before the third trimester. These results should be interpreted with caution, however, since they are based on only 29 women who continued exercising, and several potentially confounding variables were incompletely controlled.

Jarrett and Spellacy (1983) reported on 67 trained women runners who responded to a notice published in a Chicago newspaper and completed a mailed postpartum questionnaire concerning jogging during pregnancy and pregnancy outcome. There was no significant correlation between the total number of miles run during pregnancy or during the third trimester and gestational age at delivery. However, the method of subject recruitment (perhaps selecting high-mileage runners with more favorable outcomes); the fact that women who allowed themselves to run more miles may have been those whose pregnancies were uncomplicated and proceeding well; and the failure to control the potentially confounding effects of maternal age, height, prepregnancy weight, energy intake, smoking, parity, racial/ethnic origin, and socioeconomic status limit any causal inferences that can be drawn from this study.

Most of the data regarding preterm labor and delivery come from developed countries. Berkowitz et al. (1983) found no elevation in risk of delivery in working mothers after potential confounding variables were controlled, and there were no bivariate associations among preterm delivery and any of the following: physical position during work, lifting or carrying, weights of loads, frequency of lifting, number of hours worked, hours of housework per week, the use of an assistant for housework, climbing stairs, or hours of child care per work week. In fact, light and moderate leisure-time physical activity was associated with a significantly reduced risk of preterm birth. More strenuous exercise appeared to increase the risk, however. Although not statistically significant, this latter finding is consistent with that reported by Clapp and Dickstein (1984). A problem with the study of Berkowitz et al. (1983) concerns the measure of gestational age, which was based on the Dubowitz score, a measure of neurologic development, rather than the date of the mother's last menstrual period.

In one well-controlled study, Mamelle et al. (1984) reported an elevated risk of preterm delivery among working women whose work involved tiring postures, work on industrial machines, physical exertion, mental stress, or a physically uncomfortable environment. Because these work-related aspects were combined, however, it is difficult to separate the effects of fatigue and psychological stress. In a more recent attempt to validate their original findings, Mamelle and Munoz (1987) found a significantly increased risk of preterm delivery in women with an elevated summary occupational "fatigue score," but it is unclear what (if any) confounding factors were controlled in their analysis.

A recent, well-controlled interview survey of Montreal women employed for 30 or more hours a week at conception attempted to relate the risk of preterm birth to type of occupation and adverse working conditions. Modest increases in risk (relative risks of 1.25–1.35) were associated with long hours ($\geq$ 46 hours/week) and lifting heavy weights, both in women who stopped working before 28 weeks and those who continued working beyond 28 weeks. Psychiatric nurses had a particularly high risk of preterm delivery (relative risk of 2.47), but the large number of occupations examined suggests the need for caution in interpreting this intriguing result (McDonald et al., 1988). A recent Finnish study (Nurminen and Kurppa, 1988) found no difference in mean gestational age or rate of preterm birth in office versus nonoffice workers. Neither group was compared to women who did not work during pregnancy, however, nor did the investigators stratify the type of office work by exertion, stress, or other factors (other than users versus nonusers of video display terminals).

In two reports based on the U.S. National Longitudinal Survey of Labor Market Experience, Homer et al. (in press) examined the relationship between preterm, low-birthweight (LBW) delivery and work experience among 2,400 young women. Women who worked during pregnancy were at significantly lower risk for delivering a pretem, LBW infant than those who did not work, even after controlling confounding differences in race, socioeconomic and marital status, maternal height, prior history of LBW infants, and commencement of first prenatal care. Among women who worked, however, those with jobs associated with high physical exertion or psychological stress (jobs with high-demand tasks but low individual control) were at increased risk for preterm, LBW delivery when each factor was considered alone. When these two job characteristics were considered together along with potential confounders in a multivariate model, only physical exertion remained significant, with a six-fold increased risk of preterm, LBW delivery.

The studies discussed above are the best in the literature from a methodologic standpoint Unfortunately, other studies, which have been less well controlled, do not help settle the issue of whether maternal work or physical activity increases the risk of preterm delivery. Kaminski et al. (1973) found no increased risk of preterm delivery in women who said they had worked outdoors during pregnancy. Similarly, Murphy et al. (1984) reported no significant difference in preterm delivery rates in women with and without paid employment during pregnancy. A reanalysis of the same data by Williams (1984) showed a significantly reduced risk of pretem delivery in the employed women. Two reports of a single French study found a reduced risk of preterm delivery in working women, although women working more than 42 hours a week and those who worked in a standing position had an increased risk (Saurel and Kaminski, 1983; Saurel-Cubizolles et al., 1982). In a recent study of nonphysician hospital workers carried out by the same group of French investigators, the duration of the work week and commuting time had no effect on the preterm birth rate (Saurel-Cubizolles et al., 1985). Ancillary workers involved in strenuous cleaning, carrying heavy loads, and prolonged standing had higher preterm delivery rates; however, after controlling for differences in ethnic origin, these differences were no longer statistically significant. A more recent report by the same group of French researchers found that employed immigrant women, most of whom work in manual and service jobs requiring that they carry heavy loads or remain in a standing position or both, had no increased risk of preterm delivery (Stengel et al., 1986). These results, however, were not adjusted for the higher socioeconomic status, greater number of prenatal care visits, and increased attendance at prenatal classes among the employed women.

A recent French study based on a national sample of births in 1981 found a higher rate of preterm births in women engaged in manual, service, and assembly line work than in women engaged in professional, administrative, or clerical work during and beyond the first trimester (Saurel-Cubizolles and Kaminski, 1987). Within types of occupations, the risk of preterm delivery increased with an increase in the number of strenuous working conditions. In another analysis of the same study sample, Stengel et al. (1987) reported that among primiparous women who worked before pregnancy, those who also worked during the index pregnancy had an elevated risk of pretem delivery compared with those who did not (a similar effect was not seen in multiparae). The failure to control for maternal cigarette smoking and prepregnancy and gestational nutritional status in these two latter studies, however, argues for a cautious interpretation.

Fox et al. (1977) compared pregnancy outcome in 196 active duty pregnant U.S. Air Force personnel with that in 196 general obstetric clinic population patients matched for race and parity. Active duty women had a significantly increased rate of preterm labor. Unfortunately, the groups that were compared were somewhat different with respect to marital status (the proportion of single women being higher among the active duty women); and potentially confounding differences in socioeconomic status, height, prepregnancy weight, and cigarette smoking also were not controlled.

In a randomized trial from Zimbabwe, women pregnant with twins who were assigned to bed rest in the hospital from 32 weeks of gestation to the time of delivery experienced an increased rate of preterm delivery (Saunders et al., 1985). In this study, however, it was difficult to separate the possible beneficial effect of decreased work (i.e., bed rest *per se*) from the stressful effect of being hospitalized. Furthermore, bed rest also was associated with higher birth weights and raises the question of whether errors in assessing gestational age may have led to the observed findings. A recent observational study from a U.S. Air Force base found no difference in the risk of preterm delivery in women with twins hospitalized at or before 28 weeks of gestation for prophylactic ward rest (Gilstrap et al., 1987). Similarly, Rydhstrom (1987) found no difference in gestational age distribution among a small (but representative) sample of women with twin gestations who had been prescribed prophylactic leaves of absence. The relevance of these studies for rest at home in women with singleton pregnancies is limited.

Mamelle et al. (1989) attempted to assess directly the prophylactic effects of change in working conditions, reduction in work week, sick leave, and increased antenatal, maternity leave on the risk of preterm (undefined, but presumably < 37 weeks) birth in 1,168 women working in firms requiring fatiguing work. Only sick leave appeared protective (in fact, increased anteuatal maternity leave was associated with a nonsignificantly increased risk), but the potentially confounding effects of cigarette smoking and prepregnancy and gestational nutrition were not controlled.

