Lactation is a continuation of intrauterine gestation. In both processes, maternal diet plays an active role in the provision of nutrients, maternal nutritional stores and endocrine adaptations serve to buffer the short-term variations in maternal nutritional intake, blood flow plays an overriding role in nutrient transfer to the fetus and newborn infant, and the nutrient demands of the recipient are the highest of any stage in human development.

Human milk is remarkable in its variability. Recent data suggest that the variability often improves the nutrient composition as part of a complex adaptation to the infant's specific needs. A comprehensive survey of the literature on lactation and human milk is provided in two review articles.

NUTRIENTS

Lipids

Milk lipids provide the major fraction of calories in human milk, yet they are the most variable constituent. Preceding a nursing, the fluid phase of milk stored within the gland resembles skimmed milk. During the course of a nursing, the contraction of smooth muscle launches the fat droplets. This draught reflex is essential for caloric adequacy for the breast-fed infant.

Women living under unfavorable socioeconomic conditions have reduced total milk lipid. There is evidence that supplementing the diets of these women leads to increased milk fat. Under controlled metabolic ward conditions, a high-caloric, high-fat diet can be demonstrated to increase milk fat production. The distribution of the spectrum of fatty acids in human milk also is responsive to dietary changes.

Women who are malnourished also produce an excess of 12:0 and 14:0 fatty acids. Women ingesting a diet with a high content of polyunsaturated fat have high levels of unsaturated fat in milk, especially linoleic acid (18:2). Breast-fed infants of mothers on a vegetable oil diet have high plasma levels of linoleic acid (18:2).

Protein

Colostrum, the milk produced by women in the first five days post partum, is richer in protein than milk collected after 30 days of lactation. The quantitative and qualitative changes are summarized in Table 1. The “whey” proteins make up the largest fraction of human milk proteins. By definition, they are milk proteins that do not precipitate in the stomach. Lactoferrin and secretory IgA play a role in the control of susceptibility to gastrointestinal disease in the nursing infant. The caseins are proteins that give milk its characteristic, white appearance. The micelles of casein coagulate under the conditions found in the stomach and precipitate as curds. The older literature indicates that 40% of human milk protein precipitates under gastric conditions. Recent literature shows that many whey proteins precipitate with “casein.” The addition of a skimmed milk supplement sufficient to increase protein intake of an energy-adequate diet from 25 to 100 gm of protein per day increased milk yield from severely malnourished women. Total milk protein concentration was unchanged. The increase of dietary protein from 25 to 100 gm per day was associated with increased infant weight gain which became evident by the third or fourth day and was sustained throughout a four-week study period. This study confirmed the findings of previous investigators.

Carbohydrate

Lactose is the dominant sugar in human milk. Synthesis of this sugar takes place at the wall of the Golgi apparatus. This mechanism effectively
traps carbohydrate in the Golgi spaces from which lactose is released into the alveolar lumen. Although the concentration of lactose is less variable than that of other nutrients, the total production is reduced in malnourished mothers.17

Water

Water is by mass and volume the major nutrient in milk and comprises between 85% and 95% of the total volume. The total milk volume varies with the age of the infant and is related closely to maternal lactose production.1 Folklore says an increased water intake increases milk production, but several investigations have shown that in fact, forcing fluid intake above that required by normal thirst impairs milk production.20'21

Salt

The trapping of lactose within the Golgi spaces creates an electrochemical difference that is responsible for the transport of sodium and potassium into milk. The salt concentration of colostrum is higher than that of mature milk.22-24 No relationship has been demonstrated between maternal salt intake and human milk sodium concentration.

