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NUTRIENT COMPOSITION OF HUMAN MILK

Mary Frances Picciano, PhD

International agencies and various US health organizations uniformly recommend breastfeeding as the preferred method of infant feeding for the entire first year of life and thereafter as long as is beneficial to the mother–infant dyad.[1, 52] These recommendations are based on knowledge that term infants nursed by nutritionally adequate mothers are provided with sufficient energy and the proper profile of nutrients to support normal growth and development without any additional foods through the first 4 to 6 months of life. After 6 months, complimentary foods are needed to furnish nutrients likely to become limiting. Also, human milk furnishes an array of nonnutrient growth factors, immune factors, hormones, and other bioactive components that can act as biological signals and confer protection against illness in infancy and later in life.[20, 43]

From a nutritional perspective, infancy is a critical and vulnerable period. At no other stage of life is a single food adequate as the sole source of nutrition. This phenomenon occurs when immaturity in tissues and organs involved in nutrient metabolism (i.e., the gastrointestinal tract, liver, and kidneys) limits the ability of an infant to respond to excesses or deficiencies in nutrient intakes. Human milk is species specific, and many of the nutrients it contains are secreted as bound components that can offer protection from digestion and facilitate absorption and utilization.

In this article, the characteristic nutritional features of human milk and influencing factors are reviewed. Knowledge of human-milk composition and nutrient intakes of thriving human milk–fed infants are central

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to the understanding of infant nutritional requirements and the nutritional cost of lactation for mothers.

ASSESSING INFANT NUTRITIONAL REQUIREMENTS

Intakes of thriving breastfed infants often serve as the standard for infant nutrition, but other approaches for the assessment of infant nutritional requirements exist, including direct experimentation, metabolic balance studies, clinical observations of deficiencies, and theoretically based calculations.[13] The latter approaches provide information that is useful for the formulation of human milk substitutes and for assessing whether maternal nutritional inadequacy is evident and when complementary foods should be introduced to a sole milk diet. The Food and Nutrition Board of the Institute of Medicine[24] uses average intakes of nutrients by full-term infants as the primary basis for deriving adequate intakes (AIs) in the first 6 months of life. Average intakes of breastfed infants growing adequately may exceed requirements, and intakes less than the adequate intake are compatible with nutritional adequacy. Nutritional requirements can differ among individual infants, even when weight and gestational age at birth are controlled, possibly as a result of genetic individuality, transplacentally acquired nutrient stores, and other reasons not established. Thus, infants tolerate a range of nutrient intakes, but establishing the normal limits is critical to the understanding of adequate nutrition during infancy. Any deviations from normal ranges, whether caused by maternal nutrition or formulation of human-milk substitutes that result in low or excessive intakes of nutrients, can be expected to produce adverse affects. Intakes outside of normal ranges are reported to produce significant morbidity in breastfed[29] and formula-fed infants.[34]

MATERNAL NUTRITION

The nutritional requirements to support lactation are among the highest in human development. The production of 750 to 1000 mL/d of human milk represents 2100 to 2520 kJ/d transferred as energy-yielding macronutrients to nursing infants. Also, all vitamins and minerals required to support growth and development of growing infants are likewise transferred. Nutritional needs to support lactation are exceedingly high and often not fully appreciated. The estimated energy cost of 6 and 9 months of lactation exceeds that of pregnancy by approximately 42% and 98%, respectively. As with energy, recommended intakes for many vitamins and minerals are higher in lactation than in pregnancy (Table 1). Thus, nutritional deficiencies may arise during this period in reproduction and affect mothers and infants. In successful lactation, infants are well nourished, and the health of mothers remains intact.

