Harmonizing Micronutrient Intake Reference Ranges for Dietary Guidance and Menu Planning in Complementary Feeding

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ABSTRACT

There are no published harmonized nutrient reference values for the complementary feeding period. The aim of the study was to develop proposals on adequate and safe intake ranges of micronutrients that can be applied to dietary guidance and menu planning. Dietary intake surveys from 6 populous countries were selected as pertinent to the study and reviewed for data on micronutrients. The most frequently underconsumed micronutrients were identified as iron, zinc, calcium, magnesium, phosphorus, potassium, and vitamins A, B6, B12, C, D, E, and folate. Key published reference values for these micronutrients were identified, compared, and reconciled. WHO/FAO values were generally identified as initial nutrient targets and reconciled with nutrient reference values from the Institute of Medicine and the European Food Standards Authority. A final set of harmonized reference nutrient intake ranges for the complementary feeding period is proposed. *Curr Dev Nutr* 2020;4:nzaa017.

Introduction

The WHO identifies the complementary feeding period as extending from the ages of 6 to 24 mo (1). This period encompasses the gradual transition from an exclusively milk-based diet to one including a diverse range of family foods. The timing and types of foods that are introduced should ensure nutritional adequacy, avoid excess, be developmentally appropriate (2), ensure food safety (3), and help to establish lifelong taste preferences and dietary habits. Consumption of a healthy, balanced diet adequate in micronutrients is critical during this sensitive period of growth and development. Nevertheless, suboptimal intake of some micronutrients persists even in industrialized countries. The Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) (4), the European Food Standards Authority on Dietetic Products, Nutrition, and Allergies (EFSA-NDA, 2013) (5), and the National Academies of Sciences, Engineering, and Medicine (NASEM) (6) have all identified nutrients at either a global or regional level that

should be increased in the diet during this period – so-called "shortfall nutrients/micronutrients".

Breastfed infants need complementary foods to satisfy >50% of their requirements for micronutrients, including iron, zinc, magnesium, phosphorus, manganese, and fluoride, as well as vitamins B6, D, E, biotin, thiamin, and niacin, but only 25% of their energy requirements, compared with the relevant DRIs (7, 8). As the percentages of daily energy allowances from complementary foods for infants (aged 6 to 12 mo) and young children (12 to 24 mo) are relatively small, as are their estimated energy requirements, complementary foods need to be highly micronutrient-dense. Relative micronutrient density (i.e., concentration of nutrients per unit of energy) offers a framework for adjusting the fortification of complementary foods to address the micronutrient gap left in breastfed infants of this age (9).

Some micronutrients are more critical than others during the sensitive period of rapid growth and development from 6 to 24 mo, and every effort should be made to ensure their adequacy in the diet. Iron,

in particular, is a major public health concern because globally it is a shortfall micronutrient among infants and children (10). Breast milk is a source of highly bioavailable iron with studies suggesting ≤56% absorption from breast milk (11) compared with ∼10% absorption from other sources (12). Nevertheless, despite the higher bioavailability of iron in breast milk, once an infant's innate iron stores become depleted after the first months of life, additional sources of bioavailable iron are required (13). Therefore, it is recommended that exclusively breastfed infants may benefit from iron supplements (14), and iron-rich or iron-fortified foods are advised once complementary feeding begins aged 6 mo (1, 2). In addition to the risk of inadequacies, potential dietary excesses are also of concern. Some micronutrients – sodium is the main example – are frequently overconsumed, even at a young age, in both affluent and low- and middle-income countries (LMICs). It is critical, therefore, to confirm key micronutrients that are actually under- or overconsumed during the complementary feeding period. However, geographically diverse dietary surveys to identify "at-risk" nutrients, within the age range of 6 to 24 mo, have been sparse, and the definitions of inadequacy that are applied are inconsistent.

Up-to-date and broadly applicable micronutrient reference values for adequate and safe intake ranges are fundamental for developing dietary guidelines and menu planning. Current dietary intake recommendations are based on the nutrient reference values proposed by national and international organizations, but these values are not always uniform, are variably updated, and the bases for their derivation can be inconsistent. Recently, a harmonized set of nutrient reference values that can be used to define adequate and safe nutrient ranges has been proposed for children and adults (15). However, such values are lacking for infants. The principal aim of the present study was to identify a set of micronutrient reference ranges that could be applied during the complementary feeding period. For this purpose, we first identified the most critical micronutrients ("micronutrients of concern"), which were under- and overconsumed, based on relevant dietary intake surveys. Next, we assessed, compared, and reconciled the published nutrient reference values for these micronutrients. On the basis of this work, we propose a broadly relevant set of reference values and intake ranges for selected nutrients.