Calcium and Phosphorus

Milk calcium and phosphorus have mean concentrations of 34 and 14 mg/100 ml, respectively.24 Balance studies indicate that the lactating woman must receive 1.5 to 2 gm of calcium per day to absorb the 0.3 to 0.5 gm/day secreted in her breast milk.25 On usual levels of dietary intake, the mother is losing about 250 mg/day more than she is absorbing.26,27 Older clinical literature documents cases of osteomalacia and tetany in mothers who nursed for long periods while on inadequate diets.28,29 Clinical reports also document the occurrence of rickets in breast-fed infants.30,31 Measurements of total calcium and phosphorus in the milk of mothers with rachitic infants, however, revealed no significant alterations in mineral composition.25,30,31 Studies of maternal intakes of dietary calcium and phosphorus revealed no correlation with milk concentrations (Table 2).31-33

Iron

The normal infant at birth has a store of approximately 75 mg of iron per kg.45 Theoretical calculations and practical experience indicate that this is adequate to meet erythrocyte iron needs during the first four to six months of life.46-48 Breast milk supplies about 0.3 mg of iron per liter.36,49 At the usual rate of intake, many authorities believe that supplemental iron is essential during the second six months of breast feeding.36,46-50 Supplementing the diet with iron-fortified cereals during the second six months of infancy may meet these iron needs.47 Other authors argue that 210 mg of an elemental iron supplement should be given during the first year of life to prevent iron deficiency.51 The iron in human milk is better absorbed than that from other milks.34,35,51-55 Maternal iron stores do not influence milk iron concentrations.36,47 Iron-deficient anemic Indian and African women had no reduction in milk iron, and iron supplements during lactation did not increase milk iron.32,47

Zinc

Colostrum has a zinc concentration of 4.6 mg/liter37; at 6 months of age, the concentration in human milk falls to 0.9 mg/liter38; and, at 1 year of age, average milk zinc is 0.45 mg/liter.39 At 6 months of age, breast-fed infants have serum and hair zinc concentrations equivalent to those of adults. Formula-fed infants have lower serum and hair zinc

<table>
<thead>
<tr>
<th>Table 1. Protein in Human Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fraction</strong></td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>Casein</td>
</tr>
<tr>
<td>Lactoferrin</td>
</tr>
<tr>
<td>α-Lactalbumin</td>
</tr>
<tr>
<td>Secretory IgA</td>
</tr>
<tr>
<td>Lysozyme</td>
</tr>
<tr>
<td>Serum albumin</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Minerals in Human Milk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mineral</strong></td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Sodium</td>
</tr>
<tr>
<td>Calcium</td>
</tr>
<tr>
<td>Iron</td>
</tr>
<tr>
<td>Zinc</td>
</tr>
<tr>
<td>Copper</td>
</tr>
<tr>
<td>Manganese</td>
</tr>
<tr>
<td>Selenium</td>
</tr>
<tr>
<td>Iodine</td>
</tr>
<tr>
<td>Fluoride</td>
</tr>
</tbody>
</table>
concentrations despite intakes up to 5.8 mg/liter from cow's milk formula. This observation confirms earlier experiments that indicate zinc is better absorbed from human milk than from cow's milk. This is because of a 50% better bioavailability of zinc in human milk (Table 2). Dietary investigations indicate that a majority of North American women do not meet the 25 mg/day standard of intake suggested by the Recommended Dietary Allowances. No difference in milk zinc concentrations was detected when a group of women who had intakes in excess of the Recommended Dietary Allowances were compared with a group of women whose diet provided one-half this amount. No relationship has been detected between maternal serum, hair, and milk zinc concentrations.

Copper

When the infant is between 6 and 12 weeks of age, human milk has an average copper concentration of 0.3 mg/liter. Milk copper concentration averages 0.5 mg/liter during the first weeks of lactation. There is no decrease in concentration after 2 weeks of age. No relationship between maternal dietary intake and milk copper concentration has been observed.

Manganese

Human milk contains approximately 20 μg/liter of manganese. With the possible exception of an elevated level at two weeks of lactation, the concentrations of manganese are constant, even after 1½ years of milk production. There is no relationship between maternal diet and serum level, hair concentration, or milk content of American women. A relationship between diet and milk manganese levels has been reported in Finnish women.