Finally, a review of the epidemiologic evidence in the area of gestational duration would be incomplete without a discussion of the work of Papiernik and colleagues in France (Goujon et al., 1984, Papiernik and Vial, 1979; Papiernik et al., 1985). These investigators have documented a decrease in preterm delivery rates since the mid-1970 coincident with the institution of a coordinated package of prenatal care that includes an initial risk assessment, frequent pelvic examinations, teaching mothers to recognize early signs of uterine contractions, counseling women to reduce physical exertion at work and home, and aggressive treatment of threatened preterm labor. Creasy and associates (Creasy et al., 1980; Herron et al., 1982) used a similar approach in the United States and reported similar encouraging results. Unfortunately, the use of historical controls, the combination of interventions included in the overall package, and inadequate documentation of the effect of counseling on the mother's physical exertion make it difficult to attribute the reported improvements to reductions in physical activity.

In summary, the available epidemiologic evidence permits no definite conclusion about whether working during pregnancy is beneficial, harmful, or irrelevant to gestational duration. There is some suggestion that upright posture, prolonged strenuous or stressful work activities, and aerobic (endurance-type) exercise continued to term may increase the risk of preterm delivery and that moderate sports activity and exercise may reduce the risk (at least among well-nourished women in developed countries). Further studies are required in this area.

Fetal Growth

Many studies indicate that maternal work has a significant effect on fetal growth. Briend (1980) has reviewed several studies from the late nineteenth and the twentieth centuries indicating that birth weights were higher in women who worked in a sitting position during pregnancy than in those who worked standing and were higher in indigent working women who rested during the latter part of gestation than in those who continued working until the time of delivery. This combined evidence led Briend to hypothesize that the posture-related effect on uterine blood flow is the physiological mechanism that inhibits fetal growth. Although this hypothesis appears to be biologically plausible, too little information is available concerning potentially confounding differences between the different study groups to allow causal inferetices to be made.

Among more recent studies, several come from developing countries, in which maternal work usually requires larger energy expenditures. The best of these is probably the study by Tafari et al. (1980), who found higher birth weights in Ethiopian women who did not perform strenuous work activities (i.e., housewives with domestic help or women with sedentary jobs) compared with those engaging in more demanding work (i.e., housewives without domestic help or women with strenuous jobs). Although the data were stratified by prepregnancy weight and gestational weight gain, residual differences in socioeconomic status (which could affect such variables as cigarette and alcohol use and the quantity and quality of prenatal care), age, and parity may have confounded the reported relationship. A study by Manshande et al. (1987) reported an increased gestational age-standardized birth weight in full-term ($\geq$ 38 weeks) female infants born to hard-working Zairean multiparous women with longer durations of stay in a maternal rest village, although the results may be confounded by differences in energy intake. Several reports from The Gambia document lower birth weight during the labor-intensive wet season, but this effect is likely to be confounded by lower food availability and higher incidence of malarial disease during the wet season (Prentice et al., 1981; Whitehead et al., 1978).

The evidence from developed countries is mixed. Two recent, well-controlled studies from Boston reported no effect of maternal work on fetal growth (Marbury et al., 1984; Zuckerman et al., 1986). Marbury et al. (1984) noted no significant decrease in gestational age-adjusted birth weight in Boston women who continued working to term. Women who stopped working during the first 8 months of pregnancy had infants weighing, on average, 43 g less than those born to housewives. It may be that the differences resulted from the reasons for stopping work, in particular toxemia, rather than the work itself. The same explanation, called the healthy worker effect, may also have been operative in the study by Zuckerman et al. (1986), who found no difference in mean birth weight among women not performing paid work or attending school, those with jobs requiring standing who continued to work into the third trimester, and those with other work histories. McDonald et al. (1987) recently reported modestly increased risks (relative risks of 1.3–1.4) of low birth weight in Montreal chambermaids, cleaners, janitors, and nurses' aides; but similar effects were reported for preterm births (McDonald et al., 1988), and failure to control for prepregnancy or gestational nutrition make it difficult to attribute these effects to changes in fetal growth.

In fact, the most recent report from the Montreal study (Armstrong et al., 1989), which was based on gestational age-adjusted birth weight, found that the previously reported associations with low birth weight largely disappeared. On the other hand, persistent associations with lifting heavy weights and shift work suggested that the latter may in fact adversely affect fetal growth.

Among other methodologically adequate studies, two (Naeye and Peters, 1982; Ulrich, 1982) reported lower gestational age-adjusted mean birth weights in working women. Three other studies found no increased risk of intrauterine growth retardation (Saurel and Kaminski, 1983; Saurel-Cubizolies et al., 1982; Williams, 1984), whereas one recent French study (Saurel-Cubizolles and Kaminski, 1987) found an increased risk of low birth weight among women with a higher number of strenuous working conditions, even after controlling for parity, smoking habits, and preterm delivery. Most of the work done by women in these settings probably did not involve energy expenditures as large as those characteristic of working women in developing countries.

Large energy expenditures probably were involved, however, in the study done by Clapp and Dickstein (1984). Twenty-nine healthy Vermont women who continued jogging, cross-country skiing, or aerobic dancing into the third trimester had significantly lower birth weights for gestational age and rates of higher intrauterine growth retardation rates than those who either were sedentary or stopped exercising before 28 weeks of gestation. The study controlled for potentially confounding differences in age, parity, socioeconomic status, and prepregnancy weight. However, the sample size was small, and little information was given on the reasons that some women stopped exercising before 28 weeks. The small number of women who continued exercising, and their motivations for doing so, raise questions about the external validity of the findings. Furthermore, many of the women who stopped exercising before 28 weeks may have done so because of fatigue, abdominal discomfort, or low back pain. Thus, it is possible that those with greater weight gains, who would tend to have larger babies, were unable to continue exercising. The study also did not control for another potential confounding variable—maternal height—and the results should be interpreted with caution.

Large energy expenditures were also involved in studies done by Jarrett and Spellacy (1983) and Kulpa et al. (1987). The study done by Jarrett and Spellacy of self-selected Chicago runners was cited earlier in this chapter with respect to gestational duration. As with gestational age, there was no significant correlation between the total number of miles run during pregnancy or during the third trimester and birth weight. A number of the methodologic problems, discussed earlier, impede any causal inferences to be made from that study. The report by Kulpa et al. (1987) involved 141 low-risk, nonsmoking, exercise-conscious women who were randomly assigned, during the first trimester to high-versus low-frequency aerobic exercise for the remainder of gestation. No information was provided on the mode of randomization or the number of women assigned to each group. Unfortunately, 56 (39.7 percent) of the study subjects either dropped out of the trial or were disqualified because of adverse pregnancy outcomes, including toxemia, premature delivery, Caesarean delivery, and antepartum bleeding. Although no significant difference in mean birth weight was found between the two groups among the women who remained in the study, there was a deficit of more than 0.5 lb (227 g) in the high-frequency exercise group among both primiparous and multiparous woman, and a consequent high risk of Type II error.

A survey of pregnancy outcome among women obstetricians before, during, and after residency (Grunebaum et al., 1987) also examined effects on fetal growth. Among primiparous woman, the mean birth weight was significantly lower during residency than before or after residency. However, methodologic problems (particularly the possibility of selection bias because of nonresponse) seriously undermine the study's conclusions.

Swedish investigators (Langhoff-Roos et al., 1987) found no association between physical activity at 17 or 33 weeks, as measured by actometers attached to the wrist and ankle for a period of 72 hours, on gestational age-adjusted birth weight. The small sample size (N = 56), the large random measurement error, and questions about sufficient intensity of physical activity make it difficult to interpret these negative findings, however.