Methods

A mixed-methods literature review was conducted to ascertain the micronutrients of concern, identify and compare their reference values, and describe the derivations of such reference values (16). First, a PubMed database search was undertaken for dietary intake surveys conducted in heavily populated countries in which micronutrients had been identified as being inadequate, or excessive, in the diets of infants and young children within the age range of 6 to 24 mo. To ensure geographical diversity, the top 2 or 3 most populous countries in the Americas, Asia, and the European region were identified from a list of the top 20 most densely populated countries in the world (17). In the Americas these countries were the USA, Brazil, and Mexico; in Asia they were China, India, and Indonesia; and in Europe they were Russia and Germany. Our search for dietary surveys was then restricted to these countries. The following subject headings were entered as

keywords: "infant, young child OR toddler, dietary survey OR assessment, nutrients", along with the country name. To avoid dated studies, we decided to only include studies spanning the 10-y period of 2008 to 2018. To ensure global representation, the databases Google Scholar and the Russian Science Citation Index (www.elibrary.ru/) were also searched. Studies that only evaluated a subset of nutrients were rejected as were studies that assessed nutrient status via biochemical markers rather than via dietary intake. All the studies considered were published in English, with the exception of 1 Russian study. Although our review was restricted to literature published between 2008 and 2018, it should be noted that most of the reference standards had been developed prior to 2008.

Within the Americas, the most recent dietary intake surveys reported were in the USA (18) and Mexico (19). In Asia, a dietary intake survey was found for China (20) and selected because it included a large number of infants and young children; however, because the survey excluded rural areas, it cannot be considered to be nationally representative. There were no nationally representative dietary intake surveys identified that included both older infants and young children and that assessed a range of micronutrient intakes for India, Indonesia, Pakistan, or Bangladesh. However, a recent survey was identified in the Philippines that was considered eligible as it is a highly populated country in the same region, and has a similar infant mortality rate to other countries in the region (21, 22). Although Russia is the most heavily populated country in Europe, no relevant articles in the English language were identified. However, a study in Russian was included that described a dietary intake survey among young children (23). Germany was evaluated due to its ranking as the second most populous country in Europe, but a recent dietary intake survey inclusive of infants and young children could not be found. Therefore, a longitudinal study, which included children from 5 European countries (i.e., Germany, Belgium, Italy, Poland, and Spain), was used as a proxy (24). It should be noted that this review of data extracted from published studies required no human subject approval, as this had been obtained in the primary surveys; no participant information was obtained, nor was additional data collected as part of our work.

It should be noted that age groupings in the dietary intake studies tended to vary by country of origin, but in our review we focused specifically on the age ranges of 6 to 12 and 12 to 24 mo, when possible; however, in many instances the age range of 12 to 24 mo was part of larger age groupings (e.g., 1 to 3 y) when comparing intakes with the corresponding published nutrient reference values.

For the purposes of this study, a set of "micronutrients of concern" were defined as those that were under- or overconsumed in the dietary surveys above, and/or that their role in the diet was critical during complementary feeding. Once the set of micronutrients of concern had been identified, the recommendations for their intakes, and their derivations provided by the WHO/FAO, the Food and Nutrition Board of the Institute of Medicine (IOM, now the NASEM), and EFSA, were compared. Those organizations were selected because they met the following criteria: their guidance was transparent and evidence-based; their recommendations influenced public policy in >1 country; and they represented significant population coverage in terms of their span of influence. WHO reference values were generally prioritized as nutrient targets, unless those values were based on outdated

TABLE 1 Characteristics of the dietary intake surveys included in the study

Country	Study year(s) of data collection	Methodology	Design	Intake includes dietary supplements	Population groups	Infant and young child age groups (n per age group)	Method for evaluating micronutrient adequacies and excesses
China	MING study (20) 2011–2012	24-h dietary recall based on 1 d	Cross-sectional	Yes	Urban Chinese	6–11 mo (n = 444) 12–24 mo (n = 476)	By comparing mean and median intakes with the Chinese adequate intakes
Mexico	ENSANUT (19) 2012	24-h dietary recall for 1 d and a second recall with a smaller subset*	Cross-sectional	No	Nationally representative	6–11 mo (n = 228) 12–23.9 mo (n = 537)	Based on usual intake, the proportion of individuals meeting or exceeding the US DRIs
Philippines	NNS (21) 2013	24-h dietary recall for 1 d and a second recall with a smaller subset*	Cross-sectional	No	Nationally representative	6–11.9 mo (n = 362) 12–23.9 mo (n = 734)	Based on usual intake, and comparing with the Philippines DRIs
Russia	Russian National Survey (23) 2013	24-h dietary recall based on 1 d	Cross-sectional	No	Nationally representative	12–23 mo (n = 2376)	By comparing mean and median intakes with the Russian Nutrient Reference Values
USA	FITS (18) 2015–2016	24-h dietary recall for 1 d and a second recall with a smaller subset*	Cross-sectional	Yes	Nationally representative	6–11.9 mo (n = 444) 12–24 mo (n = 476)	Based on usual intake, the probability of meeting or exceeding the US DRIs
European region (Germany, Belgium, Italy, Poland, and Spain)	CHOP cohort (24) began in 2002	3-d weighed food records*	Longitudinal	No	Cohort recruited within 2 wk of birth and followed from 3 mo to 8 y	at 6 mo (n = 1202) at 12 mo (n = 1100)	Based on prevalence of adequacy and calculated based on the EAR cut point method. The EARs were from the WHO and the IOM. Adequacy at the individual level was also assessed

