ORIGINAL ARTICLE

Severely inadequate micronutrient intake among children 9–24 months in Nepal—The MAL-ED birth cohort study

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Abstract

Prevalence of micronutrient deficiencies is high among infants and children in low- and middle income countries, but knowledge about nutrient adequacy across the complementary feeding period is limited. We investigated probability of adequacy (PA) of breast milk and complementary food combined and nutrient density adequacy (NDA) of complementary food and tracking of NDA over time among 229 children from 9–24 months of age in Bhaktapur, Nepal. Monthly, 24 h dietary recalls (16 in total) were performed and subgrouped into four 4-month time periods. Ten micronutrients (thiamin, riboflavin, niacin, vitamin B₆, folate, vitamin C, vitamin A, calcium, iron, and zinc) were assessed. Nutrient density was defined as the amount of a nutrient in a child's complementary food per 100 kcal, whereas NDA was the nutrient density as percentage of the context specific desired nutrient density. Tracking of NDA was investigated using generalized estimating equations models. PA for B vitamins (except riboflavin), vitamin A, calcium, iron, and zinc (low absorption group) was very low (0% to 8%) at all time slots. Median (IQR) mean PA (of all 10 micronutrients) increased from 11% (9, 15) in the second to 21% (10, 35) in the last time slot. Median value for mean nutrient density adequacy of all micronutrients varied between 42% and 52%. Finally, tracking of NDA was low (correlation <0.30) or moderate (0.30–0.60) indicating poor association between the first and subsequent measurements of NDA. These findings raise grave concerns about micronutrient adequacy among young children in Nepal. Urgent interventions are needed.

KEYWORDS

birth cohort, complementary feeding, infant and child nutrition, low income countries, micronutrients, Nepal

1 | INTRODUCTION

Micronutrient deficiencies are associated with infectious disease, cognitive impairment, and growth retardation in infants and children (Black et al., 2013). According to World Health Organization (WHO), infants should be exclusively breastfed until 6 months after which breast milk alone is no longer sufficient and complementary foods should be introduced (Pan American Health Organization/WHO, 2003). Nutrient requirements per kilogram bodyweight are high due to intensive growth and development in infancy (Dewey, 2013). In addition, children in low- and middle income countries (LMICs) have high susceptibility to intestinal infections and parasitic infestations, which decrease nutrient absorption and appetite (Dewey & Mayers, 2011; Ochoa, Salazar-Lindo, & Cleary, 2004; The MAL-ED Network

Investigators, 2014). Because of limited gastric capacity and increased nutrients requirements of infants (Lutter & Rivera, 2003), complementary foods should be diverse with frequent consumption of nutrient dense foods such as meat, milk, eggs, and fruits and vegetables (WHO, 2001). At the same time, diets in LMICs are often cereal-based and monotonous (Dewey, 2013) where particularly iron, zinc, and calcium have been singled out as problem nutrients for children (Abeshu, Lelisa, & Geleta, 2016; Ferguson, Chege, Kimiywe, Wiesmann, & Hotz, 2015). These nutrients are found in foods consumed sparingly due to economic constraints (Neumann, Murphy, Gewa, Grillenberger, & Bwibo, 2007; Solomons & Vossenaar, 2013), and the high phytate and fibre content of cereal-based complementary foods may further inhibit mineral absorption (Gibson, Bailey, Gibbs, & Ferguson, 2010; Lonnerdal, 2000).

In Nepal, the diet is primarily based on rice, lentils, and seasonal vegetables with irregular consumption of meat, dairy, and fish (Ulak et al., 2016). The most commonly consumed home-made complementary foods in the Kathmandu valley is jaulo (lentils and rice mashed together) and lito (roasted grain/lentil flour cooked with water or milk), whereas few (<15% of children 6–23 months) consume industrially produced infant cereals (Pries et al., 2016). The diet is usually monotonous, and prevalence of micronutrient deficiencies among children ranges from 6% to 59% depending on the nutrient (Bhandari & Banjara, 2015; Ulak et al., 2016). The government runs a vitamin A supplementation program where children 6–59 months are supplemented twice a year and provides zinc supplementation to children with diarrhoea (Bhandari & Banjara, 2015). The national prevalence of stunting (41%) and wasting (29%) among children under 5 years of age is high (Ministry of Health and Population (MOHP) [Nepal]/ New ERA/ ICF International Inc, 2012), whereas the prevalence in Bhaktapur District is considerably lower at 19% and 7%, respectively (Shiwakoti, Devkota, & Paudel, 2017).

