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Review Article

Human Milk Nutrients: The Influence of Maternal Diet and Nutritional Status

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ABSTRACT

Human milk is recommended as the sole source of nutrients during the first six months of life and as a key source of nutrients for up to two years or beyond. This recommendation is backed by extensive evidence that human milk feeding reduces the risk of short- and long-term morbidity and mortality and supports optimal child development. Unlike infant formula which has a consistent composition, the composition of human milk fluctuates due to a range of different factors, of which maternal nutrition is one. Understanding the concentration of various nutrients in human milk and the influence of maternal diet and nutritional status is important for supporting optimal breastfeeding practices. Thus, this review aimed to summarize the influence of maternal diet and nutritional status on the composition of human milk nutrients.

Keywords: Human Milk; Maternal Nutrition; Maternal Diet; Maternal Nutritional Status; Breastfeeding; Breast Milk.

INTRODUCTION

Human milk is a dynamic and complex biofluid with over two hundred recognized constituents including macronutrients, micronutrients, and non-nutritive bioactive factors (1, 2). Human milk adequately provides infants with an optimal balance of nutrients during the first six months of their lives (3). Beyond six months, human milk continues to make an important contribution nutritionally as it remains a key source of nutrients for the rapidly growing child (4). The World Health Organization (WHO), the United Nations Children’s Fund (UNICEF), the American Academy of Pediatrics (AAP), and other expert organizations recommend “exclusive breastfeeding for the first six months of an infant’s life and continued breastfeeding for up to two years and beyond” (5, 6).

Unlike infant formula which has a consistent composition, the composition of human milk fluctuates. During the first few days of lactation, the concentration of the various constituents in human milk changes considerably (7). Colostrum, the thick yellowish-white fluid secreted in small quantities during the first days postpartum is rich in protein, minerals, and vitamins A, E, and K and contains less lactose and fat than mature human milk (2). Colostrum is also rich in bioactive factors such as secretory immunoglobulin A (IgA), lactoferrin, and leukocytes (2). The high concentration of bioactive factors in colostrum provides immunologic protection to the infant (1). Within 5-15 days postpartum, colostrum is replaced by transitional milk which also shares some similar characteristics with colostrum (8). Transitional milk is characterized by a decrease in the immunoglobin, lactoferrin, zinc, copper, and manganese levels and a gradual increase in volume, fat, lactose, and water-soluble components (2, 9).

From 15 days postpartum, largely matured milk is produced and it becomes fully matured by the fourth to sixth week postpartum (8, 9). In contrast to the drastic alteration observed in milk composition in the first few days of life, the composition of mature milk is more stable, however, there are subtle variations in milk composition throughout lactation (2). These changes are due to maternal (nutrition, age, parity, genetics, health), infant (age, health, gender, birth weight, sex), and physiological (stage of lactation, stage of nursing, time of the day) factors (10). Regarding maternal nutrition, "current dietary intake, nutrient stores, and changes in nutrient utilization all influence the composition of human milk" (11). The current review therefore aimed to summarize the influence of maternal diet and nutritional status on the composition of human milk nutrients.

NUTRIENT REQUIREMENTS DURING LACTATION

The production of human milk is an energy- and nutrient-intensive process, as the nutrient requirements of breastfeeding women are dramatically heightened (12). The requirements for some nutrients like protein, vitamins A, B-6, C iodine, and zinc are increased by over 50% above what is required for nonpregnant and nonlactating women (13). Table 1 presents the recommended dietary reference intakes (DRI) of various nutrients during lactation and the amount secreted into human milk. The values presented are based on what is needed for a woman to exclusively breastfeed one infant. Women who are breastfeeding multiple infants, such as twins and triplets, will require more nutrients, while women who are only partially breastfeeding will require fewer nutrients (11). Also, intake below the given DRIs does not necessarily mean that the intake is inadequate because there is a wide safety margin for most of the nutrients (11).