CHOP, Childhood Obesity Prevention; EAR, estimated average requirement; ENSANUT, National Health and Nutrition Survey; FITS, Feeding Infants and Toddlers Study; IOM, Institute of Medicine (Food and Nutrition Board); MING: Maternal Infant Nutrition Growth; NNS: National Nutrition Survey.
*Denotes studies where an adjustment was made for day-to-day variation.

science, did not exist, or had a less compelling scientific rationale than the other sources. Estimated average requirements (EARs) and tolerable upper intake levels (ULs) derived by the IOM, when available, were favored as minima and maxima, although such information for all micronutrients did not exist for infants and young children. EFSA reference values were applied whenever the other values were considered unachievable or inappropriate, i.e., if they were considered outdated or had a less rigorous rationale. Ultimately, the reference values were harmonized into 1 final set of nutrient reference ranges.

Results

Table 1 summarizes the dietary surveys that were identified as meeting the above criteria, which were assessed to determine the nutrients reported as under- or overconsumed. The surveys applied different methods for dietary assessment and data analysis, and used different nutrient reference values. Our study was designed to identify overall trends in terms of inadequate and excessive micronutrient intakes in both affluent countries and LMICs and not to estimate country differences from the data in the surveys. Therefore, the fact that differences between countries could not be directly compared was not considered to be a serious flaw.

Micronutrients of concern

Micronutrients of concern were identified by evaluating dietary intake surveys reported from the selected countries. The process was not straightforward because the nutrient standards against which intakes were benchmarked varied, and intake patterns differed substantially around the world, sometimes even within each region. In the Maternal Infant Nutrition Growth (MING) study in China, the populations studied were living in urban areas and their nutrient intakes were compared with Chinese requirements (20). In MING, mean intakes of vitamin B6, folate, and selenium were reported as inadequate among infants, and borderline among young children; in addition, the median infant intake of iron was reported as being similar to the Chinese EAR, signifying a potential risk of inadequacy. In Mexico, the National Nutrition and Health Survey (ENSANUT) study in 2012 reported inadequate

intakes of iron and zinc among both infants and young children (25). In a separate study, young children in Mexico, aged 1 to 4 y, were reported as consuming inadequate amounts of iron, calcium, vitamins D, E, A, and folate (26, 27).

The National Nutrition Survey (NNS) carried out in the Philippines found a high prevalence of inadequacy among infants for vitamin A, iron, and zinc, as well as for thiamin, riboflavin, and niacin (21), and mean intakes of vitamins E and D, phosphorus, and potassium were far below the local adequate intakes (AIs) among infants. Among young children (12 to 24 mo), there were major shortfalls in their intakes of iron, folate, vitamins B6 and A, and calcium. Inadequacy was also identified for thiamin, riboflavin, niacin, vitamin B12, phosphorus, and zinc in the same population, whereas mean intakes were far below the AI for vitamins E and D and potassium.

The Russian National Survey, conducted in 2013, found the mean intakes of iron, calcium, and vitamin C among young children aged 12 to 24 mo were below the Russian RDAs (23). In the latest US Feeding Infants and Toddlers Study (FITS), inadequate iron intakes were reported in infants aged 6 to 12 mo; additionally, young children were at risk of inadequate intakes of potassium, as well as vitamins D and E (18).

A prospective study in Europe, the Childhood Obesity Prevention (CHOP) study, examined micronutrient adequacy from infancy to 8 y, among a cohort from 5 countries (Table 1). The CHOP study identified a probability of adequacy of <80% of the population for iron, iodine, folate, and vitamin D (24).

Excessive intakes of sodium among young children were reported in most of the studies and also among infants in the Philippines. Excessive vitamin A intake was observed in China (20). Both zinc and retinol were overconsumed in the USA relative to their respective reference values (18).

Based on these findings, the micronutrients of concern were defined, for the purposes of our study, as those that were under- or overconsumed and/or that their role in the diet was critical during complementary feeding. The latter could be due to the physiological roles of the micronutrients or their likely roles in influencing preferences and feeding behavior later in life (as might be the case with sodium). On this basis, the micronutrients of concern in terms of underconsumption

TABLE 2 Terms applied by the major authoritative organizations for describing nutrient intake recommendations

Term	Organization	Definition
DRI	IOM[1]	The umbrella term that encompasses the requirements described below
Dietary reference value (DRV)	EFSA[2]	
Estimated average requirement (EAR)	WHO[3], IOM	Average daily nutrient intake that meets the needs of 50% of healthy individuals in a given age and gender group
Average requirement (AR)	EFSA	
Recommended nutrient intake (RNI)	WHO	The daily intake set at the EAR plus/minus 2 SDs, which will cover the needs of 97.5% of healthy individuals in a given age and gender group
RDA	IOM	
Population reference intake (PRI)	EFSA	
Adequate intake (AI)	IOM, EFSA	The average daily level of intake based on observed or estimated nutrient intakes by groups of apparently healthy people
Tolerable upper intake level (UL)	WHO, IOM, EFSA	Highest average daily nutrient intake level that is likely to pose no risk of adverse effects to almost all individuals in a population

[1]Institute of Medicine (Food and Nutrition Board; IOM) (2000) (28).
[2]European Food Standards Authority (Nutrition, Dietetics, and Allergies; EFSA) (2010) (29).
[3]WHO (2004) (30).