Table 1. COMPARISON OF RECOMMENDED ENERGY AND SELECTED NUTRIENT INTAKES: PREGNANCY AND LACTATION*

Nutritional Requirement	Pregnancy 0–9 mo	Lactation 0–6 mo	Lactation 7–9 mo	Lactation 0–9 mo
Energy (kJ)	340,200	483,840	192,780	676,620
Water-soluble vitamins				
Vitamin C (mg)†	18,900	17,100	2700	19,800
Thiamin (mg)‡	389	270	135	405
Riboflavin (mg)‡	378	288	144	432
Niacin (mg NE)‡	4860	3060	1530	4590
Vitamin B_6 (mg)‡	513	360	180	540
Folate (μg DFE)‡	162,000	90,000	45,000	135,000
Vitamin B_{12} (μg)‡	702	504	252	756
Pantothenic acid (mg)§	1620	1260	630	1890
Biotin (μg)§	8100	6300	3150	9450
Choline (mg)§	121,500	99,000	49,500	148,500
Fat-soluble vitamins				
Vitamin A (μg RE)†	216,000	234,000	117,000	351,000
Vitamin D (μg)‖	1350	900	450	1350
Vitamin E (mg α-TE)†	2700	2160	1080	3240
Vitamin K (μg)†	17,550	11,700	5850	17,550
Minerals				
Ca (mg)‖	270,000	180,000	90,000	270,000
P (mg)¶	324,000	216,000	108,000	324,000
Mg (mg)¶	94,500	55,800	27,900	83,700
Fe (mg)†	8100	2700	1350	4050
Zn (mg)†	4050	3240	1710	4950
I (μg)†	47,250	36,000	18,000	54,000
Fl (mg)‖	837	558	279	837
Se (μg)†	17,550	13,500	6750	20,250

*Calculations are based on recommended daily intakes, assuming 9 mo is equivalent to 270 d; 6 mo, to 180 d, and 3 mo, to 90 d.

†Recommended dietary allowances *from* Recommended Dietary Allowances, ed 10. National Research Council, 1989.

‡Recommended dietary allowances *from* Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B_6, Folate, Vitamin B_{12}, Pantothenic Acid, Biotin, and Choline [prepublication copy]. National Research Council, 1998.

§Dietary reference intakes *from* Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B_6, Folate, Vitamin B_{12}, Pantothenic Acid, Biotin, and Choline [prepublication copy]. National Research Council, 1998.

‖Adequate intakes *from* Dietary Reference Intakes for Calcium, Phosphorus, Vitamin D, Fluoride [prepublication copy]. NRC, 1997.

¶Recommended dietary allowances *from* Dietary Reference Intakes for Calcium, Phosphorus, Vitamin D, Fluoride [prepublication copy]. NRC, 1997.

NE = Niacin equivalents; DFE = Dietary folate equivalents; RE = retinol equivalents; TE = α-tocopherol equivalents.

Success of lactation should be evaluated using measures of maternal and infant nutritional status.

COMPOSITION OF HUMAN MILK

Human milk is a complex biological fluid composed of thousands of constituents in several compartments: an aqueous phase with true solutions (87%), colloidal dispersions of casein molecules (0.3%), emul-

sions of fat globules (4%), fat-globule membranes, and live cells. Human-milk constituents can be broadly categorized according to their physical or physiologic properties. These categories of constituents include:

- Proteins
  - α-Lactalbumin
  - β-Lactoglobulin
  - Caseins
  - Enzymes
  - Growth factors
  - Hormones
  - Lactoferrin
  - Lysozyme
  - Secretory IgA and other immunoglobulins
- Nonprotein nitrogen
  - α-amino nitrogen
  - Creatine
  - Creatinine
  - Glucosamine
  - Nucleic acids
  - Nucleotides
  - Polyamines
  - Urea
  - Uric acid
- Carbohydrates
  - Lactose
  - Oligosaccharides
  - Glycopeptides
  - Bifidus factors
- Lipids
  - Fat-soluble vitamins (A, D, E, and K)
  - Carotenoids
  - Fatty acids
  - Phospholipids
  - Sterols and hydrocarbons
  - Triglycerides
- Water-soluble vitamins
  - Biotin
  - Choline
  - Folate
  - Inositol
  - Niacin
  - Pantothenic acid
  - Riboflavin
  - Thiamin
  - Vitamin B_{12}
  - Vitamin B_6
  - Vitamin C