In a previous paper, we found low to moderate (3–4 out of 7) dietary diversity score (DDS) in our sample (Morseth et al., 2017). Tracking, measuring the stability of behaviour over time (Kelder, Perry, Klepp, & Lytle, 1994), was moderate for DDS but low for intake of iron- and vitamin A-rich food (Malina, 2001; Morseth et al., 2017). Although DDS is strongly associated with nutrient adequacy (Moursi et al., 2008; Working Group on Infant and Young Child Feeding Indicators, 2006), probability of adequacy (PA) based on usual intake is preferable to evaluate the probability of meeting nutrient requirements (Dodd et al., 2006). Few previous studies assess micronutrient adequacy in the same cohort of children across the complementary feeding period, and no previous studies, to our knowledge, evaluate PA longitudinally among children below the age of two. The objectives of this study were to assess PA calculated from estimated breast milk intake and complementary foods and nutrient density adequacy (NDA) of complementary foods in up to four time slots and to assess tracking of NDA among children 9–24 months in Bhaktapur, Nepal.

2 | METHODS

2.1 | Study design and study population

Participants were children 9 to 24 months living in Bhaktapur, a peri-urban agriculture-based community situated 15 km east of Kathmandu, the capital city of Nepal. All children were enrolled within 17 days of birth. Children with very low birth weight (<1500 g) were excluded. Enrolment started in June 2010, and data collection took place between February 2011 and November 2012. Out of 240 enrolled infants, 229 had complete nutritional data at 24 months. Four time slots (9–12, 13–16, 17–20 and 21–24 months) were used. The MAL-ED Nepal cohort received ethical approval from the Nepal Health Research Council and Walter Reed Institute of Research (Silver Springs, Maryland), and all participants signed informed consent forms prior to participation. Further details on design and methodology are reported elsewhere (The MAL-ED Network Investigators, 2014).

Key messages

- For most micronutrients, probability of adequacy was extremely low and increased slightly with age, whereas nutrient density adequacy varied greatly between nutrients and increased with age in this group of children aged 9–24 months.
- Both probability of adequacy and nutrient density adequacy identified iron, zinc, vitamin A, calcium, and niacin as main problem micronutrients.
- Health authorities should support families through education about the importance of feeding their children high quality complementary foods in adequate amounts and with adequate frequency.

2.2 | Dietary data collection

Monthly, 24-hr recalls (16 in total) were performed to collect data on foods and amounts consumed the previous day. Local fieldworkers were trained by experts in dietary recall technique through initial 3-day training sessions with periodic 1-day refresher sessions (Caulfield et al., 2014). Household utensils, portion size booklets, and play dough were used to estimate amounts. Details on recipes were also collected. To enable assessment of within-subject variation and increase the precision of estimated intakes, secondary recalls within 1 week of the original recall were conducted for each child once during the 16 months follow-up period (Caulfield et al., 2014).

2.3 | Dietary data analysis

To estimate nutrient intake, the Food and Agriculture Organization of the United Nations (FAO) International Network of Food Data Systems database for Asia (FAO, 2014) was used. When needed, supplementary nutrient values from other food composition tables, for instance, US Food composition table (United States Department of Agriculture), NUTTAB (Food Standards Australia New Zealand, 2010), and CoFIDS (Public Health England), were used.

PA for nutrient intake was calculated using the Institute of Medicine (IOM) probability approach (IOM, 2000a) based on the total nutrient intake from complementary foods and from breast milk. Breast milk intake was not measured but estimated based on the assumption that there is an inverse relationship between energy intake from complementary foods and energy intake from breast milk (Kimmons et al., 2005). First, the energy received from complementary foods was subtracted from the total energy requirements with moderate physical activity level (kilocalorie per kilogram per day) estimated by FAO (2004) for each child. The FAO energy requirement (kilocalorie per kilogram) for the appropriate age was multiplied by each child's body weight, which was measured monthly. The assumed energy needed from breast milk was then divided by the energy density of breast milk in developing countries (0.63 kcal/g) as described by WHO (1998) in order to estimate the assumed amount of breast milk consumed (converted from grams to litres). For each

nutrient, this amount was multiplied by the amount of nutrient in mature breast milk. For participants who consumed more than their energy requirement from complementary food, estimated nutrient intake from breast milk was set to zero. Because the breast milk content of thiamin, riboflavin, vitamin B₆, and vitamin A depends on maternal status (WHO, 1998), and PA of these nutrients among breastfeeding women in Bhaktapur is low (Henjum et al., 2015), nutrient values found among women in LMICs were used. These were 0.16 mg/L for thiamin, 0.22 mg/L for riboflavin, 0.10 mg/L for vitamin B₆ (Allen, 2012), and 227 µg/L for vitamin A (Rice et al., 1999). For the remaining nutrients, WHO's values were used (WHO, 1998). Finally, the estimated amount of nutrients consumed from breast milk was added to the amount consumed from complementary food for total intake for each child.