TABLE 3 Description of methods for deriving mineral requirements for infants and young children by WHO/FAO, IOM, and EFSA

Nutrient	Life stage*	WHO/FAO (2004)[1]	IOM DRIs	EFSA DRVs
Iron[2,3]	Infants	RNI: factorial method. Presented requirements at different levels of absorption (5%, 10%, 12%, and 15%) for both age groups	RDA: factorial method. Assumed an iron absorption of 10%	PRI: factorial method. Assumed an iron absorption of 10% for both age groups
	Young children		RDA: factorial method. Assumed an iron absorption of 18%	
Zinc[2,4]	Infants	RNI: factorial method applying studies from adults to back-calculate endogenous zinc losses. Presented requirements at different levels of absorption (15%, 30%, and 50%) for both age groups	RDA: factorial method applying studies from adults to back-calculate endogenous zinc losses. Assumed a zinc absorption of 30% for both age groups	PRI: factorial method applying studies from adults to back-calculate endogenous zinc losses. Assumed a zinc absorption of 30% for both age groups
	Young children			
Calcium[5,6]	Infants	RNI: factorial method. Assumed an absorption of 0.5 SD above the normal adult slope	AI: based on estimated intakes from breast milk and contribution from complementary foods, a calcium absorption of 60% and a calcium retention of 100 mg/d	PRI: factorial method. Assumed a calcium absorption of 60% but noted the uncertainty in factorial estimates for this age group
	Young children	RNI: factorial method. Assumed an absorption of 2 SD above the normal adult slope	RDA: factorial method. Assumed a calcium absorption of 46%	PRI: factorial method. Assumed a calcium absorption of 45% at this age
Magnesium[7,8]	Infants	AI: based on estimated intakes from breast milk and contribution from complementary foods	AI: based on estimated intakes from breast milk and contribution from complementary foods	AI: based on the midpoint of the range between the estimated intake based on extrapolating from breastfed 0–6 mo infants and the highest observed intakes in 7–12 mo infants
	Young children	RNI: based on a balance study in children suffering from protein energy malnutrition and undergoing rehabilitation	RDA: based on balance studies in older children and extrapolated based on body weight	AI: based on the midpoint of observed intakes from 4 EU countries
Phosphorus[7,9]	Infants	Not determined for populations under the age of 2 y	AI: based on estimated intakes from breast milk and contribution from complementary foods	AI: based on the AI for calcium and applying the calcium:phosphorus molar ratio of 1.4:1 to 1.9:1
	Young children		RDA: factorial method. Assumed a phosphorus absorption of 70%	AI: based on the calcium PRI and applying the calcium:phosphorus molar ratio of 1.4:1 to 1.9:1
Potassium[10,11]	Infants	Not determined for populations under the age of 2 y	AI: based on estimated intakes from breast milk and contribution from complementary foods	AI: extrapolated down from the adult AI on the basis of relative energy intakes and included a growth factor
	Young children		AI: based on the median intakes of US and Canadian children	AI: extrapolated down from the adult AI on the basis of relative energy intakes and included a growth factor
Sodium[10,12]	Infants	Not determined for populations under the age of 2 y	AI: based on estimated intakes from breast milk and contribution from complementary foods	AI: based on an upward extrapolation of exclusively breastfed infants from 0 to 6 mo

(Continued)

TABLE 3 (*Continued*)

Nutrient	Life stage*	WHO/FAO (2004)[1]	IOM DRIs	EFSA DRVs
	Young children		AI: extrapolated down from the adult AI based on rounded estimated energy requirements	AI: extrapolated down from the adult AI on the basis of relative energy intakes and included a growth factor

AI, adequate intake; DRV, dietary reference value; EFSA, European Food Standards Authority (Nutrition, Dietetics, and Allergies); EU, European; IOM, Institute of Medicine (Food and Nutrition Board); PRI, population reference intake; RNI, recommended nutrient intake.

*Infant is equivalent to WHO and IOM requirements for 7–12 mo; and EFSA for 7–11 mo. Young children are characterized by WHO, IOM, and EFSA as 1–3 y.

[1]WHO/FAO (2004) (30).

[2]DRIs for iron and zinc are from Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, iodine, iron, manganese, molybdenum, silicon, vanadium, and zinc (11).

[3]EFSA DRV for iron is from Scientific opinion on DRVs for iron (2015) (31).