- Mineral and ionic constituents
  - Bicarbonate
  - Calcium
  - Chloride
  - Citrate
  - Magnesium
  - Phosphate
  - Potassium
  - Sodium
  - Sulfate
- Trace minerals
  - Chromium
  - Cobalt
  - Copper
  - Fluoride
  - Iodine
  - Iron
  - Manganese
  - Molybdenum
  - Nickel
  - Selenium
  - Zinc
- Cells
  - Epithelial cells
  - Leukocytes
  - Lymphocytes
  - Macrophages
  - Neutrophils

Representative values for many of these constituents are listed in the Appendix to the issue (p. 263). The interested reader is referred to other detailed discussions of constituents in human milk and comparisons to the milk of other species.[23, 27, 55]

Human-milk composition varies among and within women. Changes occur in the concentrations of energy-yielding macronutrients and the micronutrients of human milk. The composition and volume of human milk secreted are influenced by factors such as genetic individuality; maternal nutrition; stage of gestation and lactation; and techniques of sampling, storage, and measurement. Some of the factors that can affect milk fat content and composition are presented in Table 2.

Fat is the most variable constituent of human milk, and the mechanisms for all observed changes are not well understood. The high long-chain polyunsaturated fatty acids (FAs) secreted in the milk of women who deliver prematurely may reflect the enhanced need for these essential FAs by premature infants.[3] These FAs that are normally stored by the fetus in late gestation are required to function in growth and brain development.[30] Elevated phospholipid and cholesterol contents of early milk merely stem from the fact that, initially, milk-fat globules secreted

Table 2. FACTORS INFLUENCING HUMAN MILK FAT CONTENT AND COMPOSITION

Factor	Influence
Duration of gestation	Shortened gestation increases the long-chain polyunsaturated fatty acids secreted.
Stage of lactation	Phospholipid and cholesterol contents are highest in early lactation.
Parity	High parity is associated with reduced endogenous fatty acid synthesis.
Volume	High volume is associated with low milk fat content.
Feeding	Human milk fat content progressively increases during a single nursing.
Maternal diet	A diet low in fat increases endogenous synthesis of medium chain fatty acids (C6 to C10).
Maternal energy status	A high weight gain in pregnancy is associated with increased milk fat.

are smaller than in later lactation, and, therefore, the membrane components of fat are higher.[45] Advanced parity and large milk volume are associated with low milk fat content.[50] In the former case, low milk fat secretion is believed to be caused by a loss of secretory mass,[42] whereas the latter may result from the interaction between the mother and infant. Butte et al[4] reported that milk volume was increased by 5% to 15% in women with low body fat stores who secreted milk with a low fat content caused by enhanced suckling by their infants.

Milk fat changes from the beginning to the end of a single nursing[22] and was the subject of early medical writings. In 1473, Metlinger advised that "the wet nurse should first milk the breast so that the watery part runs from it, and then give the child to suck."[46] Maternal nutritional intake also can exert a strong influence on the characteristic FAs secreted. Circulating lipids, which are a reflection of the maternal diet and adipose stores, are the main substrates for milk fat. When the maternal diet is low in fat content and rich in carbohydrates, mammary de novo synthesis is increased, and milk rich in medium-chain (C6–C10) and intermediate-chain (C12–C14) FAs is secreted.[25] Nonetheless, endocrine changes specific to lactation and maternal adipose stores buffer daily dietary fluctuations, so that human milk fat has a characteristic FA profile.

HUMAN MILK COMPOSITION AND PROPERTIES

Macronutrients

Protein and Nonprotein Nitrogen

Human milk protein content [(total nitrogen − nonprotein nitrogen) × 6.25] is high in early secretions, 15.8 g/L, and slowly decreases to 8.0 to 9.0 g/L with the establishment of lactation.[12, 27] The protein constituents of human milk serve diverse functions. Besides providing essential

