Journal of Paediatrics and Child Health

doi:10.1111/j.1440-1754.2009.01648.x

ORIGINAL ARTICLE

Breast milk macro- and micronutrient composition in lactating mothers from suburban and urban Shanghai

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Aim: The objective of this study was to measure and compare the macro- and micronutrient composition of breast milk in urban and suburban lactating mothers living in Shanghai, China.

Methods: Primiparous women residing in three urban regions ($n = 30$/region) and a suburban area of Shanghai ($n = 30$) were recruited. Breast milk samples were collected 8–10 days postpartum and dietary intake was determined.

Results: Women from the suburban area were of lower socio-economic status as indicated by levels of education, occupation and income. With the exception of carbohydrates, mothers in all urban areas had significantly higher macronutrient intake levels than suburban area mothers. Sodium, potassium, phosphorus and calcium intake levels were significantly lower in suburban compared to all urban women. Concentrations of protein, lipids, copper, sodium, potassium, chlorine, zinc, manganese, phosphorus and iron were all significantly lower in milk obtained from suburban compared to urban women. Concentrations of carbohydrates in milk from suburban women were significantly higher than concentrations in than two of the three urban groups. Offspring from women in Chongming county gained significantly less weight between birth and 6 months than did offspring born to women from the three other counties.

Conclusions: In summary, there were significant differences in macro- and micronutrient intake levels and breast milk concentrations between women from urban and suburban Shanghai. These differences may have important implications for the growth and development of breastfed infants.

Key words: human breast milk; macronutrients; minerals; socio-economic factors; trace elements.

There are numerous benefits associated with breastfeeding, including decreased infant morbidity and mortality.[1] For instance, it has been reported that infants fed artificial (as compared to breast) milk have a 3.1 times higher morbidity and a 7.1 times higher mortality from gastrointestinal disease.[2] Breast-fed infants are predisposed to decreased incidences of certain diseases (e.g. otitis media and gastroenteritis, urinary tract infection, invasive *Haemophilus influenzae* infection, respiratory infections and neonatal sepsis) and lower risk of obesity, when compared to formula-fed infants.[2–6] A further important benefit associated with breastfeeding is a decreased incidence of sudden infant death syndrome.[7] In a global health recommendation, the World Health Organization stated that breastfeeding provides ideal nutrition for the healthy growth and development of infants; and, that infants should be exclusively breast fed for the first 6 months of life.[8]

Key Points

1. The composition of human breast milk is affected by numerous factors including maternal diet and socio-economic status.
2. In this study we examined the macro- and micronutrient composition of breast milk from lactating women in urban and suburban regions of Shanghai, China.
3. Significant differences in maternal macro- and micronutrient intake and breast milk concentrations were apparent between the urban and suburban dwelling women.

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Accepted for publication 3 July 2009.

It is well known that the composition of human milk is affected by many factors and varies both within and between individuals.[9,10] For instance, trace element and macronutrient levels may vary with respect to the timing of delivery (pre-term vs. term delivery), maternal diet and body weight, period of lactation, time of day, locale and socio-economic status.[9–11] Rural–urban dietary difference in China has been studied in different geographical regions. Different dietary intake was observed between urban and rural adult women in Jilin province, China.[12] In that study, urban women consumed more energy, protein and lipid than rural women.[12] It was found in another study that urban and rural women had different food sources for their dietary protein and lipid intakes in Shandong, China and the protein and lipid in rural women's diet were mainly from plant-based foods.[13] However, few comprehensive studies have assessed breast milk composition amongst Chinese

women of different geographic and socio-economic strata, and even fewer have specifically examined macro- or micronutrient content such as iron (Fe), copper (Cu), potassium (K), phosphorus (P) and zinc (Zn).[14] In this study, we measured and compared the concentrations of macronutrients (proteins, carbohydrates and lipids) and micronutrients (manganese, Mn, sodium, Na, chlorine, Cl, calcium, Ca, Fe, Cu, K, Zn and P) in breast milk obtained from urban and suburban dwelling lactating mothers in Shanghai, China.

Materials and Methods

Study subjects

Potential primigravida subjects were surveyed by clinicians during hospital antenatal care visits between April and June of 2002 as to whether they intended to breastfeed or not. Women who answered in the affirmative were invited to participate in the study. A convenience sample of 120 healthy, lactating primigravida women aged from 22 to 36 years were thus recruited. All participants were free of chronic illness, consumed normal, varied diets (i.e. they were not partial to particular foods) and lived in residential areas. These women were recruited from single hospitals in three urban districts (Jingan, Hongkou and Yangpu counties: $n = 90$) and one suburban region (Chongming county: $n = 30$) of Shanghai. All babies were healthy and born full term. The study protocol was approved by the Ethics Committee of XinHua hospital, Shanghai, China. Written informed consent was obtained from all participants.