[4]EFSA DRV for zinc is from Scientific opinion on DRVs for zinc (2014) (32).

[5]DRIs for calcium are from Dietary reference intakes for calcium and vitamin D (33).

[6]EFSA DRV for calcium is from Scientific opinion on DRVs for calcium (2015) (34).

[7]DRIs for magnesium and phosphorus are from Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride (35).

[8]EFSA DRV for magnesium is from Scientific opinion on DRVs for magnesium (2015) (36).

[9]EFSA DRV for phosphorus is from Scientific opinion on DRVs for phosphorus (2015) (37).

[10]DRIs for sodium and potassium are from Dietary reference intakes for sodium and potassium (38).

[11]EFSA DRV for potassium is from Scientific opinion on DRVs for potassium (2016) (39).

[12]EFSA DRV for sodium is from Scientific opinion on DRVs for sodium (2019) (40).

were calcium, iron, magnesium, phosphorus, potassium, zinc, vitamins A, B6, B12, C, D, and E, and folate; and the micronutrients of concern in terms of overconsumption were sodium, zinc, vitamin A, and folic acid.

Table 2 outlines the definitions and key terms used for discussing nutrient reference values. They vary considerably according to the authoritative source, highlighting the differences in approach and methodology used to derive reference values and ranges. Tables 3–6 provide the derivation methods and quantitative requirements for minerals and vitamins that were separately reviewed.

Table 7 shows a final set of proposed harmonized reference intake ranges for the micronutrients of concern during the complementary feeding period, which were based on combining and reconciling the recommendations from WHO/FAO, IOM, and EFSA. The key considerations in developing harmonized reference intake ranges for specific minerals and vitamins of concern are detailed below.

Minerals

The derivation methods used in setting requirements for the minerals of concern from WHO/FAO, IOM, and EFSA are shown in Table 3. For iron, zinc, and calcium, daily requirements established by the WHO/FAO (30) were based on the factorial method for both infants and young children, which accounts for mean body weight, median basal losses, and requirements for growth, including nutrient deposition. The quantitative requirements for minerals are shown in Table 4. Of the minerals, WHO/FAO provided values for iron and zinc that varied according to their bioavailability. For infants and young children, we selected the iron recommended nutrient intake (RNI) at a moderate bioavailability of 10% because this corresponded to a diet containing a high cereal and vegetable intake, associated with a high phytic acid content, and a low meat intake. In addition, the same bioavailability level was recommended for infants by all 3 organizations. All 3 organizations proposed a zinc absorption of 30%, corresponding to moderate bioavailability. We selected the EARs and ULs established by the IOM to define the minima and maxima for both iron and zinc. However, in the case of zinc,

the ULs had been based on data that was rounded twice during the derivation process (41); therefore, we applied the unrounded values in our study.

The factorial method was applied by WHO/FAO and EFSA (34) to derive calcium recommendations in both infants and young children. The IOM based their infant requirements for calcium on estimations of actual intake. As the AI from IOM was 35% lower than the RNI derived by the WHO/FAO, we applied the AI as a minimum value in the range for menu planning and applied the RNI as a target. For young children, the EAR developed by IOM was the same as the FAO/WHO RNI of 500 mg; we therefore applied the infant AI as a minimum (260 mg), and the ULs as maximum values.

Regarding magnesium, recommendations on infant requirements from all 3 organizations were based on estimations of intake. We selected the DRIs from the IOM (35) to define the range for young children, because the DRIs included an EAR and RDA. To ensure a consistent approach, we applied the magnesium AI for infants from IOM for that age group. There was insufficient information on either magnesium or phosphorus to allow us to establish a UL for infants and young children; furthermore, WHO/FAO had not published any requirements for phosphorus. Therefore, we applied the IOM AI to both age groups (35).

The recommendations for sodium intakes were recently updated by NASEM (38) and by EFSA (40). Considering that the EFSA AI for infants is lower than that from NASEM, we applied the former as the minimum for both infants and young children. There is no sodium UL for infants (<12 mo); we therefore applied the young children's AI from the DRIs as a maximum for infant diets. We applied the Chronic Disease Risk Reduction (CDRR) value of 1200 mg/d, from the recent DRIs for young children (38), as a maximum since it is lower than the UL. We selected the potassium AI from EFSA for young children, which was 800 mg/d (39), over the new AI from NASEM. Although this new AI of 2000 mg/d is considerably lower than the previous AI of 3000 mg/d (38), the EFSA AI might be more acheivable based on current intakes (18). For consistency, we selected the infant's potassium AI from EFSA for the infant age group.