HUMAN MILK MACRONUTRIENTS

The general composition of macronutrients in human milk is "3.8% fat, 1.0% protein, and 7% lactose" (15). The energy density of human milk averages 0.67 kcal/g and is dependent on the relative amount of fat, protein, and lactose (16). In women with adequate energy reserves, the average energy density of human milk is preserved irrespective of their energy intake (16). It is predicted that the energy density of human milk may decrease in situations where there are low maternal energy reserves and low energy intakes, although the threshold at which this could happen in humans is not known yet (16).

Fats

The total fat concentration in human milk has been observed to be impacted by the fat intake of breastfeeding mothers in some studies. In one study, a 14-day full-fat dairy diet was observed to lead to increased milk fat content in comparison to a low-fat diet among fifteen breastfeeding women (17). Similarly, a high-fat diet was observed to acutely increase the total fat content of human milk in another study (18). Contrarily, some other studies found no significant correlation between maternal fat intake and human milk fat content (10, 19).

The type of fat consumed has also been observed to affect the fatty acid composition of human milk. Among Bangladeshi women whose dietary intake of total fats, total polyunsaturated fatty acids (PUFA), docosahexaenoic acid (DHA), and alpha-linolenic acid (ALA) were low, human milk concentrations of linoleic acid (LA) and ALA were very low (20). Jonsson, Barman (21), assessing the relationship between maternal diet and the fatty acid concentration of human milk reported that mothers who consumed more saturated fat had a higher concentration of saturated fatty acids (SFA) and less PUFA in their milk.

The frequency of fish intake was found to be positively correlated with the DHA content of human milk in Denmark (22). Another study however observed that habitual intake of fatty fish, rather than current consumption was associated with the concentration of omega-3 fatty acids in human milk (10). The DHA, LA, palmitic, and oleic acids in the human milk of women consuming the Mediterranean diet were positively correlated with dietary fatty acid intake (23). Antonakou, Skenderi (24) also observed a strong positive effect between the mother's PUFA intake and the concentration of PUFA, DHA, and LA in human milk during the first month postpartum. Mothers who consumed foods high in trans fatty acids such as margarine, bakery products, and confectionery also produced human milk with a high content of "trans isomers" (25).

Maternal body fat and nutritional status have been observed to influence the concentration of fat and fatty acid profiles in human milk. Studies have reported a positive correlation between the concentrations of fat in human milk and the skinfold thickness of the mothers (26, 27). Bzikowska-Jura, Czerwonogrodzka-Senczyna (10) reported that the body mass index (BMI) of mothers was positively correlated with human milk fat concentration. Soliman, Soliman (28), in a study in Egypt, found that there was a significant positive association between maternal arm circumference and triceps, skinfold thickness, and milk fat concentration. de la Garza Puentes, Martí Alemany (29) reported that an increased BMI increased SFA and omega-6 PUFAs in human milk and decreased omega-3 fatty acids.

Table 1. Energy and nutrient requirements during lactation

Nutrient	Adult Women	Lactating Women	% Increase	Estimated Secretion into Human Milk[c]
Energy *kcal*	Varies	+400 kcal/d 0–6 months +330 kcal/d 7–9 months		420–9700
Protein (g)[a]	46	71	54.35	6.3–10.5
Vitamin C (mg)[a]	75	120	60.00	24–40
Thiamin (mg)[a]	1.1	1.4	27.27	0.13–0.21
Riboflavin (mg)[a]	1.1	1.6	45.45	0.21–0.35
Niacin (ng)NE[a]	14	17	21.43	0.9–1.5
Vitamin B-6 (mg)[a]	1.3	2.0	53.85	0.06–0.09
Folate(mcg)DFE[a]	400	500	25.00	50–83
Vitamin B-12(mcg)[a]	2.4	2.8	16.67	0.6–1.0
Pantothenic acid (mg)[b]	5	7	40.00	1.6-2.0
Biotin (mcg)[b]	30	35	16.67	3-5
Choline (mg)[b]	425	550	29.41	
Vitamin A (mcg) RE[a]	700	1300	85.71	400–670
Vitamin D(mcg)[b]	5	5	0.00	0.3–0.6
Vitamin E (mg) TE[a]	15	19	26.67	1.4–2.3
Vitamin K (mcg)[b]	90	90	0.00	1.3–2.1
Calcium (mg)[b]	1000	1000	0.00	168–280
Phosphorus (mg)[b]	700	700	0.00	84–140
Magnesium(mg)[a]	310	310	0.00	21–35
Iron (mg)[a]	18	9	-50.00	0.18–0.30
Zinc (mg)[a]	8	12	50.00	0.9–1.5
Selenium (mcg)[a]	55	70	27.27	12–20
Fluoride (mg)[b]	3	3	0.00	11-21