amino acids for growth, they provide protective factors (e.g., immunoglobulins, lysozymes, and lactoferrin), carriers for vitamins (e.g., folate, vitamin D, and vitamin B_{12} binding proteins), and for hormones (e.g., thyroxine and corticosteroid-binding proteins), enzymatic activity (e.g., amylase and bile-salt–stimulated lipase) and other biological activities (e.g., insulin, epidermal growth factor, and prolactin). Qualitative and quantitative differences exist in constituent proteins and the nonprotein nitrogen components among species. The total protein content of human milk is the lowest among species, and human infants grow more slowly than do the young of other species. Evidence indicates that nitrogen use from human milk for deposition of lean body mass is remarkably high.[39] In direct contrast to true protein, nonprotein nitrogen constituents of human milk comprise a large percentage of the total nitrogen (20–25%) and are relatively constant throughout lactation. The nonprotein nitrogen fraction consists of more than 200 compounds, including free amino acids, carnitine, taurine, amino sugars, nucleic acids, nucleotides, and polyamines. Some nonprotein nitrogen components may be conditionally essential. Uauy et al[51] suggest that rapidly growing tissues, such as the intestinal epithelium and associated lymphoid cells, lack de novo synthesis capacity for nucleotides, so that exogenous sources of purine and pyrimidine bases may be required by infants. Many nucleotides are contained in human milk.[7, 26]

Maternal nutrition may alter the total protein and nonprotein nitrogen components of human milk.[10] Miranda et al[37] observed a reduction of total protein and the immunologic components C4 complement, IgA, and IgG in early milk collected from malnourished Colombian mothers. In other parts of the world where maternal malnutrition also is evident, concentrations of milk protein are reported to be low and free and total amino acid contents to be altered.[23] Even in well-nourished women, dietary protein intake (20% versus 8% energy from protein) positively influences total nitrogen, true protein, and nonprotein nitrogen contents.[14] Whether these alterations in the nitrogen constituents of human milk influence nursing infants has not been investigated.

Lipids

Lipids comprise the major energy-yielding fraction of human milk, 97% to 98% of which are triglycerides. The constituent FAs represent approximately 88% of milk fat. They are by far the most variable constituents in milk, and the characteristic features of human-milk lipids are reviewed elsewhere.[27, 28] The total fat content of human milk varies from 30 to 50 g/L, and the corresponding energy contribution is approximately 45% to 55% of total kilojoules. The assimilation of fatty acids by young infants is crucial not only for energy to support growth but also for the synthesis and development of retinal and neural tissues. Human milk is a rich source of the essential FAs, linoleic acid (C18:2ω-6, 8–17%) and α-linolenic acid (C18:2ω-3, 0.5–1.0%), and their long-chain derivatives, arachidonic acid (C20:4ω6, 0.5–0.7%) and docosahexaenoic acid

(C22:6ω-3, 0.2–0.5%). Circulating levels of the long-chain polyunsaturated FAs are reported to be low in pregnant and lactating women, which may indicate that preferential transfer to the fetus and infant by the placenta and mammary gland is accomplished at the expense of maternal stores.[30]

Fat digestion in the early neonatal period is not fully developed, primarily as a result of pancreatic insufficiency.[19, 36] Digestion of milk lipids in nursing neonates is achieved by a concert of enzymes. The first is lingual lipase, which initiates hydrolysis in the stomach; the second is gastric lipase; the third is bile salt–stimulated lipase, which is indigenous to human milk; and the fourth is pancreatic lipase. Compared with adults, fat digestion is markedly aided by gastric lipase in infants and, in breastfed infants, by the bile salt–dependent lipase of human milk. The steriometric structure of triglycerides can influence the hydrolysis rate and thus absorption. The predominant FA in human milk, palmitic acid (C16:0), is preferentially found in the steriospecific number 2 position of the triglyceride, so it is primarily absorbed as the 2-monoglyceride.

Carbohydrates

The disaccharide, lactose, which is second only to water as a major constituent of human milk, is present at an average concentration of 68 g/L.[27] Milk lactose content increases steeply in early lactation and correlates positively with milk yield and negatively with whey proteins during the establishment of lactation. Lactose is one of the most stable constituents of human milk, with most of the variability being caused by maternal individuality. Glucose also is found in human milk but in considerably lower quantities (0.02 g/L). Because of delayed lactogenesis, lactose is initially low in milk from women with insulin-dependent diabetes but increases to normal values by day 4 postpartum. Among species, the concentrations of lactose and α-lactalbumin are positively correlated because the synthesis of lactose is achieved by coupled reaction of galactosyltransferase with α-lactalbumin. In addition to lactose and glucose, human milk contains nucleotide sugars, glycolipids, glycoproteins, and oligosaccharides. Some of the oligosaccharides may have biologic activity in infants, such as inhibiting the binding of pathogens to their receptors and promoting growth of several species of bifidobacteria in the intestine.[2, 8, 40]