TABLE 4 Reference values for minerals of concern for infants and young children as defined by WHO/FAO, IOM, and EFSA

| Nutrient | Life stage[2] | WHO/FAO[1] | | IOM DRIs | | | EFSA DRVs | |
		EAR	RNI	EAR	RDA or AI*	UL	AR	PRI or AI*
Iron, [8,9] mg/d	I	—	9.3[3]	6.9	11	40	8	11
	YC	—	5.8[3]	3	7	40	5	7
Zinc, [8,10] mg/d	I	0.6[4]	4.1	2.5	3	5.8	2.4	2.9
	YC	0.6[4]	4.1	2.5	3	8.4	3.6	4.3[6]
Calcium, [11,12] mg/d	I	—	400*	—	260*	1500	—	280*
	YC	—	500	500	700	2500	390	450*
Magnesium, [13,14] mg/d	I	—	54	—	75*	—	—	80*
	YC	—	60	65	80	65[7]	—	170*
Phosphorus, [13,15] mg/d	I	—	—	—	275*	—	—	160
	YC	—	—	380	460	3000	—	250
Potassium, [16,17] mg/d	I	—	—	—	860*	—	—	750
	YC	—	—	—	2000*	—	—	800
Sodium, [16,18,19] mg/d	I	—	—	—	370*	—	—	200
	YC	—	—	—	800*	1200	—	1100

AI, adequate intake; AR, average requirement; DRV, dietary reference value; EAR, estimated average requirement; EFSA, European Food Standards Authority (Nutrition, Dietetics, and Allergies); IAEA, International Atomic Energy Agency; IOM, Institute of Medicine (Food and Nutrition Board); PRI, population reference intake; RNI, recommended nutrient intake; UL, tolerable upper intake level.

— Not determinable due to insufficient data.

*Indicates an AI.

[1]WHO/FAO (2004) (30).

[2]I = older infants, corresponding to WHO/FAO and IOM requirements for 7–12 mo; and EFSA for 7–11 mo. YC = young child, characterized by WHO/FAO, IOM, and EFSA as 1–3 y.

[3]Indicates an iron bioavailability of 10%.

[4]The EAR for zinc was derived by the WHO/FAO and the IAEA (International Atomic Energy Agency) (42).

[5]Indicates a moderate bioavailability of 30% (30).

[6]EFSA have established a UL for zinc for young children of 7 mg/d (32).

[7]The UL for magnesium is only relevant to pharmacological agents (35).

[8]DRIs for iron and zinc are from Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, iodine, iron, manganese, molybdenum, silicon, vanadium, and zinc (11).

[9]EFSA DRV for iron is from Scientific opinion on DRVs for iron (2015) (31).

[10]EFSA DRV for zinc is from Scientific opinion on DRVs for zinc (2014) (32).

[11]DRIs for calcium are from Dietary reference intakes for calcium and vitamin D (33).

[12]EFSA DRV for calcium is from Scientific opinion on DRVs for calcium (2015) (34).

[13]DRIs for magnesium and phosphorus are from Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride (33).

[14]EFSA DRV for magnesium is from Scientific opinion on DRVs for magnesium (2015) (36).

[15]EFSA DRV for phosphorus is from Scientific opinion on DRVs for phosphorus (2015) (37).

[16]DRIs for sodium and potassium are from Dietary reference intakes for sodium and potassium (38).

[17]EFSA DRV for potassium is from Scientific opinion on DRVs for potassium (2016) (39).

[18]The recent DRIs consider the Chronic Disease Reduction Risk rather than a UL for sodium.

[19]EFSA DRV for sodium is from Scientific opinion on DRVs for sodium (2019) (40).

Vitamins

The approaches for defining vitamin A requirements for infants derived by the WHO/FAO and IOM were based on the intake of the vitamin from breast milk (Table 5). The WHO/FAO (30) took into account global differences in the vitamin A content of human breast milk, which varies according to maternal status. On the other hand, their approach for young children was either to establish requirements based on breast milk intake (WHO/FAO and EFSA approach) or extrapolate from adult requirements, while adjusting for metabolic body weight (IOM approach). EFSA (43) based the vitamin A requirements on the factorial approach, which resulted in a lower requirement (Table 6). The other point of difference between the vitamin A requirements from the WHO/FAO and EFSA, compared with those from the IOM, is that the former express vitamin A in terms of retinol equivalents (RE), whereas the latter express it in terms of retinol activity equivalents (RAE). The 2 units of expression differ quantitatively in the conversion factor for carotenoids (44). We selected the UL derived by IOM (13) as the maximum for menu

planning. The UL is only applicable to preformed vitamin A (retinol), whereas the EAR/RDA and AI apply to both pro- and preformed vitamin A.