Due to uncertainty concerning requirements for children <12 months (Dewey & Brown, 2003; Moursi et al., 2008), PA was calculated only for the 13 to 24 month age groups. Also, because the content of vitamin B₁₂ in breast milk decreases with child's age (Hampel & Allen, 2016) and few previous studies to our knowledge have assessed the content of vitamin B₁₂ in breast milk fed to children >12 months, we decided to exclude vitamin B₁₂ from our analysis. As a result, PA was calculated for 10 micronutrients: thiamin, riboflavin, niacin, vitamin B₆, folate, vitamin C, vitamin A, calcium, iron, and zinc. Estimated average requirements (EARs) were based on a back calculation from FAO/WHO (2002) reference nutrient intakes (RNIs). RNI is defined as $EAR + 2 SD_{EAR}$ (FAO/WHO, 2002). EARs were calculated using the variability coefficients from IOM, namely, 15% for niacin, 20% for vitamin A, 25% for zinc, and 10% for the remaining nutrients (IOM, 2000c, 2000b, 2001). For participants with a mean phytate:zinc ratio > 15 for the time slot, requirements based on low absorption were used (WHO/FAO/International Atomic Energy Agency, 2002), otherwise requirements were based on medium absorption. Because iron requirements are skewed (IOM, 2000a), adequacy was estimated based on Table I-5 in the IOM report on iron requirements (IOM, 2001). The 5th percentile for phytate:iron ratio in our population was three, whereas the recommended ratio is <1 (Gibson et al., 2010). Probability of adequate iron intakes was therefore assessed by comparing participant's intakes with a matrix for iron requirements consistent with very low absorption (5%; Table S1).

The probability (%) of adequate nutrient intake was assessed based on mean usual intakes calculated from four recalls in each time slot or five recalls for time slots with secondary recalls. Skewed nutrient intakes were transformed using a Box-Cox transformation. After calculating within- and between person variance, the best linear unbiased predictor (BLUP) for usual intake was calculated for each nutrient for each child. A BLUP minimizes the prediction error variance and shrinks the individual means of a variable towards the group-level means. BLUPs were then used to estimate PA for each micronutrient. Mean probability of adequacy (MPA) was calculated using PA across all micronutrients for each participating child. Due to highly skewed data, median values for MPA are presented.

Nutrient density (ND) and NDA of complementary foods were calculated based on methodology by the Working Group on Infant and Young Child Feeding Indicators (Working Group on Infant and Young Child Feeding Indicators, 2006), for the same 10 micronutrients.

The nutrient densities of complementary food were defined as the amount of nutrient consumed per 100 kcal of complementary food. For each time slot and for each nutrient, desired nutrient densities were calculated the following way:

$$[RNI \text{ of nutrient } \chi - (\text{concentration of nutrient } \chi \text{ in breastmilk} \\ \times \text{median breast milk intake in time slot}) \\ / \text{median energy intake from complementary} \\ \text{food in time slot}] \times 100.$$

Requirements, amounts of micronutrients in breast milk, and absorption rates for iron and zinc were similar to those used when calculating PA. For recalls where the child had not been breastfed FAO/WHO's (2002) requirements were divided by median energy intake in the nonbreastfed group. Individual NDs were calculated as mean of four measurements within each time slot. NDAs were calculated for each nutrient for each observation as the ND as percentage of the desired nutrient density. Further, individual NDAs were calculated as mean NDA of four recalls within each time slot. Finally, mean nutrient density adequacy (MNDA) was calculated as the mean of individual NDAs for all 10 micronutrients each capped at 100%. Due to skewed data, median values are reported.

2.4 | Socioeconomic status

Socioeconomic status was measured at 12, 18, and 24 months by the WAMI index (Psaki et al., 2014). The WAMI index, a measure of socioeconomic status developed for MAL-ED, ranges from 0 to 1 and consists of the following variables: **Water and sanitation**, **Assets**, **Maternal education**, and **Income**. The eight assets included are separate room for a kitchen, household bank account, mattress, refrigerator, TV, people per room (mean), table, and chair or bench (Psaki et al., 2014). In our sample, all households had access to improved water and sanitation.