Selenium

Selenium is of interest in infant nutrition because of its role in the requirement for vitamin E. The mean concentrations in human milk have been reported to be 30 μg/liter in Germany, and 20 μg/liter in the United States. The selenium in human milk was three times higher than that in commercial infant formulas.

Iodine

Human milk contains a total of about 100 μg of iodine per liter during mature milk production. The use of iodized salt by the mother was associated with levels of twice this concentration. Colostrum has an iodine concentration of about 200 μg/liter. There is a milk-to-plasma gradient for inorganic iodine that is greater than 10.

Breast-feeding for six months has been reported to mitigate the impact of congenital cretinism on physical and mental development. This is explained largely by the transfer of thyroid hormones in breast milk. The studies of the Montreal screening program for congenital hypothyroidism have not confirmed that breast-feeding provided protection in 12 infants with thyroid insufficiency diagnosed and treated by 6 weeks of age.

Fluoride

The fluoride concentration of human milk collected on the fourth and fifty days post partum averages 50 μg/liter. This is one-half the concentration found in whole cow's milk. When milk collected from women living in a low fluoride area was compared to milk from women in an area where the drinking water was fluoridated, the mean concentrations did not differ significantly. Fluoridation of drinking water is not associated with a major increase in human milk fluoride concentrations.

Vitamin D

Fifty years ago, rickets was observed commonly in breast-fed infants who were seen at public hospitals in the United States. This continues to be true among mothers who, because of social or religious practices, do not drink vitamin D-fortified milk. A daily supplement of approximately 1,000 IU/day of vitamin D given to lactating mothers prevents rickets in breast-fed infants. The effect is in proportion to the total quantity of vitamin D ingested by the lactating mother (Table 3).

Early bioassays could not document nutritionally adequate quantities of vitamin D in human milk. Current advances in vitamin D chemistry have revealed that cholecalciferol and 25-hydroxycholecalciferol are in the lipid fraction of human milk. The sulfated form also is present in the aqueous phase. Japanese investigators report that water-soluble vitamin D sulfate is as potent as the lipid-soluble form in the prevention or healing of rickets in rats. They further report that the total vitamin D potency in human milk was bioassayed to be 750 IU/liter, most of which was accounted for by the sulfated form of the vitamin. This work requires confirmation before new recommendations can be made regarding vitamin D supplementation of the breast-fed infant.

Vitamin K

Hemorrhagic disease of newborn infants is a dis-
order associated with prolonged prothrombin times and reduced blood prothrombin levels (Table 3). It is prevented effectively by the administration of 100 μg of vitamin K soon after delivery. The mother does not provide for the vitamin K requirements of the fetus or her nursing infant (Table 3). Cow’s milk formula contains vitamin K. Newborn infants who receive a cow’s milk formula have a reduction in prothrombin time (and therefore increased prothrombin level) equivalent within 24 hours to that observed in infants receiving vitamin K supplement. The breast-fed infant or the infant who is fasted in the perinatal period must rely on a vitamin K supplement to restore the prolonged prothrombin time observed at birth.77

Vitamin A

Colostrum is rich in vitamin A. Despite adequate maternal vitamin A intake and serum concentration, the milk content of the vitamin decreases during the course of lactation from 2,000 to 250 μg/liter56,78,79. The vitamin A concentration of colostrum or milk can be increased about fourfold by acute loading of the mother with excessive supplements (Table 3).66–68 The ratio of milk-serum concentration is approximately 0.6. The effect of increased dietary vitamin A reflects the dependence of milk concentrations of alimentary intake. Efforts to build up the liver reserves by prenatal supplementation,66 by a long-term supplement,80 or by administration of carotene66,69 did not increase milk vitamin A concentrations.