Micronutrients

Vitamins

The vitamin content of human milk is affected by several factors, the most important of which is the maternal vitamin intake or vitamin nutritional status. In general, when maternal vitamin status is low, human-milk contents are correspondingly low and respond rapidly to maternal intake; when maternal status is adequate, milk vitamin content is relatively stable and less responsive to intake.[27]

Fat-Soluble Vitamins. The vitamin A content of human milk, which is comprised principally of retinyl esters, decreases with advancing lactation from 200 mg/L to 300 to 600 mg/L and is more influenced by maternal dietary intake than by her vitamin A status.[21, 44] Plasma concentrations of retinol-binding protein are elevated in early lactation and decrease in parallel with milk vitamin A content. The sources of vitamin A for milk synthesis are plasma RBP-retinol and retinyl esters in chylomicrons. The former source is relatively constant after the initial decrease regardless of vitamin A status (liver stores), whereas the latter is directly related to maternal intake, which explains why a large dose of vitamin A (>15 mg) causes only a transient increase in milk content. Human milk also contains various carotenoids (α-carotene and β-carotene, lutein, cryptoxanthin, and lycopene) in concentrations similar to those of retinol (2 mg/L in early milk and 0.2–0.4 mg/L in mature milk).

The quantity of vitamin D and its metabolites in human milk range from 0.1 to 1.0 μg/L. These sterols are present in the nonlipid fraction of milk at 1.5% to 6.0% of their concentration in maternal plasma and are secreted attached to plasma or cytosol vitamin D–binding proteins. Maternal vitamin D intake is related to the milk content, but milk is nonresponsive. Breastfed infants can and do develop rickets, especially infants nursed by mothers who restrict their intake of vitamin D–rich foods (i.e., strict vegetarians), shield their body from sunlight, or who live in northern latitudes. Thus, maternal plasma levels of vitamin D can decrease to critically low levels and limit transfer by milk. Results of clinical studies about whether human milk feeding can provide sufficient vitamin D for infant bone mineralization are mixed.[16] Vitamin D supplementation (10 μg/d) often is recommended for breastfed infants, especially for infants living in northern latitudes.

Vitamin K concentration of human milk ranges from 1 to 9 μg/L, whereas typical values are approximately 2 to 3 μg/L. Transplacental transfer of vitamin K is minor and infants are born with low tissue stores. Maternal dietary intake bears little relationship to milk vitamin K content, possibly because of varying bioavailability of food sources, but maternal supplementation of 5 or 20 mg/d causes increases in milk and infant plasma levels of the vitamin.[15, 17]

Approximately 83% of the total vitamin E content of human milk is α-tocopherol; β-, γ-, and δ-tocopherols also are present in small quantities. The concentrations of tocopherols, which are high in colostrum (8 mg/L), decrease and stabilize in mature human milk (3–4 mg/L). Supplementation of the maternal diet with relatively large amounts of vitamin E is necessary to increase the milk levels of this vitamin.

Water-Soluble Vitamins. The average vitamin C content of mature human milk from well-nourished women is approximately 100 mg/L. A maternal intake of more than 100 mg/d does not alter the milk content. A corresponding decrease in milk level occurs with maternal intakes of

less than this amount. Human milk vitamin C concentration is approximately 8-fold to 10-fold higher than the maternal plasma concentration.[27]

The thiamin concentration is low in early milk (20 μg/L) and increases severalfold (7–10) in mature milk (200 μg/L). Riboflavin content, which is largely a reflection of the maternal diet, is high in early milk and decreases to 400 to 600 μg/L with the progression of lactation. After the initial increase in the niacin concentration from early (0.5 mg/L) to mature (1.8–2.0 mg/L) human milk, levels are largely dependent on maternal intake and may be as high as 6 mg/L.