2.5 | Statistical methods

Statistical Package for Social Science version 23.0 and STATA version 14.0 were used to analyse data. The significance level was 0.05. Continuous data were presented as mean and standard deviation if normally distributed, and as medians if not normally distributed.

Generalized estimating equations (GEE) models with unstructured correlation structure were used to calculate stability (tracking) coefficients for NDA across all four age intervals. In a GEE model, the value of the outcome variable at Time 1 is regressed on the longitudinal development of the outcome variable from Time 2 to Time m (number of measurements). This provides one stability coefficient taking into account that measurements within one individual are correlated and may be adjusted for both time dependent and time independent covariates (Twisk, 2003). Models were adjusted for WAMI measured at 12 months. Stability correlation coefficients of <0.30 were classified as low, 0.30 to 0.60 as moderate, and >0.60 as moderately high (Malina, 2001).

3 | RESULTS

The mothers were on average 27 (SD 4) years old, and the average number of years of education was 8 (SD 4). The average WAMI-index in our sample was 0.7, representing middle to high socioeconomic status in a Nepali context. Fifty-four percent of participants were male.

Data on breastfeeding and complementary feeding are presented in Table 1. Breastfeeding was frequent (about 10 times per day), and almost all children (> 97%) were breastfed up to 21 months. The estimated median (IQR) percent of energy intake from breast milk out of total energy intake decreased from 65% (48, 79) in the first to 35% (15, 55) in the last time slot.

Micronutrient usual intakes and PA are presented in Table 2. Mean usual intake was below the EAR for all nutrients, apart from vitamin C and riboflavin, across all time slots. PA for B vitamins (except riboflavin), vitamin A, calcium, iron, and zinc (low absorption group) was very low, ranging from 0% to 8% for all time slots. There was a marked increase in PA for riboflavin from 4% to 87% and zinc (medium absorption group) from 12% to 47% through time slots, whereas PA for vitamin C decreased from 100% to 54% in the last time slot. For the remaining nutrients, there were small or marginal improvements in PA. Median (IQR) MPA increased from 11% (10, 15) to 14% (10, 24), and finally, 21% (10, 35) through the three time slots compared. Corresponding numbers when excluding vitamin C were 1.6%, 7%, and 17%, respectively (data not shown).

ND and NDA of complementary food are presented in Table 3. The lowest median NDAs at baseline were 4.3% for iron, 17% for zinc, 22% for vitamin A, and 31% for calcium and niacin. Median NDA for iron, zinc, and vitamin A increased gradually through time slots to 17%, 43%, and 39% in the last time slot, respectively. NDA for calcium and niacin dropped slightly between the first and the second time slot then increased to 52% and 43% in the last time slot, respectively. The same pattern was seen for thiamin and folate. The highest median NDA was found for vitamin C, with values above 100% for the first three time slots. The only significant difference ($p < .05$) in ND between recalls with and without breastfeeding was found for calcium (data not shown). Median MNDA decreased from 42% in the first to 39% in the second time slot then increased to 52% in the last time slot.

Tracking of NDA is presented in Table 4. The stability coefficients calculated by GEE models adjusted for WAMI were low for thiamin (0.27), niacin (0.22), vitamin B₆ (0.12), vitamin C (0.21), vitamin A (0.25), and iron (0.28). For the remaining nutrients, stability coefficients were moderate, with the highest value found for calcium (0.47). The stability coefficient for MNDA was 0.27.

4 | DISCUSSION

In this longitudinal study of micronutrient adequacy among infants and young children in Nepal, we found that PA was extremely low for most micronutrients, apart from vitamin C and riboflavin, whereas NDA varied greatly between nutrients and was lowest for iron, vitamin A, and zinc. Tracking of NDA was low or moderate.

The low median PA observed for most micronutrients reflects poor quality of complementary food and inadequate nutrient content

in breast milk to cover the nutrient gap. Although the proportion of energy intake from complementary foods compared to breast milk should increase with age, the optimal balance will depend on the quality of complementary foods available and will differ in various settings (Dewey & Brown, 2003). In one study on 6–12 months old children in Bangladesh, the intake of 100 additional kcal of complementary foods led to a small increase in adequacy for iron, calcium, zinc, and riboflavin, and a small decrease for vitamin C (Kimmons et al., 2005). The same trends are reflected in our data. The median of MPA in our study was lower than MPA in 24–71 month old nonbreastfeeding Filipino children (Kennedy, Pedro, Seghieri, Nantel, & Brouwer, 2007). Also, PA for all nutrients, apart from vitamin C and calcium, and MPA were higher in a study on children 24–48 months in Bangladesh compared to our findings (Arsenault et al., 2013). No previous studies, to our knowledge, assess PA in the same age group as our study.