Finally, a recent study from Toledo, Ohio (Pascoe et al., 1987) reported a significantly increased risk of low birth weight among 201 low-income women who had no help with daily tasks (grocery shopping, fixing things around the house, paying bills). These results are difficult to interpret for several reasons. The investigators did not distinguish between intrauterine growth retardation and preterm delivery and did not control for maternal height or prepregnancy or gestational nutritional status. Moreover, 6 of the 11 low-birthweight study infants were twins. Nor is it clear whether such prenatal help represents a reduction in work or physical activity or a form of social support.

In summary, based on the evidence from epidemiologic studies, the effect of maternal work and physical activity on fetal growth is uncertain. Since energy intake has a well-established effect on fetal growth, high energy expenditure should lead to growth impairment, unless caloric intake also rises in proportion to energy expenditure. When food availability is limited, such compensation may not be possible. The possible interaction between strenuous work and maternal nutritional status will be considered in the next section.

The subject of the effects of physical activity on pregnancy should receive a high priority for future research. Studies are needed that define the particular type of work performed and that focus on physically taxing activities. They should also distinguish, whenever possible, between the effects of energy expenditure, posture, fatigue, and stress and as for energy intake, should control for differences in infections morbidity that may be associated with both differences in physical activity and effects on fetal growth. Energy intake should be held constant when trying to isolate the effect of energy expenditure, and net energy balance should be held constant when trying to examine non-energy-related effects. Well-controlled experimental studies, especially randomized trials, of economically feasible work-saving interventions would provide an excellent means for investigating such effects. Use of early ultrasound-validated estimates of gestational age would facilitate distinction between effects on fetal growth and those on gestational duration.

Spontanous Abortion

The previously cited hospital-based case-control study of spontaneous abortions in New York City found no association with maternal reports of regular stair-climbing activity during pregnancy. Another published report from the same study found no increased risk of chromosomally normal spontaneous abortions in women engaging in certain occupations (including nursing) but did not focus specifically on energy expenditure or physical exertion (Silverman et al., 1985). One study found no spontaneous abortions among 33 pregnant runners and 11 controls (Dale et al., 1982), but the potential for both Type II error and confounding bias is large. Another report (Beral et al., 1985) identified no difference in spontaneous abortion rates between working and nonworking women in London. However, the sample was relatively small and there was a low incidence of spontaneous abortions. This fact and the researchers' failure to control for potential confounding variables renders interpretation difficult. The previously cited Montreal survey (McDonald et al., 1987) found modestly elevated risks (relative risks of 1.2–1.3) of spontaneous abortion in nurses' aides and women in sales and food and beverage service occupations, but the large number of occupations examined makes these findings difficult to interpret.

Finally, a case report from the New York City Study of Spontaneous Abortion found that an episode of hyperthermia (reported temperature >100°F [37.8°C]) occurring in the same month as the spontaneous abortion was associated with a relative risk of 6 for chromosomally normal spontaneous abortion (Kline et al., 1985). A similar episode occurring in the previous month carried a relative risk of 3. The major problem in this study, however, was that infection may well have been the cause of both the hyperthermia and the spontaneous abortion; there was no evidence that the hyperthermia was exercise induced.

Congenital Anomalies

Interest in congenital anomalies as a function of maternal physical activity arises principally from concerns that exercise-induced hyperthermia may have teratogenic effects. Numerous case reports in humans have suggested that maternal hyperthermia at a critical period in gestation may lead to central nervous system malformations, especially anencephaly, facial and eye anomalies, and neural tube defects (Fraser and Skelton, 1978; Halperin, 1978; Leck, 1978, Shiota, 1982; Smith et al., 1978).

None of these studies is definitive, and none provides sufficient evidence on which to base quantitative risk estimates. As with spontaneous abortion, no direct evidence points to exercise or other physical activity as the cause of the hyperthermia among these women, and infection may well have been responsible for both the hyperthermia and the reported malformations. There appears to be insufficient evidence to incriminate external sources of heat (e.g., saunas or climatic extremes) (Warkany, 1986) in human studies, although this is not the case with animal studies (Edwards, 1986).

Regarding other aspects of physical activity, the subcommittee located five studies that investigated the effect of maternal employment on the risk of congenital malformations (Beral et al., 1985; Estryn et al., 1978; Marbury et al., 1984; McDonald et al., 1987; Shilling and Lalich, 1984). All five of these studies used a cohort research design; two had grossly insufficient sample sizes for detection of an important increased risk of congenital malformations. Two large studies found no crude association, but no multivariate analyses were performed to exclude the possibility of negative confounding (Marbury et al., 1984; Shilling and Lalich, 1984). Furthermore, selection bias due to a healthy worker effect may have influenced the results. The previously cited Montreal study (McDonald et al., 1987) found increased risks of delivering infants with congenital anomalies among workers in child care; in other service occupations; and in leather, metal, and electrical manufacturing. As with the other outcomes examined, however, the large number of occupations examined renders interpretation of the results difficult.

Maternal Mortality

The subcommittee did not find any epidemiological studies relating maternal work or physical activity to mortality occurring during pregnancy or parturition.

Other Pregnancy Complications

One study from Paris reported an increased crude risk of pregnancy-induced hypertension among women working in hospitals (Estryn et al., 1978), although a subsequent report from the same research group found no differences by specific hospital occupation (Saurel-Cubizolles et al., 1985). Neither of these studies controlled for differences in medical surveillance or potential confounders. The previously cited study by Fox et al. (1977) reported that active-duty pregnant U.S. Air Force personnel had a higher rate of toxemia than control women matched for ethnicity and parity, although other potentially confounding differences between the groups were not controlled. Marbury et al. (1984) found an increased risk of toxemia among employed women who stopped working before term, but these women may well have been selected for pregnancy complications. In fact, toxemia may have been the cause of stopping work among some of them, although no data are provided on the exact cause. One study examined the relationship between physical work capacity measured at 10–14 weeks of gestation and the subsequent occurrence of toxemia (Erkkola, 1976) and found no association, although the small sample size and failure to control for confounding present problems in drawing inferences from this study. Finally, a recent study from Quebec (Marcoux et al., in press) found a significantly *reduced* risk of preeclampsia (with proteinuria) associated with increased duration and intensity of leisure-time physical activity, even after controlling for prepregnancy physical activity and work during pregnancy, diastolic blood pressure before 20 weeks, and a variety of other covariates. A similar, albeit nonsignificant, protective effect was seen with pregnancy-induced hypertension alone (i.e., without proteinuria).

Clapp and Dickstein (1984) found no difference in the rate of primary Caesarean section among sedentary women, those who engaged in endurance-type exercise during pregnancy but stopped before 28 weeks, and those who continued such exercise into the third trimester. The indications for the Caesarean differed considerably, however, in that none of the 29 women who continued exercising had a Caesarean for cephalopelvic disproportion, compared with 19 out of 199 (9.5 percent) of those in the other two groups. These results must be interpreted cautiously because the group that continued exercising consist of only 29 women, and no attempt was made to control for confounding differences among the three groups. Furthermore, two other studies found the opposite effect on Caesarean section: physically fit women actually had a trend toward higher rates (Dale et al., 1982; Erkkola, 1976). Fox et al. (1977) reported a significantly higher rate of primary Caesarean sections in active-duty, pregnant U.S. Air Force personnel than in race-and parity-matched controls.

In a separate report based on the recent Montreal survey of employment and pregnancy outcome, Cherry (1987) reported an increased occurrence of new and persistent varicose veins among women working at least until 27 weeks in a job requiring 2 or more hours of standing (without a break) per day. There was no effect of such standing, however, or of lifting or other physical demands on hemorrhoids or back symptoms.