Milk vitamin B_6 content is low in early lactation and ranges from 0.09 to 0.31 mg/L in mature milk. Vitamin B_6 content of mature milk is 10-fold higher than in maternal serum, which is directly related to maternal intake and can be reduced to critically low levels in mothers with a long-term history of oral contraceptive use.[31]

Vitamin B_{12} and folate in milk are secreted bound to whey proteins that are usually present in excess. Heat processing drastically reduces milk excess binding capacities for these vitamins. Milk and isolated binding proteins for vitamin B_{12} and folate inhibit the growth of organisms that require these vitamins in vitro, but a similar role in vivo has not been established.

The accepted normal range for the vitamin B_{12} concentration of mature human milk is 0.5 to 1.0 μg/L. In well-nourished women, supplementation with vitamin B_{12} seems to have little or no effect. Several cases of vitamin B_{12} deficiency in infants nursed by mothers who were strict vegetarians have been reported.[53] The milk concentrations of vitamin B_{12} that deficient infants received were between 0.05 and 0.075 μg/L. Even though vitamin B_{12} supplementation leads to rapid resolution of hematologic abnormalities and cerebral atrophy in infants, evidence suggests that vitamin B_{12} deficiency early in infancy may cause lasting neurodisability.[53]

Human milk folate content is much higher than previously reported because of improved methods of analysis. Typical values for mature human milk of well-nourished Japanese and US women are between 80 and 140 μg/L.[41] Folate in human milk bears a relation to maternal serum concentration only in overtly deficient women and increases with the progression of lactation or remains stable even as maternal indices of folate status (serum and erythrocyte folate levels) decrease. The mammary gland shows priority for the use of folate over the maternal hematopoietic system. Folate supplementation of lactating women with megaloblastic anemia caused by folate deficiency causes an immediate increase in milk folate even though maternal plasma values are unchanged. US lactating women on self-selected diets furnishing approximately 80% of the recommended amount (500 μg/d) show a diminution of folate stores from 3 to 6 months to maintain milk folate secretion.[35] Human milk contains 5 to 9 μg/L of biotin. Concentrations in milk are 20-fold to 50-fold greater than corresponding values in maternal plasma.

Minerals

Unlike their organic counterparts, the concentrations of inorganic constituents in human milk generally do not correlate with amounts in the maternal diet or maternal serum. Studies have emphasized the high bioavailability of human milk minerals and their interrelationship with other nutrients that may affect their absorption, metabolism, and excretion.

Major Minerals. Calcium, phosphorus, and magnesium concentrations in human milk generally do not correspond to their respective values in maternal serum; however, Greer et al[18] observed a weak correlation between maternal calcium intake and milk concentration. In that longitudinal investigation, human milk phosphorus levels decreased from 147 mg/L at 3 weeks of lactation to 107 mg/L at 26 weeks of lactation. At those time frames, values for human milk calcium and magnesium were 259 to 248 and 290 to 330 mg/L, respectively. Although infant serum phosphorus concentrations correlated with milk levels and decreased as lactation progressed, serum calcium and magnesium concentrations increased. The investigators speculated that elevated values for serum calcium and magnesium and depressed values for phosphorus are important for bone remodeling in infancy.

An electric potential gradient in mammary secretory cells determines the concentrations of milk electrolytes.[27] The synthesis of lactose osmotically draws water, and the passage of water establishes the potential difference necessary to maintain the low milk electrolyte concentrations. Average amounts of sodium, potassium, and chloride in mature human milk are 7, 15, and 12 mEq/L and are approximately 66%, 31%, and 36%, respectively, of their respective amounts in early milk when lactose content is low.[27] Women with mastitis or mammary inflammation secrete milk high in sodium and chloride because the normally tight junctions between mammary epithelial cells are open and allow for passage of these electrolytes from plasma to milk.