Breast milk sampling and dietary intake

Breast milk samples (20 mL, exclusive of foremilk) were obtained by manual expression from all women 8–10 days postpartum during the hours of 9:00–11:00 a.m. Samples were stored within 30 min of collection at –20°C until analysis.[15,16] Dietary information was obtained from all subjects using 24 h recall and dietary questionnaires. The women were contacted 1 day before milk sample collection and were asked to record the type and amount of all food consumed over the ensuing 24 h. The dietary interviews were conducted on the day of milk sample collection by a clinician and nurse. The records were analysed and the intake was calculated according to Chinese food tables.[17]

Macro- and micronutrient analysis

Frozen milk was processed for analysis as previously described.[15,16] Briefly, milk was thawed with tap water for 30 min, vortexed in ice water for two 15 min periods and then divided into aliquots and placed in polypropylene tubes for further component examination.

Protein was measured using the Kjeldahl method of nitrogen analysis.[18] Fat content was determined using the Soxhelt method for quantitative determination. Carbohydrate content was assessed by calculation.[19] Specifically, total solids, ash, protein and fat content were determined and the carbohydrate content calculated using the following formula: carbohydrate content = total solids − (ash + protein + fat). Iron, Mn, Cu, Zn, Na, K and Ca were measured using atomic absorption spectrophotometry (Perkin Elmer 2100, Perkin Elmer, Waltham, MA). Phosphorous was measured using inductively coupled plasma spectrophotometry (Belderl, PS-6), while Cl was measured by ion chromatography (Dien, DX 500).

Statistical analysis

All statistical analyses were carried out using SAS 9.1.3 statistical software (SAS Inc, Cary, NC, USA). Continuous variables were compared by Kruskal-Wallis test and categorical variables were compared by chi-square test. Mann–Whitney *U*-test was used to compare the difference in continuous variables when a significant result was revealed by the Kruskal-Wallis test (multiple comparisons). Categorical data are represented by numbers (%), and continuous data are presented as median (interquartile range). All statistical tests were two sided, and 0.05 was used as the significance level. The adjusted significance level of 0.01 was used when multiple comparisons were made.

Results

Demographic characteristics of lactating mothers

The demographic characteristics of the subjects are summarised in Table 1. Maternal age was significantly lower in Chongming compared with all other counties ($P < 0.001$). Compared with other counties, more women from Chongming county were farmers or unemployed (70.0%), had elementary school education levels (73.4%) and were of low-income status (90.0%). Similarly, the weight gained by infants in Chongming county between birth and 6 months of age was significantly less than that of infants from the other three urban counties ($P < 0.001$).

Dietary macro-and micronutrient intake

Table 2 shows the macro- and micronutrient intakes of urban and suburban groups of women in the study. There were overall significant differences detected for all of these variables ($P < 0.05$) except for Cu. For the majority of the macro- and micronutrients (protein, lipids, Na, K, P and Ca), intake was significantly lower in women residing in Chongming county as compared to all other three counties ($P < 0.05$ for all comparisons). Carbohydrate intake was significantly higher in women from Chongming compared with the three other counties ($P < 0.05$ for all). Manganese intake was significantly greater in Chongming compared to Hongkou women ($P < 0.05$). The majority of the macro- and micronutrient intake levels were similar between the groups of women from Yangpu, Hongkou and Jingan counties. There were no significant differences in total daily energy intake between the groups of women.

Macro- and micronutrient concentrations in breast milk

Table 3 shows the macro- and micronutrient breast milk concentrations for all groups of women in the study. As was the case with macro- and micronutrient intake, all macro- and micronutrient concentrations (except for carbohydrates) were

Table 1 Demographic characteristics of breastfeeding primigravidas in the three urban (Yangpu, Hongkou and Jingan) and one suburban (Chongming) Shanghai regional groups