Finally, the subcommittee located five studies that examined the relationship between duration of labor and physical fitness (Clapp and Dickstein, 1984; Collings et al., 1983; Erkkola, 1976; Pomerance et al., 1974; Wang and McKenzie, 1987). Although none of these studies adequately controlled for important confounding differences among women of varying degrees of fitness, two found a significant relationship. One (Pomerance et al., 1974) reported significantly shorter labors among physically fit multiparas. A second study (Wang and McKenzie, 1987) reported shorter first, second, and third stages among physically fit primiparous women, but the small sample size and absence of significance testing suggest the need for cautious interpretation of the results.

COMBINED EFFECTS OF MATERNAL NUTRITION AND PHYSICAL ACTIVITY

Background

There are a variety of ways of considering the combined effects of maternal nutrition and physical activity. First, we can assess these effects indirectly by examining the evidence relating gestational weight gain (GWG) to pregnancy outcome because GWG represents a net balance between maternal energy intake and energy expenditure. The evidence remains indirect because the individual contributions of gestational nutrition and work remain unknown. Moreover, overall weight gain provides an incomplete picture about changes in body composition. A more *direct* approach would seek evidence of synergistic effects (statistical interaction) between energy intake and expenditure. Unfortunately, far more data are available concerning GWG than direct nutrition-work interactions.

Assessing the effect of GWG on fetal, neonatal, and maternal outcomes of pregnancy requires adequate consideration of both confounding bias and effect modification (by prepregnancy nutritional status). Factors that may confound the relationship between GWG and pregnancy outcome include maternal height and prepregnant weight, age, parity, racial or ethnic origin, socioeconomic status, cigarette and alcohol consumption, prenatal care, general health status, and exposure to toxic substances during work. As was the case for energy intake, length of gestation is also an essential control variable because women who deliver prematurely have less time to increase their weight. To avoid this temporal predence (reverse causality) artifact, gestational weight gain should be expressed as a rate (e.g., grams gained per week) rather than the total number of kilograms gained over the pregnancy. In assessing the effect on fetal growth, overall GWG (or, preferably, net weight gain; i.e., after subtracting the infant's birth weight) may be used if gestational age is controlled.

Gestational Duration

Relatively few published reports have examined the relationship between maternal weight gain and gestational duration. Papiernik and Kaminski (1974) found a significantly increased risk of subsequent preterm birth in mothers with either low (< 5 kg) or high (> 9 kg) weight gain up to 32 weeks. These results were based on bivariate (i.e., potentially confounded) associations, however. A companion report (Kaminski and Papiernik, 1974) showed that low weight gain by 32 weeks significantly discriminated between subsequent low-(< 2,500 g) and normal-($\geq$ 2,500 g) birthweight infants, but a specific relationship with preterm birth (as opposed to intrauterine growth retardation; IUGR) was not examined. Miller and Merritt (1979) reported a higher rate of preterm birth in 108 white women who gained less than 227 grams per week during the last two trimesters, but no such effect was seen among the 70 black women with low weight gains.

Berkowitz (1981) reported a four-fold increased risk of preterm delivery in women with "inadequate" weight gains versus those with "adequate" gains. No details were provided, however, on the criteria used for assessing adequacy other than a general statement that the assessment was based on "a schedule...which adjusted for pregnancy duration." Hingson et al. (1982) found a significant positive partial correlation (i.e., simultaneously adjusted for multiple potential confounding variables) between total weight gain and mean gestational age, but this result was based on total gain, rather than rate of gain, and may therefore reflect a reverse causal influence of gestational duration on total weight gain.

Picone et al. (1982) compared women with predicted low (≤ 15 lbs) and adequate (> 15 lbs) total weight gains, where the prediction was based on weight gain at 20 weeks gestation of < 8 versus ≥ 8 lbs. There was no difference in mean gestational age between the two groups when based on the mother's last menstrual period (LWP), but a slightly shorter (38.5 versus 39.2 weeks; $P < .01$) gestational age based on neonatal (Dubowitz) examination. These results are even more difficult to interpret in light of the fact that the investigators "reclassified" two of the women whose ultimate total weight gains did not agree with their predictions at 20 weeks.

Based on the large Child Health and Development Studies in the San Francisco Bay area, Bracken (1984) reported a highly significant increased risk of preterm birth (based on LMP) in women with weight gains averaging < 0.5 lbs/week after 20 weeks gestation. These results are closely paralleled by those in a recent study by Abrams et al. (in press), in which an increased risk of preterm delivery was seen in women with a low (< 0.27 kg/week) rate of weight gain (a 60-percent increase in risk over women gaining 0.27–0.52 kg/week). Of note is the fact that the magnitude of elevated risk reported in the latter study was not materially altered when the analysis was restricted to preterm births whose gestational ages were confirmed by ultrasound examination before 28 weeks. Finally, two other reports of a recent study among adolescents (Hediger et al., 1989) also found that a low rate of GWG was associated with preterm delivery. The magnitude of the increased risk varied from 50–75 percent, depending on whether the gestational age was based on the last menstrual period or an "obstetric" (undefined) estimate. The risk appeared to be even higher if the low gain occurred both before and after 24 weeks.

One important methodologic caveat should be kept in mind in interpreting studies linking GWG to gestational duration. As discussed earlier in the section on the effect of energy intake, errors in estimation of gestational age (particularly when based on menstrual dates) may well lead to misclassification of some growth-retarded infants as preterm. Since GWG has been shown to have an effect on fetal growth and the risk of IUGR (*vide infra*), evidence of effects on gestational duration that are based on menstrual dates should be interpreted with caution. Even with this caution, however, some existing data do suggest a possible effect of low weight gain on reducing gestational duration and increasing the risk of preterm delivery. Further research in this area using validated (e.g., based on early ultrasound) gestational age measurements should receive high priority, given the well-known importance of preterm delivery on infant mortality and infant and child morbidity and performance.

Fetal Growth

The data are clearer concerning an effect of GWG on intrauterine growth. All of the methodologically acceptable studies the subcommittee examined reported a positive effect of GWG on gestational age-adjusted birth weight and a reverse effect on the risk for intrauterine growth retardation. The causal effect of maternal gestational weight gain on birth weight may have been overestimated, however, since few of the examined studies subtracted the weight of the newborn from the maternal weight gain in assessing the association between GWG gain and birth weight. Although most of the studies originated from privileged populations in developed countries, studies in Peru (Frisancho et al., 1984) and in a sample of black women of low socioeconomic status in New York City (Rush et al., 1972) reported similar results.

Investigators examining the effect of a given GWG in women of varying prepregnant nutritional status have been virtually unanimous in concluding that the two factors strongly interact. Miller and Merritt (1979), for example, showed a clear trend for increasing rates of intrauterine growth retardation with decreasing pregnant weight-for-height among women with low GWG. Similar results were reported in several studies investigating mean birth weight (Abrams and Laros, 1986; Mitchell and Lerner, 1989; Naeye, 1981a,b; Winikoff and Debrovner, 1981). Thus, it seems clear that undernourished women receive a greater benefit from a given GWG than do those who are adequately or over-nourished. The effect of modification of prepregnancy nutritional status could be of major importance in developing countries. Because a large proportion of pregnant women can be expected to be undernourished in such a setting, low GWG may be a major risk factor for IUGR.

Quantitative estimates of the effects of GWG are summarized in Table 5-3 (Kramer, 1987). These estimates derive from studies in women with adequate prepregnancy nutritional status. Although the effects are likely to be considerably greater in undernourished women, available data do not permit accurate quantitative estimates.

Other Pregnancy Outcomes

High weight gains, particularly in the second and third trimesters, have long been associated with an increased risk of pregnancy-induced hypertension and pre-eclampsia (toxemia) in primiparae (Tompkins et al., 1955; Thomson and Billewicz, 1957; Naeye, 1981a; Shepard et al., 1986). In fact, recognition of this association reinforced the earlier obstetric practice of limiting weight gain, which appears to have originated with the previously noted observed reduction in eclampsia in Germany that was temporally associated with food shortages during World War I (Anonymous, 1917; NRC, 1970). But sorting out the "cart" and the "horse" in this association is highly problematic because the edema and increased body water accompanying pre-eclampsia will, of course, be manifested by an increased maternal weight, irrespective of any change in maternal lean or fat mass. The typical pattern is a sudden increment in weight between visits in the third trimester.