Trace Minerals. Within the first month of life, breastfed infants are in negative balance for copper, iron, and zinc, even though human milk contents are highest immediately following parturition.[6] Copper and iron contents of milk decrease rapidly in early lactation and apparently stabilize in mature milk at 0.3 mg/L, whereas zinc content continues to decrease. Early milk contains an average of 4 mg/L of zinc; the value at 6 months is 1.1 mg/L and at 1 year is 0.5 mg/L. Maternal diet does not seem to influence milk concentrations of these elements.[38, 54] Serum copper concentration in breastfed infants is more related to plasma ceruloplasmin concentration, which is low at birth, than to milk content. Serum iron concentration of breastfed infants likewise parallels transferrin synthesis. Serum zinc concentration of infants is comparable with that of adults and does not exhibit a developmental pattern. Liver stores accumulated primarily during the last trimester of pregnancy have a strong influence on infant copper, iron, and zinc status in early infancy.[56]

High bioavailability of human milk iron and zinc is reported; how-

ever, the bioavailability of copper is unknown. The mechanism of iron absorption from human milk and factors responsible are incompletely understood. Under similar conditions, iron from human milk is absorbed fivefold more efficiently than is a similar amount from bovine milk.[47] Approximately one third of iron in human milk is associated with the lipid fraction; one third, with the aqueous fraction; and approximately 10%, with casein. Lactoferrin, an iron-binding protein of immunologic significance, probably binds 20% to 30% of the iron in the aqueous fraction and often is claimed to account for the high bioavailability; however, heat treatment of human milk, which destroys lactoferrin, does not alter the iron-absorption rate.[33] Zinc in human milk also exhibits high bioavailability. Breastfed infants maintain high plasma zinc values compared with formula-fed infants, even when the concentration of zinc is three times that of human milk.[48] The molecular species and the total amount of zinc affects its bioavailability from milk.

Manganese decreases in mature milk from approximately 6 μg/L at 1 month of lactation to 3 μg/L at 3 and 6 months. Chan et al[5] reported differences between human milk and infant formula in number and type of ligands binding manganese, which may affect bioavailability.[9] Human milk selenium concentration is high at the initiation of lactation (40 μg/L), associated with several protein fractions, and mean values in mature milk display a geographic distribution (7–33 μg/L).[49] Maternal selenium status has a strong influence on milk selenium content, which decreases with advancing lactation in women on self-selected diets.[32] Milk selenium is positively correlated with infant plasma content and activity of the classic selenium-containing enzyme, glutathione peroxidase. Iodine in human milk varies widely according to geographic region and maternal intake. In areas where iodine-deficiency disorders are prevalent, human milk iodine content is approximately 15 μg/L and in iodine-sufficient areas, approximately 150 μg/L. Iodine is required for synthesis of thyroid hormones that are required for brain development during fetal and early postnatal life. Iodine deficiency is a leading cause of brain damage and mental retardation, and maternal iodine supplementation during pregnancy and early lactation can reverse this leading cause of mental impairment worldwide.[11]

SUMMARY

A complex interplay of maternal homeostatic mechanisms influences nutrient transfer to nursing infants, and with a few exceptions, excess maternal intake or a moderate deficiency in the maternal diet does not appreciably alter nutrient transfer to infants unless it has persisted for some time. Milk vitamins D and K contents, even in apparently well-nourished women, may not always provide adequate amounts for infants. Investigations provide evidence that human milk possesses many unique characteristics and that maternal and environmental influences are stronger than previously recognized and appreciated. A complete body of knowledge does not exist to serve as a basis for dietary recommendations to ensure optimal nutrition for mothers and infants. The success of lactation usually is measured in terms of infant performance, and cost and consequence to the mother are seldom considered. Human milk feeding is recommended for the entire first year of life, but few studies focus on the nursing dyad for more than 3 months' duration. Continued study is needed so that nutritional adequacy may be maintained and appropriate dietary guidance can be provided. When human milk feeding is not practiced, modern and reliable data on human milk constituents and their significance to infants also are essential for the preparation of formulas, especially those not based on bovine milk. The adequacy of human milk substitutes cannot be predicted from compositional analysis because of possible differences in compartmentalization and molecular form of nutrients, and such preparations must be evaluated using specific indices of nutrient use, together with traditional anthropometric measures in infants.

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