Source: (12, 13); a and b are Recommended Dietary Allowance (RDA), and Adequate Intake (AI) respectively; NE: niacin equivalents; DFE: dietary folate equivalents; RE: retinol equivalents; TE: tocopherol equivalents. [c] at volumes of 600–1,000 ml/day, based on milk composition data (14).

Protein

The association between maternal dietary protein intake and protein composition in human milk is mixed. In a study by Bzikowska-Jura, Czerwonogrodzka-Senczyna (10), maternal protein intake was not associated with protein concentration in human milk. Another study also did not find any correlation between protein content in milk and dietary intake (30). However, an older study conducted in Sweden with only three participants reported that human milk total protein was higher on a maternal diet high in protein compared to a diet low in protein (31).

A positive relationship between maternal nutritional status and human milk protein concentration has been reported. In a study by Bzikowska-Jura, Czerwonogrodzka-Senczyna (10), there was a positive association between maternal BMI and adiposity and the concentration of protein in human milk. Other studies have also reported a positive relationship between protein contents in human milk and maternal BMI (32, 33). It has been observed that the concentration of protein in human milk is more dependent on a higher maternal fat mass percentage than the BMI (32, 34). The concentration of free amino acids in human milk is also different between normal-weight mothers and mothers who have obesity. In a study, mothers who were obese had 20% to 30% more tyrosine in their human milk than normal-weight mothers (35).

Carbohydrates

The carbohydrate content in human milk is stable and remarkably similar among women (36). Studies have not found any significant relationship between the total carbohydrate concentration of human milk and maternal dietary energy intake (19, 32). Carbohydrate composition in human milk is also not associated with maternal BMI or the body composition of breastfeeding women (10).

HUMAN MILK MICRONUTRIENTS

Vitamin A

Maternal dietary intake of vitamin A is positively associated with human milk vitamin A concentration (37, 38). Human milk concentrations of vitamin A also correlate with maternal plasma concentrations as nutritionally deficient mothers have been shown to have lower human milk retinol levels (39). Because maternal vitamin A reserves in the liver are utilized to compensate for inadequate dietary intake, low human milk concentration of vitamin A, therefore, suggests both insufficient maternal reserves and inadequate dietary intake (40). Vitamin A deficiency among human milk-fed infants is however rare including in areas where vitamin A deficiency is widespread (41).

Vitamin D

The human milk concentration of total vitamin D is positively correlated with the dietary intake of the mother (42). The human milk cholecalciferol concentrations are also positively correlated with maternal plasma or serum (42). Studies have demonstrated that supplementation with a high dose of vitamin D can improve maternal vitamin D status and vitamin D concentrations in human milk (43, 44).

Vitamin E

Studies have not observed a relationship between the concentration of vitamin E in human milk and maternal dietary intake (24, 45) or maternal plasma or serum concentration of vitamin E (46). However, maternal total fat intake has been shown to affect the concentration of vitamin E in human milk (24).

Vitamin K

Human milk concentrations of vitamin K have not been observed to be correlated with maternal dietary intake or plasma concentrations (47).

Vitamin C

The concentration of vitamin C in human milk varies with maternal intake: Increasing vitamin C intake among mothers who had poor status of the vitamin resulted in a more than threefold increase in human milk, however, this effect was not observed in well-nourished mothers (48). Another study reported that there was a significant correlation between the vitamin C content of human milk and the maternal intake of the vitamin, and values were higher during seasons when fresh fruits and vegetables are widely available and consumed (49). Vitamin C deficiency leading to scurvy has not been reported in breastfed infants. This is because only a small amount of vitamin C (7mg/d) is required to prevent overt vitamin C deficiency (11).