Vitamin E

Vitamin E concentration is greatest in colostrum, averaging 13.3 mg/liter,79 and it is approximately equal to maternal plasma levels.81 Concentrations in milk decrease to half at two weeks post partum and to one-fourth at one month post partum.79 Breast-fed infants have an increase in vitamin E blood level from 3.8 to 14.6 mg/liter during the first six days of life. Concentrations thereafter parallel the maternal serum levels. Unless a supplement is provided, formula-fed infants have a persistence of low serum levels for at least six months.81

Vitamin C

Higher concentrations of vitamin C exist in the plasma and in leukocytes of cord blood than are found in the mother. This is true even when maternal blood levels are extremely low.82 Balance studies carried out during lactation suggest that the mother provides milk ascorbic acid at her own expense.83 The older literature claims that scurvy is rare in breast-fed infants (Table 4).66–69 Seasonal fluctuations in milk concentration reflect the availability of vitamin C in the diet.66,79,81 Milk concentrations reflect the intake of ascorbic acid among subjects on a reduced intake33,89. The subjects respond to administration of vitamin supplements in proportion to the intake; milk levels increase from 24 to 61 mg/liter when the supplement provided is 200 mg/day.86

Thiamine (B1)

Infantile beriberi has been observed in breast-fed infants when unfortified, machine-milled rice was the main cereal in maternal diets. The addition of thiamine provided dramatic relief to the infants.85 Milk thiamine concentrations from women on this diet reveal a drastic reduction in vitamin content.97

TABLE 3. Fat-Soluble Vitamins in Human Milk

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Recognizable Deficiency</th>
<th>Clinical Effect of Maternal Supplements</th>
<th>Dietary Effect of Intake on Milk Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Yes25,62</td>
<td>Yes25,62</td>
<td>Unknown</td>
</tr>
<tr>
<td>K</td>
<td>Yes54</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>A</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>E</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

TABLE 4. Water-Soluble Vitamins in Human Milk

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Recognizable Deficiency</th>
<th>Clinical Effect of Maternal Supplements</th>
<th>Dietary Effect of Intake on Milk Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascorbic acid</td>
<td>Rare66</td>
<td>Yes69</td>
<td>No84</td>
</tr>
<tr>
<td>Thiamine</td>
<td>Yes85</td>
<td>Yes83</td>
<td>Yes63,66,68,89,90</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>Unknown</td>
<td>Yes68</td>
<td>Yes83,99,11</td>
</tr>
<tr>
<td>Niacin</td>
<td>Unknown</td>
<td>Yes68</td>
<td>Yes83,99,11</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>Unknown</td>
<td>Yes68</td>
<td>Yes83,99,11</td>
</tr>
<tr>
<td>Pyridoxine</td>
<td>Unknown</td>
<td>Yes68</td>
<td>Yes83,99,11</td>
</tr>
<tr>
<td>Biotin</td>
<td>Yes92</td>
<td>Yes93</td>
<td>No86</td>
</tr>
<tr>
<td>Folate</td>
<td>Unknown</td>
<td>Yes93</td>
<td>No86,94,104</td>
</tr>
<tr>
<td>Cyanocobalamin</td>
<td>Rare85</td>
<td>Yes93</td>
<td>Yes96</td>
</tr>
</tbody>
</table>

In normal women, milk thiamine is increased from an average 20 µg/liter in colostrum to 140 µg/liter in mature milk. Concentrations of milk from poorly nourished women have shown the same increase during lactation. In both well nourished and poorly nourished mothers, milk concentrations respond to thiamine supplementation (Table 4).

Riboflavin (B2)

Riboflavin resembles thiamine in the relationship between dietary intake and milk vitamin concentration. The concentration in colostrum is approximately 200 µg/liter compared to 370 µg/liter in mature milk. The concentrations tend to fall to lower levels with prolonged lactation. The concentration in milk reflects the average dietary intake. The administration of riboflavin either as a loading dose or as a continuing supplement results in the elevation of milk concentrations as high as 2,000 µg/liter (Table 4).