TABLE 5-3 Effect of Gestational Weight Gain (GWG) on Gestational Age, Preterm Birth, Birth Weight, and Intrauterine Growth Retardation for Women with Adequate Prepregnancy Nutrition

Outcome	Effect
Gestational Age	None
Preterm Birth	None
Birth Weight	20.3 g/kg total GWG
Intrauterine Growth Retardation	RR[a]: 1.98

[a]RR: relative risk of intrauterine growth retardation in women with total gestational weight gain <7 kg versus those with gestational weight gain ≥ 7 kg.
SOURCE: Kramer, 1987.

The subcommittee was unable to locate any evidence linking increases in maternal lean or muscle mass early in pregnancy to subsequent pre-eclampsia. In fact, an expert committee of the World Health Organization concluded "that it is difficult on the evidence available to define the precise role of nutrition in toxaemia" (WHO, 1965). Tompkins et al. (1955) did note a higher risk of toxemia in women with low prepregnancy weight-for-height who had low weight gains during the second trimester. In his review of the published evidence, Chesley (1976) found that, despite the cart-versus-horse bias discussed above, most women who develop pre-eclampsia have total weight gains below average. Thus, the causal relationship between GWG and pre-eclampsia remains unclear. Low early gains may be a marker, or even a determinant, of subsequent pre-eclampsia, but firmer inferences must await the results of future research.

Large GWGs are associated with an increased risk of high birth weight, with a corresponding increase in risk for dysfunctional labor, midforceps delivery, birth trauma, asphyxia, and Caesarean section (Koff and Potter, 1939; Modanlou et al., 1980; Boyd et al., 1983). Moreover, there is some evidence that these consequences of fetopelvic disproportion are exacerbated in women with short stature or small pelvic size (Frame et al., 1985; Hughes et al., 1987).

Varma (1984) has examined the direct relationship between gestational weight gain and pregnancy complications. Although he reports a significantly higher rate of forceps delivery and Caesarean section in women with high weight gains, these results are unadjusted for potentially confounding differences among women with different weight gains. Using a more sophisticated multivariate approach, however, Shepard et al. (1986) confirmed that women with high weight gains (measured as a proportion of prepregnancy weight) had higher rates of Caesarean sections and other operative deliveries (forceps and vacuum extraction). They also found such women to have a prolonged second stage of labor.

DIRECT EVIDENCE OF COMBINED EFFECTS

Previously cited studies from The Gambia have also provided some direct evidence concerning the combined effects of low energy intake and high energy expenditure (Prentice, 1980; Prentice et al., 1981). As discussed earlier, these studies found a substantial decrement in birth weight during the wet season, when food availability is lowest and agricultural labor demands are highest. Prentice et al. (1981) documented a difference in birth weight between the wet and dry seasons of 240 gm, a mean of 2,740 gm in the wet season and 2,980 gm in the dry season. These findings were somewhat surprising because the differences in energy intake were only about 200 kcal/day and persisted for only a few months. Averaged over the entire pregnancy, there were only modest differences in energy intake. Although energy intake is difficult to measure with precision, the difference in birth weight is much greater than would be predicted from the difference in energy intake alone, even among poorly nourished women (see Table 5-2). The additional birthweight effect might therefore be attributable to increased energy expenditure during the wet season. Unfortunately, however, this effect is likely to be confounded with a higher prevalence of malarial illness during the wet season, which is also likely to decrease birth weight.

Similar results of a smaller magnitude were reported from Taiwan (Adair and Pollitt, 1983). Birth weights were significantly lower in the summer rainy season, when food availability is low and both agricultural activity and infectious morbidity (particularly from gastroenteritis) are high. However, as in The Gambia, it is not possible to distinguish the individual and combined effects of the various seasonally related factors.

Few investigators have examined the actual interactions (i.e., effect modification) between maternal physical activity and nutritional status before or during pregnancy. Studies by Tafari et al. (1980) in Ethiopia, and by Naeye and Peters (1980) using data from the U.S. Collaborative Perinatal Project both found a greater reduction in birth weight attributable to maternal work in women with low prepregnant weight and gestational weight gain. Interestingly, Naeye and Peters (1982) attributed this effect to the higher frequency of placental infarcts found in women whose work required them to stand and continued into late gestation. No such infarcts were observed in the Ethiopian study, however, despite the expectation of more strenuous physical work in the latter setting (Tafari et al., 1980).

The studies described above suggest an interaction that is potentially highly significant for the development of public policies and programs regarding maternal nutrition and strenuous work. As was described in Chapter 2, many women in developing countries are undernourished and must continue to perform work activities that include heavy energy expenditure throughout pregnancy. Further study of this interaction should receive high priority in future epidemiologic research.

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6

Impact of Physical Activity and Diet on Lactation

Physical activity during pregnancy has potential effects on subsequent lactation performance in humans, but these effects are difficult to assess because of the limited available data. The consideration of any relationship requires the definition of at least two terms: lactation performance and physical activity. Lactation performance usually is defined from measurements of milk volume and composition and infant growth (Hamosh and Goldman, 1986). A few studies have incorporated other variables that reflect maternal health, but such broad evaluations are uncommon. The effects of maternal nutritional status on milk volume and composition have been reviewed by various authors and thus will not be of primary interest in this report (Belavady, 1979; Garza and Butte, 1985; Jelliffe and Jelliffe, 1978). In generally, milk volume appears to be more sensitive to maternal nutritional status than is gross milk composition. Although dietary intake may alter selected milk components, milk protein, carbohydrate, and total fat appear to be fairly unaffected unless the diet becomes excessively restrictive.

It is more difficult to provide an unambiguous definition of physical activity than the term's familiarity may suggest. All healthy pregnant and lactating women, regardless of socioeconomic context, remain active to some degree. For purposes of this discussion, physical activity refers to moderate and heavy work loads, as defined by the World Health Organization (WHO), and the Food and Agricultural Organization of the United Nations (FAO), unless otherwise indicated (WHO, 1985). Mean energy expenditures at specified work loads for 55-kg reference woman are 1.6–1.8 times their basal metabolic rate. The mean rates of expenditure allow 1,000 and 1,400 kcal/8 hours of moderate and heavy work, respectively. The equivalent rates expressed per minute are 2.1 and 2.9 kcal, respectively.

Although assessments of the effects of physical activity during pregnancy on lactation performance have not been published, the nature of the interaction can be inferred from studies of women with presumably heavy work loads and marginal or adequate nutritional status. Physical activity appears to exacerbate the negative effects of poor nutritional status on milk volume. Data from studies done in The Gambia illustrate this point in comparisons of milk volume under conditions of work and maternal planes of nutrition (Prentice et al., 1982). The physiologic basis for this view and representative data that examine potential relationships between physical activity and lactation performance are considered in more detail in subsequent sections of this chapter.

INFLUENCE OF PHYSICAL ACTIVITY ON FAT STORAGE DURING PREGNANCY AND LACTATION

Because the nutrient demands of physical activity are closely associated with energy, concern arises for the sufficiency of maternal energy stores at the end of a physically active woman's pregnancy. As reviewed earlier in this report, a significant proportion of weight gained during pregnancy represents maternal adipose tissue. One possible functional role of fat stores accumulated during pregnancy may be to buffer the need for additional dietary energy imposed by lactation. If physical activity during pregnancy interferes with the accumulation of normal quantities of fat, lactation performance may be affected adversely. Two mechanisms that can be postulated for those adverse influences are 1) a putative dependence on minimal fat stores to produce milk of normal volume and composition for an acceptable period of time and 2) the likelihood that increased demands for dietary energy for lactation will not be met if the mother has insufficient stores of energy.