The drop in NDA between the first and second time slot for many nutrients is likely caused by increased requirements (FAO/WHO, 2002) and low energy intake from complementary food in the second time slot, causing high desired nutrient densities. The high NDA for vitamin C may be caused by a combination of fruit intake and fruit juice intake and low desired NDs due to high vitamin C content in breast milk. ND was overall lower in our study (first time slot) compared to ND for infants 10–12 months (Campos, Hernandez, Soto-Mendez, Vossenaar, & Solomons, 2010) and lower for all nutrients apart from riboflavin (second time slot) than among infants 12–15 months in Guatemala (Dewey & Brown, 2003). Further, ND in our study (first time slot) was higher for all nutrients apart from thiamin, niacin, vitamin A, and iron than ND among infants 9–11 months in Bangladesh (Dewey & Brown, 2003). Finally, mean micronutrient density adequacy was higher (66–67 vs. 42–52%) among children 9–23 months in Madagascar than in our study (Moursi et al., 2008). Meanwhile, none of these previous studies used context specific NDA. Our desired NDs were generally higher than those proposed by Dewey and Brown (2003). Direct comparisons should thus be made with caution.

The problem nutrients identified by both PA and NDA were primarily iron, vitamin A, zinc, calcium, and niacin, comparable to other studies (Campos et al., 2010; Dewey & Brown, 2003; Fahmida & Santika, 2016; Vossenaar, Hernandez, Campos, & Solomons, 2013). For iron and zinc in particular, small amounts are found in breast milk (WHO, 1998), and requirements are high, especially for children <12 months. In addition, bioavailability is a significant problem (Gibson et al., 2010; Lonnerdal, 2000), which was clearly demonstrated by differences in PA between groups with different absorption rates for zinc in our data. During complementary feeding, meat is an invaluable source of readily absorbed iron and zinc (Hambidge et al., 2011). An intervention study showed that 86% of 9 months old infants met EAR for zinc when meat intake was 60 g/day (Krebs et al., 2012). Such high intakes imply that meeting requirements through consumption of family foods alone seems near impossible (Dewey, 2013; Krebs et al., 2012; Solomons & Vossenaar, 2013), especially in the youngest age groups. Meat intake in our population is probably limited by cost (Dewey, 2013) and religious and cultural factors (Siegel et al., 2006). In addition, animal source foods are not commonly served to the youngest children in Nepal,

TABLE 1 Breastfeeding and energy intake from complementary food, children 9–24 months, Bhaktapur, Nepal (*n* = 909)

	9–12 months	13–16 months	17–20 months	21–24 months	<i>p</i> -value
Children being breastfed, %	99.9	99.9	97.3	78.8	
Breastfeeding frequency (times/day), mean (SD)	11 (3)	11 (3)	10 (3) ^a	8 (3) ^a	<.001 ^b
Total energy needs (kcal), mean (SD) ^c	662 (81)	742 (90)	794 (93)	844 (95)	<.001 ^d
Energy intake from food (kcal), median (IQR)	227 (137, 342)	316 (208, 451)	424 (274, 580)/871 (694, 1201) ^e	542 (383, 719)/ 873 (651, 1161) ^e	<.001 ^b
Estimated amount of breast milk consumed (L), median (IQR) ^f	0.68 (0.50, 0.84)	0.67 (0.44, 0.86)	0.60 (0.33, 0.80)	0.47 (0.20, 0.75)	<.001 ^b
Estimated percent energy intake from breast milk out of total energy intake, median (IQR) ^a	65 (48, 79)	57 (39, 73)	48 (28, 65)	35 (15, 55)	<.001 ^b

Note. Calculations based on total number of observations within each time slot.

Parts of this table has been presented previously.

^aOnly children breastfed the previous day included.

^bFriedman's test.

^cEstimated based on FAO (2004) energy requirements and body weight measured monthly.

^dRepeated measures ANOVA.

^eBreastfed/non-breastfed children.

^fCalculated only if assumed amount of breast milk >0. Energy density of breast milk based on WHO (1998).

due to a common perception that these foods are hard to digest (Chandyo et al., 2016).