Niacin

Milk niacin levels are reduced in colostrum to 750 µg/liter and increase during the first two weeks of lactation to three times this level. In mature milk production, dietary niacin intake influences milk niacin concentration (Table 4). The bioavailability of niacin can be reduced on a corn diet and will result in reduced milk niacin concentrations despite apparently adequate maternal vitamin intake. Supplementary intakes of the vitamin increase milk niacin concentration acutely and produce sustained effects. Milk contains sufficient tryptophan which is convertible to niacin to protect the infant against niacin deficiency.

Pantothenic Acid

Human milk pantothenic acid levels increase to an average concentration of 2 to 3 mg/liter during the first weeks of lactation. In poorly nourished women with milk concentrations averaging 1 mg/liter, supplementary vitamin intake has increased milk content in proportion to the intake (Table 4). In well nourished North American women with basal levels of 3 mg/liter, no increase was detected after supplementations.

Pyridoxine (B6)

Fetal pyridoxine levels, as reflected in cord blood, are about three times the levels found in the maternal circulation. The pyridoxine level in colostrum is equivalent to maternal blood levels; mature milk levels are 16 times maternal blood levels. Pyridoxine levels in poorly nourished populations are lower than those observed in the United States. Supplementary pyridoxine given to these poorly nourished women resulted in a twofold increase in milk concentrations, 80 to 160 µg/liter (Table 4). In North American women, supplementation with pyridoxine resulted in a statistically significant increase in milk content from 204 to 237 µg/liter.

Biotin

The biotin content of human colostrum is low; it increases from 1 to 8 µg/liter in mature milk. Poorly nourished women with low milk folate levels averaging 2 µg/liter responded to a vitamin supplement with a peak content at 5.6 µg/liter. In lactating women who develop megaloblastic anemia, folic acid is excreted preferentially in milk. This affords protection of the infant hemoglobin concentration in severe maternal anemia. In North American women with milk folate concentrations of 50 µg/liter, the administration of an oral “one-a-day” supplement was not associated with increased milk concentrations. (M. R. Thomas, S. M. Sneed, C. Wei, et al, unpublished data, 1981).

Folate

Folic acid levels are low in human colostrum, 0.5 µg/liter, and they increase in mature milk. Poorly nourished women with low milk folate levels averaging 2 µg/liter responded to a vitamin supplement with a peak content at 5.6 µg/liter. In lactating women who develop megaloblastic anemia, folic acid levels in the last trimester of pregnancy, but fetal and cord blood concentrations remain high. Administration of labeled cyanocobalamin to the mother resulted in transfer of the vitamin to the fetus. Stores of maternal liver B12 are not transferred across the placenta. Milk vitamin levels range from 50% to 90% of the maternal serum level. The high extraction occurred in vegetarian women who had lower serum vitamin levels. Milk vitamin B12 levels, however, were not lower than those in nonvegetarian women control subjects. When women from a poorly nourished community received a vitamin B12 supplement, milk concentration increased only from 0.8 to 1 µg/liter (Table 4). When well nourished women received a “one-a-day” supplement,
milk concentration increased significantly from 0.6 to 1 μg/liter. No change in serum vitamin levels could be detected in these normal women.  

FAILURE TO THRIVE

Growth is the most practical assessment of nutritional adequacy in childhood. The percentile classification of lengths and weights of normal breast-fed infants has been developed by a group of investigators from Iowa. The data from these measurements on 178 normal, full-term infants are given in the Figure. As with the more familiar charts, loss of percentile channels is a cause for careful surveillance.  

Failure to grow “normally” may be a transient phenomenon associated with either infantile or maternal factors, some of which are poorly understood. Severe failure to thrive in breast-fed infants is a recognized clinical entity. Case reports indicate that the infants usually are brought for treatment when approximately 30 days old, and they have obvious malnutrition. Weight at the time of examination commonly is 20% lower than birth weight. The infants are said to feed poorly but to appear satisfied. Chemical determinations commonly reveal a reduction in total serum protein and elevated serum urea nitrogen. The infants respond to supplemental feedings or maternal support designed to augment milk production, such as increased maternal caloric intake. One of the common characteristics of these severely ill infants is a lack of pediatric supervision between delivery and the time of the examination. These case reports emphasize the need for frequent contact between the mother and physician during the period of transition to mature milk production. The initial visit for health evaluation should be two weeks after discharge, and at appropriate intervals thereafter.