Vitamin B1

Human milk concentrations of thiamin have been observed to be strongly dependent on maternal dietary intake (50, 51). In women with adequate thiamine status, the concentration of thiamin in their milk has been observed to be associated with their thiamine status (50, 51). However, despite the high incidence of thiamine deficiency among Karen mothers in Thailand, the concentration of thiamine in their milk remained at a normal level, and this suggests that thiamine is preferentially delivered to the human milk at the expense of the mother (52).

Low concentrations of thiamine in human milk because of poor maternal dietary intake can result in deficiency symptoms in infants (53). Maternal deficiency during pregnancy is likely to increase the risk of thiamine deficiency in infants (54). Infantile beriberi is known to occur in exclusively breastfed infants whose mothers are thiamine deficient (55). Infantile beriberi was identified to be responsible for 40% of all infant mortality among refugees in northwestern Thailand from 1987 to - 1990 (56). In a more recent study, twenty-nine exclusively breastfed infants from Kashmir, India whose mothers were thiamine deficient presented with symptoms of infantile beriberi (55).

Vitamin B2

Riboflavin in human milk has been observed to be positively correlated with maternal dietary intake and status (37, 51). However, a study showed that the concentration of riboflavin was comparable between Indian women who were deficient and Western women with no deficiency (57).

Vitamin B3

Maternal dietary intake of niacin has been observed to be positively associated with human milk concentrations during the second month postpartum (58). Daniels, Gibson (37) also reported a significant association between the usual intake of niacin by mothers and concentrations in human milk.

Vitamin B6

The concentration of vitamin B6 in human milk has been observed to be dependent on maternal dietary intake (59) and maternal serum/plasma vitamin B6 levels (60). Vitamin B6 deficiency in breastfed infants was shown to present as neurological and behavioral abnormalities (59). However, a more recent study observed no association between maternal vitamin B6 intake and human milk concentration (37)

Folate

The concentration of folate in human milk is kept at a relatively constant level and unaffected by maternal dietary folate intake or status unless in cases where maternal deficiency of folate is severe (53, 61). This is because folate secretion into human milk is tightly regulated and there is preferential uptake of folate by secretory mammary glands (61). This happens at the expense of maternal stores as normal human milk folate concentration is maintained despite declining blood folate concentration during lactation as observed in a study (62). The consequence of this is that women who have low intakes are at risk of becoming depleted with the progression of lactation (53). Data from studies demonstrate either a high prevalence of suboptimal serum folate concentrations during lactation or a reduction in blood folate with the progression of lactation (62, 63). A study by Keizer, Gibson (64), however, suggests that this decline in folate status may be unrelated to lactation because the decline in folate status has been observed among mothers who did not breastfeed between four and twelve weeks postpartum.

Vitamin B12

Vitamin B12 in human milk is positively associated with maternal dietary intake (65, 66)and maternal serum levels of the vitamin (66-68). Maternal dietary intake has a stronger influence on human milk concentration than maternal serum levels because infants can become quickly deficient when the mother’s diet is low in vitamin B12 for a short time (69). Exclusively breastfed infants with limited hepatic reserves of vitamin B12 at birth may develop deficiency symptoms a few months after birth if the mother is severely deficient (69). Contrary to all these findings, Sandberg, Begley (70) found no correlation between maternal dietary intake and B12 concentration in human milk, and concentrations did not improve with supplementation. Another study also did not find any association between maternal B12 intakes and human milk concentrations among rural Indonesian women (37). In a Kenyan study, although 89% of women produced low human milk concentrations of vitamin B12, there was no correlation with maternal dietary intake (71).

Choline

The effect of maternal diet on human milk choline concentration is mixed. In a study by Wiedeman, Barr (72), the concentrations of choline in the milk of Canadian and Cambodian women were comparable, despite the likely variation in choline intakes. Furthermore, no significant association was observed between maternal dietary choline intake and the choline concentrations in human milk within a subgroup of Canadian participants. Among women following vegan, vegetarian, and nonvegetarian diets, no differences in human milk choline concentration were found despite the likely differences in choline in their diets (73). However, Fischer, da Costa (74) observed that maternal dietary intake influenced the concentration of choline in human milk. Davenport, Yan (75) also reported that choline intake above the current recommendations for breastfeeding women improved its concentration in human milk by increasing the production of choline metabolites generated by the phosphatidylethanolamine-*N*-methyl transferase pathway. The concentration of choline in human milk has also been observed to be correlated with maternal status (76).