Tracking of NDA was low or moderate, which indicates that nutrient density of complementary food was not very stable within our participants over time (Kelder et al., 1994). Little is known about tracking of dietary intake for infants and young children (Robinson et al., 2007), but moderate tracking for dietary behaviours has been observed among children and from childhood to adolescence in Western populations (Madruga, Araujo, Bertoldi, & Neutzling, 2012). Tracking of micronutrient intake between 9 and 18 months among Australian children was slightly higher for vitamin A and niacin but lower for minerals, B-vitamins, and vitamin C than in our sample (Lioret, McNaughton, Spence, Crawford, & Campbell, 2013). On the one hand, tracking of nutrient density in our age group might be low due to changes in types of foods that are introduced with increasing age. On the other hand, closely spaced observations increases the likelihood of higher tracking coefficients (Twisk, 2003). The lowest tracking was seen for vitamin B₆ and vitamin A. For vitamin A, this may in part be due to seasonal variations in intake of green leafy vegetables (Shrestha et al., 2014).

In general, our results paint a very bleak picture regarding micronutrient adequacy among young children in Nepal. Bhaktapur is a peri-urban society with higher socioeconomic status than national averages (Shrestha et al., 2014), and it is likely that nutrient adequacy is higher here than in other regions. There is thus an urgent need for measures to improve the situation. A study on complementary feeding practices among Nepali mothers showed that only 16% fed their children appropriate complementary foods in adequate amounts and with adequate frequency (Chapagain, 2013). Advice about feeding the most nutrient dense foods in the household (Dewey & Mayers, 2011) in adequate amounts and with adequate frequency to the infants should thus be given before and during the period of complementary feeding. In addition, fortification (Arsenault et al., 2010) or dephytinization (Gibson et al., 2010) of cereals either at home or industrially may also be viable options to increasing the amounts of absorbed iron and zinc.

The major strength of this study is the longitudinal design and the large number of dietary recalls performed, providing estimates for usual intakes that account for between- and within subject variance (Dodd et al., 2006). The number of dietary measurements (4–5 in each time slot) seems adequate to describe nutrient intake in this age group, where intraindividual variation is usually small (Lanigan, Wells, Lawson, Cole, & Lucas, 2004; Piernas, Miles, Deming, Reidy, & Popkin, 2016). Another strength of the study is the inclusion of children directly after birth, because few children <2 years possess birth certificates (Ministry of Health and Population (MOHP) [Nepal]/ New ERA/ ICF International Inc, 2012), and reporting of exact age may be challenging. Finally, retention throughout the study was nearly complete at 95%.

The major weakness of our study was lack of data on the amount of breast milk consumed and the amount of nutrients in breast milk. Our method for calculating PA and NDA, using the amount of nutrients from breast milk based on total energy needs, is admittedly not ideal. However, given the substantial variation in energy intake from complementary foods and frequent breast feeding observed, this method was deemed superior to using average amounts of breast milk intake for the whole group as proposed by WHO (1998). Also, others

TABLE 2 Micronutrient usual intake and probability of adequacy, children 12–24 months, Bhaktapur, Nepal (*n* = 229)

Nutrient	Requirement ^a EAR (SD)	13–16 months		17–20 months		21–24 months	
		Usual intake according to BLUP ^b		Usual intake according to BLUP		Usual intake according to BLUP	
		Mean (SD)	Median	PA ^b % Median (IQR)	Mean (SD)	Median	PA % Median (IQR)
Thiamin (mg/d)	0.4 (0.04)	0.23 (0.06)	0.22	0 (0, 0.1)	0.26 (0.07)	0.25	0 (0, 1.4)
Riboflavin (mg/d)	0.4 (0.04)	0.34 (0.1)	0.31	3.8 (0, 62)	0.39 (0.13)	0.36	31 (4.7, 96)
Niacin (mg/d)	4.6 (0.69)	2.2 (0.4)	2.1	0 (0, 0.1)	2.5 (0.5)	2.4	0 (0, 0.8)
Vitamin B ₆	0.4 (0.04)	0.24 (0.08)	0.22	0 (0, 0.1)	0.29 (0.1)	0.28	0.5 (0, 23)
Folate (μg/d)	133 (13.3)	91.9 (18.1)	90.2	0 (0, 0.5)	95.9 (19.7)	94.5	0 (0, 2.1)
Vitamin C (mg/d)	25 (2.5)	31.7 (8.4)	31.5	99 (38, 100)	31.6 (9.1)	31.5	100 (31.4, 100)
Vitamin A (μg/d)	286 ^c (57.1)	52.8 (42.5)	43.5	0 (0, 0)	77 (52.5)	65.6	0 (0, 0.8)
Calcium (mg/d)	417 (41.2)	291 (69)	286	0.1 (0, 2.5)	305 (81)	292	0.1 (0, 4.4)
Iron (mg/d)	NA ^d			0 (0, 0)			0 (0, 0)
Zinc (mg/d) _{low} ¹	5.6 ^e (1.4)	1.8 (0.4)	1.7	0.8 (0.4, 0.9)	2 (0.4)	2	0.4 (0.3, 0.8)
Zinc (mg/d) _{medium} ²	2.7 ^e (0.7)	1.9 (0.4)	1.9	12 (7, 24)	2.2 (0.5)	2.2	27 (13, 44)
MPA, median (IQR)				11 (10, 15)			14 (10, 24)