Regarding vitamin D, the more recent recommendations published by IOM (33) and EFSA (45) indicated a daily intake of ≥10 μg/d to ensure maintenance of adequate serum 25-hydroxy vitamin D levels, defined as 50 nmol/L among infants. Therefore, we applied 10 μg/d as the minimum for infants. We disregarded the recommendations from WHO of 5 μg/d because they were outdated and therefore informed by less current science. We applied the UL for vitamin D as the maximum limit, and the IOM DRIs for vitamin D for young children (33). The requirement for vitamin E defined by WHO/FAO was characterized as being a best estimate, which is similar to the concept of an AI. That estimate was based on infant intakes of breast milk and was almost 50% lower than the IOM estimation, or AI, for vitamin E. The young child vitamin E requirement defined by WHO/FAO was based on the level needed to prevent oxidation of PUFAs. In contrast, the IOM requirement was extrapolated from data on 1 vitamin

TABLE 5 Description of methods for deriving vitamin requirements for infants and young children by WHO/FAO, IOM, and EFSA

Nutrient	Life stage[‡]	WHO/FAO (2004)[1]	IOM DRIs	EFSA DRVs
Vitamin A[2,3]	Infants	AI: termed a "safe intake level", it is based on the contribution from breast milk	AI: based on estimated intakes from breast milk and contribution from complementary foods	PRI: based on the factorial approach which considered the need to maintain a concentration of 20 µg retinol/g liver and applied a growth factor
	Young children	AI: based on the requirement of older breastfed infants	RDA: extrapolated down from adult requirements on the basis of metabolic body weight	PRI: as above
Vitamin D[4,5]	Infants	RNI: based on the IOM 1997 recommendations, established on maintaining plasma 25 (OH)D levels above 27 nmol/L	AI: based on maintaining a serum 25(OH)D above 50 nmol/L, which is associated with good bone mineralization	AI: based on maintaining a serum 25(OH)D above 50 nmol/L
	Young children	RNI: as above	RDA: as above	AI: as above
Vitamin E[6,7]	Infants	AI: based on the contribution from breast milk	AI: extrapolated up from younger breastfed infant requirements on the basis of the metabolic body weight ratio and included a variability factor	AI: extrapolated up from younger breastfed infant requirements on the basis of the metabolic body weight ratio
	Young children	RNI: based on prevention of oxidation of PUFAs	RDA: extrapolated down from adults and adjusted for metabolic body weight and growth	AI: based on the midpoints of the range of mean intakes and rounded
Vitamin C[6,8]	Infants	RNI: arbitrarily set higher than the level required to prevent scurvy (8 mg/d)	AI: based on the estimated intake from breast milk and the contribution from complementary foods	PRI: established by the SCF (1993), it is based on 3 times the level required to prevent scurvy
	Young children	RNI: as above	RDA: extrapolated down from adult requirements on the basis of body weight	PRI: extrapolated down from adult requirements on the basis of body weight and applied a CV of 10%
Vitamin B6[9,10]	Infants	AI: based on the recommendations of the FNB	AI: based on the average of 2 extrapolation approaches, applying the metabolic body weight ratio to extrapolate up from younger breastfed infant AIs and down from the adult AIs and applying a growth factor	AI: based on the average of 2 extrapolation approaches, applying the metabolic body weight ratio to extrapolate up from younger breastfed infant ARs and down from the adult ARs and applying a growth factor
	Young children	RNI: As above	RDA: extrapolated down from adult requirements on the basis of the metabolic body weight ratio method and applying a growth factor and a CV of 10%	PRI: extrapolated down from adult requirements on the basis of the metabolic body weight ratio method and applying a growth factor and a CV of 10%
Folate[9,11]	Infants	AI: based on the recommendations of the FNB	AI: extrapolated up from younger breastfed infant requirements on the basis of the metabolic body weight ratio	AI: extrapolated up from younger breastfed infant requirements on the basis of the metabolic body weight ratio
	Young children	RNI: as above	RDA: extrapolated down from adult requirements on the basis of the metabolic body weight ratio and applied a CV of 10%	PRI: extrapolated down from adult requirements on the basis of the metabolic body weight ratio and applied a growth factor

(*Continued*)

TABLE 5   (*Continued*)

Nutrient	Life stage[‡]	WHO/FAO (2004)[1]	IOM DRIs	EFSA DRVs
Vitamin B12[9,12]	Infants	AI: based on the upper end of breast milk concentrations	AI: extrapolated up from younger breastfed infant requirements on the basis of the metabolic body weight ratio	AI: extrapolated down from adult requirements on the basis of the metabolic body weight ratio method and applying a growth factor
	Young children	RNI: based on the recommendations of the FNB	RDA: extrapolated down from adult requirements on the basis of the metabolic body weight ratio	AI: extrapolated down from adult requirements on the basis of the metabolic body weight ratio and applied a growth factor

AI, adequate intake; AR average requirement; DRV, dietary reference value; EFSA, European Food Standards Authority (Nutrition, Dietetics, and Allergies); FNB, Food and Nutrition Board; IOM, Institute of Medicine (FNB); PRI, population reference intake; RNI, recommended nutrient intake; SCF, Scientific Committee for Food; 25(OH)D, 25-hydroxy vitamin D.

[‡]Infant is equivalent to WHO and IOM requirements for 7–12 mo; and EFSA for 7–11 mo. Young children are characterized by WHO, IOM, and EFSA as 1–3 y.

[1]WHO/FAO (2004) (30).

[2]DRIs for vitamin A is from Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, iodine, iron, manganese, molybdenum, silicon, vanadium, and zinc (11).