	Yangpu ($n = 30$)	Hongkou ($n = 30$)	Jingan ($n = 30$)	Chongming ($n = 30$)	*P*-value
Age (years)†	28 (26, 32)	27 (25, 28)	28 (26, 29)	25 (23, 26)	<0.001*
Offspring gender‡					
Male	17 (56)	19 (63)	18 (60)	17 (57)	0.944
Female	13 (43)	11 (37)	12 (40)	13 (43)	
Occupation‡					
White collar	19 (63)	17 (57)	17 (57)	1 (3)	<0.001*
Blue collar	3 (10)	2 (7)	6 (20)	6 (20)	
Grey Collar	3 (10)	2 (7)	3 (10)	2 (7)	
Farmer or unemployed	5 (17)	9 (30)	4 (13)	21 (70)	
Education‡					
Elementary school	7 (23)	4 (13)	6 (20)	22 (73)	<0.001*
Junior high school	6 (20)	4 (13)	1 (3)	6 (20)	
Senior high school	12 (40)	14 (47)	11 (37)	1 (3)	
College above	5 (17)	8 (27)	12 (40)	1 (3)	
Income‡					
Low	9 (30)	12 (40)	9 (30)	27 (90)	<0.001*
High	21 (70)	18 (60)	21 (70)	3 (10)	
Pregnancy duration (weeks)†	39.0 (38, 40)	39 (38, 40)	39 (39, 40)	40 (39, 41)	0.065
Neonate weight (g)†	3405 (3035, 3680)	3262 (2170, 23420)	3300 (3150, 3630)	3300 (3074, 3650)	0.803
Weight gained by infants at 6 months (g)†	4683 (4248, 5135)	4720 (3840, 5720)	4565 (3378, 4945)	3602 (3075, 4224)	<0.001*
Delivery‡					
Spontaneous	8 (27)	6 (20)	10 (33)	6 (20)	0.539
Cesarean section or obstetrical forceps	22 (73)	24 (80)	20 (67)	24 (80)	
Apgar score†§	10 (10, 10)	10 (10, 10)	10 (10, 10)	10.0 (9, 10)	0.658

Data are expressed as median (interquartile range) for continuous variables and number (percentage) for categorical variables. *Indicates a significant difference amongst the four groups ($P < 0.05$). †Compared by Kruskal-Wallis test. ‡Compared by chi-square test. §Determined 5 min after birth.

Table 2 Maternal dietary intake of macronutrients and minerals in the three urban (Yangpu, Hongkou and Jingan) and one suburban (Chongming) Shanghai regional groups

	Group 1: Yangpu ($n = 30$)	Group 2: Hongkou ($n = 30$)	Group 3: Jingan ($n = 30$)	Group 4: Chongming ($n = 30$)	*P*-value†	*Post hoc* test‡
Total energy (kcal/d)	2153.8 (2038.5, 2274.1)	2076.5 (1827.8, 2226.3)	2084.0 (1984.4, 2268.9)	2043.8 (1979.6, 2130.9)	0.235	
Protein (g/d)	124 (112, 129)	118 (100, 131)	124 (115, 132)	100 (91, 104)	<0.001*	G1 = G2 = G3 > G4
Lipid (g/d)	56 (51, 61)	52 (49, 59)	59 (42, 64)	40 (36, 44)	<0.001*	G1 = G2 = G3 > G4
Carbohydrates (g/d)	289 (260, 309)	279 (229, 304)	272 (259, 297)	320 (308, 330)	<0.001*	G1 = G2 = G3 < G4
Mn (mg/d)	7.9 (7.0, 9.4)	7.2 (6.1, 7.9)	8.8 (6.2, 12.9)	8.5 (7.4, 9.0)	0.022*	G2 < G4
Fe (mg/d)	31 (27, 34)	30 (27, 31)	32 (28, 34)	27 (25, 30)	0.031*	G1 = G3 > G4
Cu (mg/d)	2.6 (2.1, 3.1)	2.6 (2.2, 2.9)	2.6 (2.1, 2.9)	2.3 (2.0, 2.6)	0.131	
Na (mg/d)	3901 (3539, 4155)	3827 (3461, 4053)	3935 (3720, 4099)	3154 (3047, 3481)	<0.001*	G1 = G2 = G3 > G4
K (mg/d)	2602 (2436, 2943)	2724 (2513, 2964)	2704 (2437, 3198)	2320 (2129, 2685)	0.002*	G1 = G2 = G3 > G4
P (mg/d)	1629 (1407, 1772)	1516 (1451, 1785)	1623 (1477, 1715)	1396 (1289, 1483)	<0.001*	G1 = G2 = G3 > G4
Ca (mg/d)	890 (73, 950)	902 (819, 992)	849 (675, 1009)	625 (509, 783)	<0.001*	G1 = G2 = G3 > G4
Zn (mg/d)	17 (16, 17)	17 (14, 18)	17.8 (16, 19)	14 (14, 16)	<0.001*	G1 = G3 > G4

Data are presented as the median (interquartile range). *Indicates a significant difference amongst the four groups ($P < 0.05$). †Compared by Kruskal-Wallis test. ‡Compared by Mann–Whitney *U*-test with adjusted alpha value ($\alpha' = 0.01$). Mn, manganese; Fe, Iron; Cu, copper; Na, sodium; K, potassium; P, phosphorous; Ca, calcium; Zn, Zinc.