Note. EAR = estimated average requirement; PA = probability of adequacy; BLUP = best linear unbiased predictor.

^aBased on RNI from FAO/WHO Vitamin and Mineral Requirements (2002). EAR back calculated with a variability coefficient of 15% for niacin, 20% for vitamin A, 25% for zinc, and 10% for the remaining nutrients (IOM). PA for iron based on Table I-5 in IOM (2001) iron requirements report.

^bBased on four recalls (or five if secondary recall in time slot).

^cFrom British Nutrition Foundation (2014), UK Nutrition requirements.

^dIron requirements are not normally distributed. PA calculated by comparing usual intake to Table I-5 from IOM (2001) iron requirements report converted to 5% bioavailability (Table S1).

^eEAR and SD based on low (phy:zn ratio > 15) and median zinc absorption respectively.

¹*n* = 129 (13–16), 117 (17–20) and 103 (21–24 months) respectively.

²*n* = 101 (13–16), 112 (17–20) and 126 (21–24 months) respectively.

TABLE 3 Median nutrient density and nutrient density adequacy of complementary food intake, children 9 to 24 months, Bhaktapur, Nepal (n = 229)

Nutrient	9–12 months			13–16 months			17–20 months ^a			21–24 months		
	Desired ND ^b			Desired ND			Desired ND			Desired ND		
	ND ^c	NDA median (IQR)		ND	NDA median (IQR)		ND	NDA median (IQR)		BF	NonBF ^e	NDA median (IQR)
Thiamin (mg/100 kcal)	0.08	0.04	49 (35, 61)	0.1	0.04	41 (31, 50)	0.1	0.04	46 (34, 57)	0.08	0.06	52 (40, 67)
Riboflavin (mg/100 kcal)	0.1	0.06	58 (39, 85)	0.1	0.06	60 (39, 82)	0.09	0.06	67 (52, 89)	0.07	0.06	94 (64, 127)
Niacin (mg/100 kcal)	1.3	0.40	31 (25, 37)	1.6	0.4	26 (21, 33)	1.2	0.43	36 (30, 45)	0.1	0.7	43 (36, 54)
Vitamin B ₆ (mg/100 kcal)	0.1	0.06	56 (43, 72)	0.1	0.06	56 (44, 70)	0.1	0.06	61 (46, 77)	0.08	0.06	72 (58, 98)
Folate (μg/100 kcal)	9.8	10.6	111 (81, 159)	33	11.4	36 (28, 47)	26	11	44 (35, 57)	22	18	51 (40, 66)
Vitamin C (mg/100 kcal)	1.2	1.3	119 (79, 199)	1.1	1.6	196 (108, 345)	1.4	1.9	156 (86, 251)	2.1	3.4	79 (49, 128)
Vitamin A (μg/100 kcal)	87	19	22 (13, 33)	79	20.5	26 (16, 36)	62	19.9	33 (23, 45)	55	46	39 (29, 55)
Calcium (mg/100 kcal)	93	29.3	31 (17, 48)	100	28.7	30 (17, 45)	78	30.3	39 (25, 54)	68	57	52 (35, 69)
Iron (mg/100 kcal) ^g	8.3	0.36	4.3 (3.2, 5.7)	3.7	0.36	10 (8, 13)	2.8	0.37	13 (11, 16)	2.2	1.4	17 (14, 21)
Zinc (mg/100 kcal)	3.3/1.5 ^h	0.36	17 (12, 23)	2.4/1	0.34	24 (17, 32)	1.8/0.8	0.33	32 (23, 42)	1.5/0.7	1/0.5	43 (31, 53)
MNDA ⁱ , median (IQR)			42 (35, 49)			39 (33, 45)			44 (38, 51)			52 (43, 58)

Note. ND = nutrient density; NDA = nutrient density adequacy; BF = breastfed; Non-BF = nonbreastfed; MNDA = mean nutrient density adequacy.