Calcium

Calcium in human milk is derived from the release of calcium through increased resorption of bone during lactation and upregulation of calcium absorption in the intestines (77, 78). For these reasons, the concentration of calcium in human milk is tightly regulated and it is not influenced by maternal dietary intake of the mineral (79, 80). Although bone is lost during lactation, bone loss is rapidly and completely reversible after weaning (78).

Iodine

The concentration of iodine in human milk is positively related to maternal dietary intake and iodine status (40, 81). Women living in areas where there is an effective iodized salt program are not at risk of iodine inadequacies (82). In the situation of maternal inadequacy, the mammary gland concentrates iodine and adequate concentrations of iodine are provided to the infant at the expense of maternal iodine reserves (82). However, this compensatory mechanism may not be adequate for very deficient mothers (81). In a Norwegian study where over a third of the participating breastfeeding women had a total iodine intake below recommendations, many of the infants received suboptimal levels of iodine (83). Supplementing a mother with 150 μg/d of iodine during the first 6 months of postpartum in another study in New Zealand did not meet the iodine needs of breastfed infants (84).

Selenium

Mean values of selenium in mature milk differ geographically both within countries and internationally due to different levels in the soils and local food supply (85). Dietary intake of selenium is positively associated with the concentration of selenium in human milk (86, 87). However, some studies have not found any significant correlation between the concentration of human milk selenium and maternal dietary selenium intake (88, 89).

Iron

Iron is the only nutrient with a decreased requirement during lactation (11). This is because the concentration of iron in human milk is very low, and the amount of iron secreted into human milk is less than the amount ordinarily lost through menstruation (11). The concentration of iron in human milk is not affected by maternal dietary intake or status (90, 91). Supplementing anemic (92) and nonanemic (93) mothers with iron does not increase the concentration of iron in their milk either. Although the bioavailability of iron in human milk is high, it is still not sufficient to meet an infant’s iron needs at any stage during infancy (92). However, iron deficiency is not common in breastfed infants during the first 6 months as they rely on hepatic stores to meet requirements (94).

Zinc

The concentration of zinc in human milk is low, and it decreases substantially as lactation progresses (95, 96). However, the absorption of zinc from human milk is approximately 50% and this can meet the infant’s needs for at least the first several months (97, 98). In addition, full-term infants are born with sufficient stores of zinc in their liver and are at very low risk of becoming deficient (11). Studies have shown that the concentration of zinc in human milk is tightly regulated, and it is not affected by maternal dietary zinc intake, zinc supplementation, or maternal zinc status (90, 97, 99).

Magnesium, Phosphorus, Copper, and other Minerals

The concentrations of magnesium, phosphorus, copper, and all other minerals in human milk are tightly regulated and have not been observed to be influenced by maternal dietary intake or supplementation (40, 100).

CONCLUSION

The concentration of most nutrients in human milk does not fluctuate due to maternal dietary intake or nutritional status. Nevertheless, there is a need to pay special attention to some nutrients which include vitamins A, B-1, B-2, B-6, B-12, C, and D, essential fatty acids, selenium, and iodine, as the concentration of these nutrients in human milk has been observed to be at least partially dependent on maternal dietary intake or nutritional status. Maternal deficiency of these nutrients can result in suboptimal concentrations in human milk and potentially lead to deficiency in the breastfed child. For the other remaining nutrients in human milk not influenced by maternal dietary intake or nutritional status, concentrations may be maintained satisfactorily at the cost of maternal nutrient stores. Thus, healthful dietary practices among breastfeeding mothers are important and should be emphasized. Future interventions promoting breastfeeding should address the diet and nutritional status of the mother as crucial elements of breastfeeding success. Furthermore, additional research is needed on the influence of maternal nutrition on human milk composition as most identified studies were conducted decades ago and there is a current dearth of information.

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