Table 3 Composition of postpartum milk samples from primigravidas in the three urban (Yangpu, Hongkou and Jingan) and one suburban (Chongming) Shanghai regional groups

	Group 1: Yangpu ($n = 30$)	Group 2: Hongkou ($n = 30$)	Group 3: Jingan ($n = 30$)	Group 4: Chongming ($n = 30$)	*P*-value†	*Post hoc* test‡
Energy content (kcal/dL)	63.3 (61.4, 65.8)	63.5 (60.1, 69.8)	63.8 (57.8, 67.2)	57.0 (53.8, 29.6)	<0.001*	G1 = G2 = G3 > G4
Protein (g/dL)	1.9 (1.8, 2.0)	1.6 (1.4, 2.2)	2.0 (1.8, 2.2)	1.2 (1.1, 1.2)	<0.001*	G1 = G2 = G3 > G4
Lipid (g/dL)	2.9 (2.8, 3.1)	2.7 (2.5, 2.9)	3.0 (2.3, 3.3)	2.2 (2.0, 2.4)	0.001*	G1 > G2 = G3 > G4
Carbohydrates (g/dL)	7.3 (7.1, 8.1)	7.7 (6.8, 9.4)	7.2 (7.1, 7.5)	8.1 (7.8, 8.3)	<0.001*	G1 = G3 < G4
Mn (mg/dL)	1.9 (1.6, 2.1)	1.9 (1.7, 2.1)	1.8 (1.6, 2.1)	0.7 (0.5, 1.3)	<0.001*	G1 = G2 = G3 > G4
Fe (mg/dL)	69 (64, 70)	65 (62, 68)	64 (60, 67)	41 (38, 43)	<0.001*	G1 > G3 > G4, G2 > G4
Cu (mg/dL)	48 (40, 53)	45 (39, 53)	49 (44, 53)	32 (20, 36)	<0.001*	G1 = G2 = G3 > G4
Na (mg/dL)	30 (21, 36)	26 (18, 37)	24 (19, 30)	12 (9, 16)	<0.001*	G1 = G2 = G3 > G4
K (mg/dL)	62 (53, 69)	61 (56, 68)	63 (59, 68)	47 (43, 48)	<0.001*	G1 = G2 = G3 > G4
Cl (mg/dL)	69 (58, 83)	68 (60, 88)	79 (58, 89)	49 (41, 52)	<0.001*	G1 = G2 = G3 > G4
P (mg/dL)	17 (16, 18)	16 (14, 17)	16 (15, 17)	13 (12, 14)	<0.001*	G1 > G2 = G3 > G4
Ca (mg/dL)	30 (27, 31)	29 (28, 30)	28 (27, 29)	27 (25, 28)	<0.001*	G1 = G2 > G4
Zn (mg/dL)	0.4 (0.3, 0.5)	0.5 (0.3, 0.5)	0.4 (0.3, 0.5)	0.2 (0.1, 0.2)	<0.001*	G1 = G2 = G3 > G4

Data are presented as the median (interquartile range). *Indicates a significant difference amongst the four groups ($P < 0.05$). †Compared by Kruskal-Wallis test. ‡Compared by Mann–Whitney *U*-test with adjusted alpha value ($\alpha' = 0.01$). Mn, manganese; Fe, Iron; Cu, copper; Na, sodium; K, potassium; P, phosphorous; Ca, calcium; Zn, Zinc.

significantly lower in milk obtained from women residing in Chongming as compared to all other counties ($P < 0.05$ for all comparisons). Carbohydrate concentrations were significantly higher in milk from Chongming compared with Jingan and Yangpu women ($P < 0.05$ for both). Furthermore, women residing in Chongming county had significantly lower breast milk energy content levels than those women living in the other counties ($P < 0.05$ for all, Table 3). Various other significant differences were detected between the Yangpu, Hongkou and Jinhan groups (see Table 3), but there was no real trend in terms of concentrations being consistently higher in one group over another.

Discussion

In this study we found regional differences in macro-and micronutrient intake levels and as a consequence breast milk concentrations in lactating mothers in Shanghai, China. Specifically, women from Chongming, a suburban area of Shanghai, tended to have lower intake levels and breast milk concentrations of many of the macro-and micronutrients assessed as compared with women residing in the three urban regions. The fact that breast milk from women residing in this suburban area of Shanghai was of poorer nutritional quality has obvious implications for infant nutrition. Indeed we found that offspring born to these women gained significantly less weight between birth and 6 months of age. Women from Chongming were of lower socio-economic status than their urban counterparts as indicated by education level and income.