^aCalculated only for breastfed children.

^bBased on RNIs from FAO/WHO Vitamin and Mineral Requirements (2002), median breast milk intake and median contribution of energy (kilocalorie) from complementary foods for time slot.

^cMedian values reported.

^dBased on all observations within time slot.

^eBased on RNIs from FAO/WHO and median amount of energy (kilocalorie) from recalls where child was breastfed.

^fBreastfed/nonbreastfed.

^gRequirements corresponding to 5% absorption rates used in calculation.

^hRequirements based on low (phy:zn ratio > 15) and medium absorption used in calculation.

ⁱAverage NDA for all 10 micronutrients, each capped at 100%.

TABLE 4 Tracking of nutrient density adequacy of complementary food intake, children from 9 to 24 months, Bhaktapur, Nepal (n = 229)

Nutrient	Coefficient ^a (CI)
Thiamin (mg/100 kcal)	0.27 (0.18, 0.35)
Riboflavin (mg/100 kcal)	0.38 (0.28, 0.48)
Niacin (mg/100 kcal)	0.22 (0.15, 0.29)
Vitamin B ₆ (mg/100 kcal)	0.12 (0.04, 0.20)
Folate (μg/100 kcal)	0.37 (0.25, 0.49)
Vitamin C (mg/100 kcal)	0.22 (0.07, 0.36)
Vitamin A (μg/100 kcal)	0.25 (0.16, 0.34)
Calcium (mg/100 kcal)	0.47 (0.37, 0.57)
Iron (mg/100 kcal)	0.28 (0.19, 0.36)
Zinc (mg/100 kcal)	0.33 (0.28, 0.42)
MNDA ^b	0.27 (0.15, 0.38)

Note. Generalized estimating equations analysis, adjusted for WAMI.

^aTracking coefficients calculated by general estimating equations.

^bAverage nutrient density adequacy for all 10 micronutrients, each capped at 100%.

have estimated energy intake from complementary food (Dewey & Brown, 2003; Kimmons et al., 2005) and breast milk (Mallard et al., 2016) based on total energy requirements similar to our approach. A previous study showed that infants aged 9–12 months in Bangladesh consumed slightly more (105%) energy than their requirements per body weight but slightly less (94%) energy than their requirements per ideal body weight for length (Kimmons et al., 2005). Although it seems unrealistic to assume that all our participants cover their energy needs, monthly anthropometric measurements in our view improve the validity of our imputation method for breast milk intake because the estimated energy need of a growth faltering child was reduced the subsequent month. Finally, our estimated intakes from breast milk and complementary foods resemble estimates for children with high breast milk consumption reported by Dewey and Brown (2003).

To our knowledge, no data exist on the content of the 10 micronutrients assessed in breast milk of Nepali women. For nutrients known to vary with maternal status (Allen, 2012), we assumed a breast milk content comparable to that of women from other LMICs (i.e., India and Bangladesh; Allen, 2012; Rice et al., 1999). Based on low probability of micronutrient adequacy among breastfeeding women in Bhaktapur (Henjum et al., 2015), it is probable that our estimates are more valid than if WHO values based on breast milk from western women (WHO, 1998) had been used. Finally, over-reporting of intake has been found to be more common than under-reporting in this age group (Lioret et al., 2013). This could have led to lower estimated energy and nutrient intakes from breast milk when calculating PA and lower desired nutrient densities resulting in slightly higher NDA.

The severe micronutrient inadequacy demonstrated, especially for iron, vitamin A and zinc among Nepali children 9–24 months in our study reflect low micronutrient content of complementary food and inadequate content in breast milk to cover the nutrient gap. In light of the potentially severe consequences for health, growth, and cognitive development, health authorities should urgently consider measures to improve micronutrient intake in this age group. Educating mothers about the importance of feeding children nutrient dense complementary foods is an important first step. However, because

achieving micronutrient adequacy consuming local foods or/and breast milk seems improbable, micronutrient supplementation of breastfeeding women and dephytinization or fortification of foods commonly consumed by breastfeeding women and children must also be considered.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

CONTRIBUTIONS

MSM performed the statistical analysis and drafted the manuscript. LET and SH assisted with statistical analysis and contributed to revising the manuscript for intellectual content. RKC, MU, and SKS supervised and contributed to data acquisition. BS was in charge of data management. AHP conducted GEE analysis. All authors read and approved the final manuscript.

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SUPPORTING INFORMATION

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