Women who gain 11 to 13 kg body weight during pregnancy should have stored 2 to 4 kg of fat. Those energy stores may be assumed to have been accumulated in a physiologic anticipation of lactation. On the basis of an estimated mean milk output during the first 4 to 6 months of lactation of approximately 750 ml/day and a gross caloric concentration in milk of approximately 0.64 kcal/ml, the lactating woman loses approximately 500 kcal/day in milk (Butte, et al., 1984). Estimates of the efficiency of milk production range from 80 percent to 95 percent. The energy required to synthesize 750 ml of milk, therefore, is approximately 25 to 125 kcal/day plus 500 kcal accounted for by the gross energy content of the milk. If a conservative estimate of 500 kcal/day (i.e., 100-percent efficiency) for the cost of milk production is used, 2 to 4 kg of fat (i.e., 17,000 to 34,000 kcal) would theoretically represent sufficient energy for approximately 1.2 to 2.5 months of milk production. If an estimate of 625 kcal/day (i.e., 80-percent efficiency) is used, 2 to 4 kg of fat stores would theoretically represent sufficient energy for approximately 1 to 2 months of milk production.

Those estimates are based on two assumptions. The first is that energy intake during lactation is balanced against all other maternal energy needs. An excessive or deficient intake of energy has a corresponding effect on the length of time that will lapse before fat accumulated during pregnancy is exhausted. If energy intakes before and after work is begun are similar, an increased work load imposes correspondingly greater demands on maternal energy stores. Under low energy intake, it is not known whether maternal functions are defended at the expense of milk production, or whether milk production is maintained at a cost to maternal functions. The second assumption is that reductions in milk production (in terms of volume or composition) and maternal well-being occur concurrently under unfavorable circumstances. Quantitative relationships among maternal nutrient stores, activity patterns, diet, and milk production have not been described for humans.

It is assumed that all maternal adipose tissue stores accumulated during pregnancy are directly or indirectly available for milk production. The general availability of energy derived from fat, however, depends partially on an individual's aerobic conditioning, the type of work that is performed, and the duration of work episodes (Astrand and Rodahl, 1970). All three factors determine the proportion of fat and glucose required to perform specific tasks. Generally, individuals with good aerobic status, compared with those less aerobically conditioned, oxidize greater proportions of fat when performing specific energy-requiring work.

Knowledge of milk composition is pertinent to these considerations. Only 50 percent of milk energy is derived from fat; the remaining 50 percent is represented by protein and lactose, neither of which is obtained from fat. Because neither protein nor glucose is stored like fat, they must be supplied from the diet. Dietary carbohydrates that are not used immediately for energy are either converted to fat or are used to replenish glycogen stores. Dietary protein is used for the production of milk, is used to replenish body protein lost through the inefficiency of the body's protein turnover, or is converted to fat or glucose. Fat and glucose derived from protein are oxidized immediately or stored in either adipose tissue or glycogen. If dietary carbohydrate and excess protein can be redirected to the production of milk, and if a corresponding amount of stored fat can be substituted in the other usual metabolic pathways that produce energy, the 2 to 4 kg of fat accumulated during pregnancy should suffice for 1 to 2.5 months of milk production without concurrent reductions in prepregnancy maternal stores. If maternal needs for carbohydrate-derived energy cannot be adjusted, the use of maternal fat stores may be limited largely to the provision of fat for milk.

Such a limitation may prolong the availability of accumulated fat, but will increase the demand on dietary requirements and maternal lean body mass. Physical activity during pregnancy is likely to contribute to the maintenance of aerobic conditioning in the postpartum state, and thus, the redirection of nutrients for milk production should not be impaired. There are no data, however, to evaluate that possibility.

Nevertheless, if maternal energy intakes increase sufficiently to meet all needs except those represented by the loss of stored fat into milk, there should be no adverse effects on maternal function. If maternal energy intakes do not increase sufficiently to meet requirements, then milk production, other maternal functions, or both will be impaired. The degree of impairment will depend on the demands of physical activity, nutrient stores, and diet. Data are insufficient, however, to support quantitative inferences.

The relationships among lactation performance, maternal diet, and body composition have been evaluated in the lactating ruminant, but results of these studies are difficult to assess because of genetic inbreeding of ruminants for milk production and significant differences in the derivation of milk components from rumen metabolism (Larson and Smith, 1974). The few studies done in nonruminants that address these relationships suggest that dietary intake during pregnancy influences the balance between milk production and the maintenance of maternal well-being. As a typical example, studies in the sow have demonstrated that milk production assessed by litter weight gain is not hampered by dietary deprivation during pregnancy if adequate or surplus nutrients are provided during the subsequent lactation. If, however, an inadequate diet during lactation follows an inadequate diet during pregnancy, litter weight gain is compromised (Mahan and Mangan, 1975).

Other studies in the rat have compared energy expenditures for maintenance and activity in virgin and lactating animals (Roberts and Coward, 1984). Lactating rats fed restricted amounts of food expended less energy for maintenance and activity than did virgin rats on similar diets. Those results suggest an increased efficiency of energy use during lactation among food-restricted rats. How maternal activity patterns during pregnancy may influence such responses is difficult to predict, even if confident extrapolations of the results of animal studies to humans were possible.

As in other physiologic processes, endocrine signals are expected to influence the use of nutrients either for milk production or for more immediate maternal needs. Endocrine controls of milk production have been evaluated primarily in animals. The investigations suggest that animals with high milk yields tend to maintain lower insulin levels and higher growth hormone (GH) levels than do those with low milk yields (Hart et al., 1979).

The link between insulin levels and milk production may be the subsequent availability of glucose. Relatively low levels of insulin usually are associated with increased levels of glucose output by the liver, decreases in the uptake of glucose by competing tissues, and higher levels of lipolysis. Higher levels of circulating free fatty acids should decrease glucose oxidation by tissues able to metabolize either fat or glucose. The net result would be an increased availability of glucose for milk production. This chain of events, though plausible, is speculative; few data obtained in human experiments are available to assess its accuracy. Nonetheless, if physical activity during pregnancy helps to maintain lower baseline insulin levels in the postpartum state, this mechanism may promote increased milk production and thereby modulate other factors that affect lactation performance adversely.

RELATED FUNCTIONAL ASPECTS OF ENERGY STORES

Although diet and activity patterns during pregnancy may influence the amount and distribution of stored fat, available data do not allow confident predictions of their effects on lactation performance. Adipose tissue does not appear to be mobilized uniformly under all conditions during lactation, and evidence suggests that adipose tissue is not functionally homogeneous. Subscapular skin fold thickness has been noted to decrease during the first 4 months of lactation at a greater rate than the decrease of the triceps or suprailiac region in well-nourished American women (Butte et al., 1984).

The lipolytic and lipoprotein lipase (LPL) activities in biopsies of sample femoral and abdominal adipose tissues of healthy nonpregnant women and of pregnant and lactating women also suggest that there are important functional differences that are specific for site and physiologic state (Lafontan et al., 1979; Rebuffe-Scrive et al., 1985). Basal lipolytic rates are similar in both tissues in nonpregnant women, but significantly higher in the femoral depot of lactating women. The lipolytic effect of noradrenaline administration is similar in both sites during lactation, but is significantly less in the femoral tissue of nonpregnant women and women during early pregnancy. The LPL activity in abdominal adipose tissue remains the same in all three physiologic states (nonpregnant, pregnant, and lactating), but it is decreased in the femoral adipose tissue of lactating women. These observations suggest that lipid accumulation in both nonpregnant and pregnant women is favored in femoral stores over the abdominal depot. Femoral adipose tissue undergoes unique adaptations, however, during lactation. The LPL activity falls and the response to lipolytic stimuli increases. Lipid mobilization, therefore, is favored by femoral tissue during lactation. Thus, in specific physiologic states, different adipose tissue sites appear to be specialized in their relative availability as energy sources.