There was a difference in the lipid content between breast milk from urban and suburban lactating mothers, with concentrations being significantly lower in the suburban compared to all urban groups. Other studies have reported regional and socio-economic differences in lipid content of breast milk. Al-Tamer and Mahmood found that lactating Iraqi women of lower socio-economic status had altered lipid content and fatty acid composition of breast milk, especially the levels of n(3) long-chain polyunsaturated fatty acids.[20] While Ruan *et al.* reported in their study of milk composition from five different regions of China, that geography and maternal diet had a marked influence on milk fatty acid content.[14] We also found significant differences in the concentrations of protein and micronutrients (Mn, Fe, Cu, Na, K, Cl, P, Ca and Zn) in the breast milk of lactating mothers between Chongming and the three urban counties. Given the apparent socio-economic differences between the suburban and urban groups, it would appear that socio-economic status (indirectly) influences the macronutrient, mineral and trace element composition of breast milk.

There are several explanations for the apparent poorer nutritional status of the suburban women. As previously noted, women from this region of Shanghai were of lower socio-economic status than their urban dwelling counterparts. Being less educated, these women may have been less aware of the importance of maternal nutrition for the breast-fed infant's nutrition and the need for a well balanced diet. Furthermore, the fact that the suburban women tended to be of low-income status would certainly have resulted in limitations regarding food purchases. Indeed, we generally found that women from Chongming tended to consume less milk, eggs, seafood and meat than women from the other areas, while consuming more affordable (carbohydrate rich) foods such as rice, noodles and porridge (data not shown). This increased consumption of carbohydrate rich foods presumably underlies the higher carbohydrate concentrations in breast milk from these women.

We found that maternal Ca intake was low in both the urban and suburban groups of women studies. Mackey *et al.* reported that when lactating mothers self selected diets, Ca, Zn, folate and vitamins E, D and B-6 were often lacking.[21] The average

intake of Ca in Chinese populations is low, with less than 5% of individuals meeting the recommended daily intake level.[22] Further to this, it has been demonstrated Ca intake is even lower in Chinese females compared to males.[6] The findings of the current study are consistent these previous reports. We do note, however, that the use of a one-time 24-h dietary recall, without additional interviews by seasoned nutritionists or physicians, may have been overly subjective for describing maternal dietary intake on a daily basis. Patient interviews or use of food diaries to record consecutive dietary intake over several days may control for this limitation in the future.

The concentrations of Ca in breast milk ranged from a low of 27 mg/100 mL in the suburban Chongming group to 30 mg/100 mL in the urban Yangpu group. If one assumes that exclusively breastfed infants consume an average of 750 mL milk/per day at 8–10 days postpartum, then total Ca intake ranged from approximately 203–225 mg per day in the cohort studied. To our knowledge, infants younger than 1 month old are expected to have a lower daily milk intake than 750 mL. With this in mind it would be possible that for some time the breast milk obtained from some lactating women in this study (especially those residing in Chongming) contained insufficient Ca to meet the recommended daily intake of 210 mg for infants aged 0–6 months.[23]

We also found that Zn concentrations were low in milk from suburban lactating mothers (0.16 ± 0.03 mg/100 mL). Assuming a daily milk intake of 750 mL, suburban infants would only obtain 1.2 mg of Zn per day. This is far below the recommended daily intake of 2.0 mg Zn for infants aged 0–6 months.[24]

It should be noted that breast milk samples were obtained from a one-time collection. Previous studies have indicated that the composition of breast milk varies on a day to day basis, making it difficult to provide consistent data on breast milk composition over the entire period of breastfeeding.[25,26] Testing serial breast milk samples obtained at multiple time points over a 24 h time period would address this limitation. Such studies are needed to comprehensively determine whether Ca and Zn content in the transition and mature breast milk of lactating women in Shanghai (particularly suburban dwelling) can meet the recommended levels.

In conclusion, we found a number significant differences in macro-and micronutrient intake levels and breast milk concentrations between women from urban and suburban Shanghai. More robust 24 h compositional and longitudinal studies are warranted to determine whether these differences may further influence the growth and development of breastfed infants and help identify appropriate interventions to ensure healthy growth and development.

Acknowledgements

We thank Mr Pan Xi-He, senior chief specialist at the Shanghai Municipal Center for Disease Control & Prevention for assisting in the sample measurement.

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IMAGE OF THE MONTH

A neonate with a desquamating rash

A 32-week gestation baby aged 2 weeks developed this rash. What is the diagnosis? (For answer, see page 137)

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