SUPPLEMENTATION

Maternal diet and nutritional status influence the quantity and quality of human milk. Lactation also has a profound influence on maternal nutrient physiology. The unique biologic advantages of human milk justify the promotion of lactation as the normal method of infant feeding. The variability of milk quality and quantity justify an ongoing assessment of the infant’s weight gain and state of hydration by the pediatrician as part of the promotion and supervision of the extension of normal gestation.

The nutritional needs of the mother during lac-
tation have been summarized by the National Academy of Sciences in the Recommended Dietary Allowances and are shown in Tables 5 and 6. An increase in intake is recommended for lactating women to meet the needs for milk production and protect against deficiencies in maternal nutrients. When related to caloric intake, the increased requirement is not uniform. A woman at nutritional risk probably could not meet these recommended intakes by increasing her usual diet. The milk of women at nutritional risk may have low nutrient composition; a vitamin supplement can be demonstrated to improve the quality of their milk. In North American women consuming a contemporary diet, milk composition varies; but low nutrient values are rare and the administration of vitamin supplements is probably unnecessary. A deviation from a normal dietary pattern should lead to a reassessment of nutrient needs and dietary counseling, and/or a prescription of multivitamin-multimineral supplements adequate for the special circumstances.

The breast-fed infant requires a vitamin K supplement during the newborn period. There are arguments in favor of providing vitamin D and fluoride as supplements during the first six months of life; disagreement, however, remains about whether these nutrients must be provided to all breast-fed infants. During the latter half of the first year of life, iron (either in a supplement or in fortified infant cereals) should be recommended. Supplementary calories in the form of infant foods and infant formulas should be started when weight gain and other findings indicate that the milk supply is not adequate to meet the needs of continuing rapid growth.

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**TABLE 5. Daily Requirements of Lactating Women**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Recommended Allowance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>+500 kcal</td>
</tr>
<tr>
<td>Protein</td>
<td>+20 gm</td>
</tr>
<tr>
<td>Calcium</td>
<td>+400 mg</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>+400 mg</td>
</tr>
<tr>
<td>Magnesium</td>
<td>+150 mg</td>
</tr>
<tr>
<td>Iron</td>
<td>+30-60 mg</td>
</tr>
<tr>
<td>Zinc</td>
<td>+10 mg</td>
</tr>
<tr>
<td>Iodine</td>
<td>+50 µg</td>
</tr>
</tbody>
</table>

*Calculated from Recommended Daily Allowances.*

**TABLE 6. Daily Requirements of Lactating Women**

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Recommended Allowance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin A</td>
<td>+400.0 µg RE</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>+5.0 µg</td>
</tr>
<tr>
<td>Vitamin E</td>
<td>+3.0 mg TE</td>
</tr>
<tr>
<td>Vitamin C</td>
<td>+40.0 mg</td>
</tr>
<tr>
<td>Thiamin</td>
<td>+0.5 mg</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>+0.5 mg</td>
</tr>
<tr>
<td>Niacin</td>
<td>+5.0 mg NE</td>
</tr>
<tr>
<td>Vitamin B6</td>
<td>+0.5 mg</td>
</tr>
<tr>
<td>Folacin</td>
<td>+100.0 µg</td>
</tr>
<tr>
<td>Vitamin B12</td>
<td>+1.0 µg</td>
</tr>
</tbody>
</table>

*Calculated from Recommended Daily Allowances.*

Abbreviations used are: RE, retinol equivalents; TE, tocopherol equivalents; NE, niacin equivalents.


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