Specific changes in adipose tissue also occur during lactation in rats and mice (Trayhurn and Brown, 1985). Lipolysis is favored in white adipose tissue during lactation. Lactation also is associated with a decrease in the number of insulin receptors and a heightened insulin resistance. Changes also are observed in brown adipose tissue (BAT). The concentration of uncoupling protein in BAT mitochondria is substantially decreased in lactating mice. The inverse relationship between the number of pups and the levels of uncoupling protein and cytochrome oxidase activity suggest that the suppression of thermogenesis in BAT is related directly to the nutritional demands imposed on the mother. Although the suppression of thermogenesis promotes a heightened efficiency of energy use by the lactating rat, functional consequences of that adjustment are poorly defined. The insulin resistance reported for adipose tissue is in direct contrast to the generally increased insulin sensitivity and responsiveness reported for the lactating rat (Burnol et al., 1986). Insulin concentrations that induce half maximal stimulation of glucose use and metabolic clearance are decreased by 50 percent during lactation. The interactive effects, however, between physical activity during pregnancy and lactation and the accumulation and use of fat stores in each physiologic state have not been described.

INFLUENCE OF PHYSICAL ACTIVITY DURING PREGNANCY ON THE EFFICIENCY OF MILK PRODUCTION

There are no apparent physiologic mechanisms through which physical activity during pregnancy is expected to affect the efficiency of milk synthesis in the subsequent postpartum period. The few studies that have measured the resting metabolic rate (RMR) or the basal metabolic rate (BMR) in lactating women are inconsistent in their conclusions. Studies of Guatemalan women in month 10 of lactation reported an RMR of 46 ± 6 kcal/hour or 32.5 kcal/m^2/hour, values that were similar to measurements in nonlactating controls (Schutz et al., 1980). Studies of Indian lactating women report a BMR approximately 6 to 12 percent above those reported for nonlactating control women in India (Khan and Benady, 1973); the reported mean values for lactating women 1 to 6 months postpartum ranged from approximately 35 to 37 kcal/m^2/hour.

In contrast to reports of RMRs in women in Guatemala and India, RMRs in young Gambian women whose intakes were not supplemented have been reported to fall at 10 to 25 weeks gestation but to rise after the provision of a daily food supplement. The reduction in RMR appears to persist during lactation in the unsupplemented group (Lawrence et al., 1984; Whitehead et al., 1986). Whether the fall in the RMR represents a response to increased nutritional stress analogous to that seen with starvation is not clear from those studies. If the analogy is appropriate, impairment of functions that require multiple organ systems should be expected, as was documented in partial starvation studies of young adult men in Minnesota (Keys, 1950). If the higher metabolic rates of the supplemented group represented responses to an excessive intake of energy, the functional consequences are less certain.

CARDIOVASCULAR ADAPTATIONS

Physical activity during pregnancy and lactation is expected to influence a woman's cardiovascular status. The supply of substrates to the mammary glands for milk production should also require significant cardiovascular adaptations. Unfortunately, there are few studies in humans that evaluate this aspect of normal lactation physiology. Most studies of postpartum physiology do not describe activity patterns during pregnancy and the postpartum period and do not indicate whether the subjects chose to breast or bottle feed their infants. The best animal studies are those of Hanwell and Linzell (1973a), who reported that cardiac output remains above prepregnancy levels when lactation follows pregnancy, and there is a heightened flow of blood to the mammary glands and to organs of the alimentary system. There is no certainty, however, whether those changes occur in humans or what the interactive effects with physical activity may be.

The mechanisms responsible for the cardiovascular changes in animals are not well defined. Hanwell and Linzell (1973b; 1972) demonstrated that increased cardiac output in rats appears to be dependent upon the suckling stimulus and not necessarily on milk removal. Mammary blood flow and high cardiac outputs in these animals were maintained by administration of prolactin or growth hormone. Prolactin stimulation due to physical activity also has been reported, but studies in lactating or pregnant women have not been published (Cavanaugh, 1982).

FIELD STUDIES AND LACTATION PERFORMANCE

Lactation in well-and marginally nourished women with distinct activity patterns has been assessed in field studies. For example, Gambian women were reported to consume approximately 1,600 kcal/day and to lose approximately 500 to 600 kcal/day in milk (Prentice et al., 1981) in the dry season characterized by lessened farm work activities. When energy intake, weight changes, and milk output were compared, the residual energy available for basal and activity needs was approximately 1,000 kcal. That amount of energy should be sufficient only to cover basal metabolic costs. Yet, those women were reported to have deposited subcutaneous fat and therefore appeared to be in positive energy balance. The volume of milk produced by the Gambian women appears similar to that produced by North American women who consume approximately 600 additional kcal/day and presumably have lower work loads. Similar calculations of energy available to North American women suggest that after basal needs are met, 300 kcal/day remain for activity (Butte et al., 1984).

Periods of the heaviest work loads in the Gambian population were characterized by intakes of approximately 1,400 kcal/day. Lactating women lost weight during periods of lowest energy intakes and highest work loads, that is, the wet season. Energy output in milk may be examined in two ways. For the period 2 to 6 months postpartum, milk production was reported to decrease from. 850 g/day in June (dry season) to 540 g/day in October. Alternatively, energy outputs in milk during similar trimesters may be compared. Such contrasts indicated that milk production was, on average, only 2 percent greater in the dry season than in the wet one. An earlier publication reported a negative correlation between milk production at 3 months and in skinfold thickness over the second 6 weeks of lactation. The authors interpreted this observation to indicate that repletion of maternal fat stores adversely affected the volume of milk that was produced. The alternative hypothesis, that is, that skin fold changes were a result of milk production, was not given sufficient consideration (Paul et al., 1979).

The estimate of energy available for basal and activity needs that was derived from estimates of intake, weight changes, and milk production during the period of more intense work (i.e., the wet season) was also approximately 1,000 kcal. The efficiency of energy use appears to be much greater than anticipated in both seasons. The energy expenditure of lactating women also was measured by the doubly labeled water method in preliminary studies conducted in The Gambia. Higher estimates of energy expenditure than were predicted by more conventional methodologies were reported (Prentice, 1987). Estimates of energy expenditure from those studies were not consistent with estimates of residual energy made by more conventional methods (Prentice, 1987). In these studies, as well as in others, the lack of correlation between energy intake and expenditure measurements is alarming.

The growth of breast-fed infants also may be used to assess lactation performance. Gambian infants are reported to grow at acceptable rates until approximately 3 months of life, the approximate age at which weaning foods are added to their diets (Rowland et al., 1981). The basis for the drop in growth rates from the expected values is not known. Increased morbidity is one potential explanation. An inadequate intake of milk is another. Milk volumes appear to decrease at about 3 months post partum. In contrast to the lowered outputs, sustained outputs are common in North American women who continue to breastfeed their infants exclusively through 4 to 5 months. However, once solid foods are introduced into the diets of exclusively breast-fed North American infants, their milk intakes also drop. The magnitude of the decreased intake of milk appears to be proportional to the intake of solid foods. Therefore, whether the fall in milk volumes in Gambian women represents a maternal inability to sustain adequate volumes of milk production or is the result. of the introduction of other foods to their infants' diet is unclear (Stuff et al., 1986).

The Gambian studies also included assessments of the effects of dietary supplementation on milk volume and quality (Prentice et al., 1983). When a food supplement was added to the mothers' diets, their energy intakes were increased from 1,568 kcal/day to 2,291 kcal/day. The supplement had no effect on milk volume at any stage of lactation or in any season of the year, and the effects on milk composition appeared trivial. Also, there were no selective effects on women with the lowest rates of milk production.

The energy provided in the supplement could not be accounted for by increased maternal weight (Prentice et al., 1983b). Although a weight gain of 1.8 kg was noted over the year the supplement was provided, the subjects still experienced weight loss during the period of heaviest activity. The increased average weight increment accounted for approximately 7 percent of the total energy provided by the supplement over the year. Supplemented women were noted to have fewer health-related complaints, but maternal morbidity was not well characterized. The authors speculate that unaccounted energy may have been used for increased activity or accounted for by changes in the efficiency of energy use.

Other investigators who have examined the effects of supplementation on milk yield report data that are not in agreement with the Gambian observations. Sosa et al. (1976) report significant improvements in lactation performance from intensive observations on one undernourished woman. More recently, Girija et al. (1984) have evaluated the effects of a supplement that provided 417 kcal and 30 g protein for approximately 12 weeks to women with baseline diets providing approximately 1,700 kcal/day and 40 g/day of protein. Supplemented women gained approximately 1.3 kg; control women lost weight. Milk yields of supplemented and control women were similar until the third month postpartum. After that time, the supplemented group produced approximately 30 percent more milk than the control group.

Animal studies also have shown a positive influence of supplements during lactation (Roberts and Coward, 1985).

A confident evaluation of the relationship among activity during pregnancy, supplements provided during pregnancy, and subsequent lactation performance is not possible with the data currently available. Maternal nutritional status in the Gambian studies did not appear to deteriorate with increasing parity. Body weight and nutrient status with respect to iron, hemoglobin, riboflavin, and vitamins A and C are reported to be independent of parity (Prentice et al., 1981). Those data suggest that repeated cycles of pregnancy and lactation superimposed on heavy work loads in that population do not lead to a detectable impairment of maternal well-being.

Nonetheless, a disparity in available data is evident from reviews such as those of Jelliffe, in which impaired lactation performance is reported in marginally nourished women, some with presumably heavy work loads (Jelliffe and Jelliffe, 1978). Recent reports, such as that of Manjrekar et al. (1985) indicate that women who consumed approximately 1,500 or 1,100 kcal/day produced insufficient volumes of milk within the first 4 months of lactation. Women who delivered low-birthweight infants (< 2.6 kg) produced insufficient milk volumes by 2 months. These findings are complicated by various factors. Many of the subjects returned to work in the early postpartum period, and their early return may have affected lactation performance. Also, milk production is known to depend on both maternal factors and infant behaviors. Conditions that may have an adverse effect on an infant's feeding behavior (e.g., low birth weight) may also have negative results on the volume of milk produced.

The effects of maternal physical activity on birth weight also are relevant to this discussion. Part of the rationale for postulating that physical activity may impair birth weight is an expected adverse effect of activity on placental perfusion. That expectation rests on the suggestion that the sympathetic nervous system is activated by physical activity. Its activation may result in the redirection of cardiac output to priority organs that may not include the placenta. If the blood supply is directed away from the mammary glands during physical activity, one may speculate that the glands' preparation for milk synthesis is adversely affected and that after parturition, increased sympathetic activity may continue to impair mammary gland function. Such a response may explain why nutrient supplementation was not associated with an increased volume of milk production in the Gambian studies.

SUMMARY

The potential effects of physical activity during pregnancy on lactation performance are difficult to predict. If physical activity during pregnancy limits or interferes with fat deposition, maternal well-being may be adversely affected. Conversely, maintenance of a high level of activity may promote more efficient use of fat stores during pregnancy, reduce baseline insulin levels, and result in higher milk yields.

The effects of continued activity during lactation on lactation performance also are difficult to predict. The added demands of physical activity impose greater nutritional needs on the mother, and the maintenance of higher sympathetic "tone" may impair mammary gland function. Although this is highly speculative, there is little question of the need for sound experiments that define lactation physiology in humans.

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7

Conclusions and Recommendations

CONCLUSIONS

1. Our knowledge of the metabolic adjustments that occur during human pregnancy are insufficient to establish energy requirements during pregnancy and lactation under different conditions of energy and other nutrient intake, body composition, physical activity, work position, etc. Similarly, we know very little about how such metabolic adjustments (and their limits) may affect pregnancy or lactation outcomes under these various conditions.
2. Epidemiologic studies, mostly from developing countries, strongly suggest that women who are underweight before pregnancy and who have insufficient energy intakes during pregnancy are at higher risk of delivering growth-retarded infants. Improving the nutrition of women during pregnancy and lactation reduces the risk of intrauterine growth retardation and may improve lactation performance. These effects occur without apparent change in physical activity and have been interpreted as being due to improvement in energy balance, although such an interpretation may be overly simplistic. The effect of such nutritional improvement on other maternal (mortality, postpartum health, and nutritional status) and fetal/child (spontaneous abortion, congenital anomalies, and morbidity) outcomes is difficult to evaluate from the available evidence.
3. Studies from both developed and developing country settings suggest that strenuous physical activity may adversely affect energy balance in

women with low prepregnancy weight-for-height and thereby impair fetal growth in women who already are undernourished before or during pregnancy. Despite a large number of studies, the effects of work conditions, activity patterns, and physical exercise on other outcomes of pregnancy and lactation are unclear. Although many observational studies from developed countries suggest that strenuous exercise or fatiguing work in the third trimester may increase the risk of preterm delivery, the findings have not been consistent. Moreover, their relevance for working women in developing country settings is unclear.

4. Gestational weight gain reflects, in part, a balance between energy intake and expenditure. The epidemiologic evidence is very strong that low weight gain increases the risk of intrauterine growth retardation, especially in women with low prepregancy weight-for-height. Several studies suggest a similar increased risk for preterm delivery, but methodologic problems with these studies do not permit firm inferences.

RECOMMENDATIONS

1. The foremost recommendation is for more research related to nutrition, physical activity, and reproductive performance of pregnant women in different ecological settings. Greater efforts should be made to examine effects on outcomes beyond fetal growth and gestational duration, including lactation performance; maternal outcomes of pregnancy (e.g., complications of delivery, duration of labor, gestational hypertension and pre-eclampsia, and subsequent health and nutrition status); and neonatal mortality, morbidity, growth, and functional performance.

- To provide useful information for clinical and public health intervention, future studies should attempt to isolate the effects of diet and physical activity, as well as measure any tendency for their interaction (i.e., synergistic effects).
- Similar studies should be undertaken in animals, focusing on possible physiological mechanisms by which diet and physical activity may affect fetal growth, uterine contractile activity, and mammary gland function.
- Studies are needed on lactation physiology, particularly on those aspects that are expected to be influenced by interactions between physical activity and nutritional status. Effects on milk composition,

milk volume, duration of lactation, and maternal abilities to respond to changing demands of infants and the short-and long-term effects of lactation on maternal health merit special attention.

- Studies are needed to document the conditions of work, the required physical activity of women during pregnancy and lactation, and the economics and sociology of work among specific population groups and ecological conditions.
- The effects of urbanization on the working patterns of women during pregnancy and lactation requires documentation.
- Measurements are needed of the energy requirements of common activities in specific ecological settings.
- Studies are needed of the metabolic adjustments that occur during pregnancy under different ecological conditions.

2. At present, in spite of the meager evidence at hand, it appears reasonable to promote programs that attempt to reduce energy expenditure and improve nutrition in pregnant and lactating women. These programs should complement, rather than replace, existing nutritional and prenatal and postnatal care programs designed to improve the health and nutrition of women of reproductive age before, during, and after pregnancy and lactation. These programs should be an integral part of efforts to improve the social and economic status of women in developing countries.