[3]EFSA DRVs for vitamin A are from Scientific opinion on DRVs for vitamin A (2015) (43).

[4]DRIs for vitamin D are from Dietary reference intakes for calcium and vitamin D (33).

[5]EFSA DRVs for vitamin D are from Scientific opinion on DRVs for vitamin D (2016) (45).

[6]DRIs for vitamin E are from Dietary reference intakes for vitamin C, vitamin E, selenium, and carotenoids (46).

[7]EFSA DRVs for vitamin E are from Scientific opinion on DRVs for vitamin E (2015) (47).

[8]EFSA DRVs for vitamin C are from Scientific opinion on DRVs for vitamin C (2013) (48).

[9]DRIs for vitamin B6, folate, and vitamin B12 are from Dietary reference intakes for thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, pantothenic acid, biotin, and choline (49).

[10]EFSA DRVs for vitamin B6 are from Scientific opinion on DRVs for vitamin B6 (2016) (50).

[11]EFSA DRVs for vitamin folate are from Scientific opinion on DRVs for folate (2014) (51).

[12]EFSA DRVs for vitamin B12 are from Scientific opinion on DRVs for vitamin B12 (2015) (44).

E-depleted population of adult males, which had been corrected for growth and metabolic body weight (46). The IOM DRIs for adequacy have been criticized as being too high (52), but at 6 mg/d the EFSA requirement for young children is the same, although it is based on observed intakes (47). We therefore set the WHO/FAO reference value as a minimum.

The WHO/FAO and EFSA (48) approaches for deriving vitamin C requirements were similar in that both organizations considered a level higher than that needed to prevent scurvy (i.e., frank deficiency). We selected the RNIs developed by WHO/FAO as the minima for infants and young children, both being 30 mg/d. The 3 organizations applied similar approaches for deriving the requirements for vitamin B6 and folate, and the published requirements were almost the same. The WHO/FAO (30) recommendation for vitamin B12 intake in infants was based on the upper end of human breast milk concentrations, whereas the IOM requirements were based on average breast milk concentrations of the vitamin (49). Given the more conservative approach of the IOM, we selected their vitamin B12 reference values. The young child requirements for vitamin B12 had been extrapolated from adult requirements and were consistent across the 3 organizations. As with many of the nutrient requirements for infants, there were no EAR/RDAs available for the vitamins mentioned here – only an AI. In such cases, we applied the AI as a minimum requirement (53).

Based on the results above, we have proposed reference ranges for the micronutrients of concern, which can be applied to dietary guidance and used as menu planning ranges during the complementary feeding period. A summary of our proposals is in Table 7.

Discussion

The micronutrients of concern that we have identified on the basis of our review of the selected dietary surveys were consistent with those identified by key international organizations. The CCNFSDU determined that, worldwide, the most common shortfall micronutrients among infants and children aged 6 to 36 mo were iron, zinc, calcium, iodine, and vitamins A and D (6). The critical gap micronutrients identified by the EFSA-NDA (2013), during complementary feeding in Europe, were iron, vitamin D, and in some regions, iodine (7). Among infants and young children receiving the US Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), the micronutrients of concern (nutrients to be increased) recognized by a 2017 report from the NASEM included iron, zinc, calcium, vitamin D, and potassium (8).

When addressing micronutrients of concern in menu plans or dietary guidance, it is advisable to stay within a range of reference values such that the distribution of usual intakes is between minimum (i.e., the EAR) and maximum (i.e., the UL) recommended values (54). However, we consider that it is also useful to include a target value (i.e., the RDA/RNI). Having a range avoids the risk of potentially inadequate or excessive intakes (28, 29, 55), but having a target value avoids the resulting menu or guidance being too close to the extremes. That said, in the case of infants and young children, target values only exist for a limited number of micronutrients, iron, zinc, and calcium being among them. The other micronutrients of concern have only AIs, based on estimations of intake, which are often culture-bound, unlikely to reflect true physiological requirements, and more likely to be changed over time

TABLE 6 Nutrient reference values as defined by WHO/FAO, IOM, and EFSA of the vitamins of concern for infants and young children

| Nutrient | Life stage[‡] | WHO/FAO[1] | | IOM DRIs | | | EFSA DRVs | | |
		EAR[§]	RNI or AI*	EAR	RDA or AI*	UL	AR	PRI or AI*	UL
Vitamin A, [2,3,4] μg/d	I	190	400	—	500	600[5]	190	250	—
	YC	200	400	210	300	600[5]	205	250	800
Vitamin D, [6,7] μg/d	I	—	5	—	10*	37.5	—	10*	25
	YC	—	5	—	10	62.5	—	15*	25
Vitamin E, [8,9] mg/d	I	—	2.7*	—	5*	—	—	5*	—
	YC	—	5*	5	6	200	—	6*	100
Vitamin C, [8,10] mg/d	I	—	30*	—	50*	—	—	20*	—
	YC	25[§]	30	13	15	400	15	20	—
Vitamin B6, [11,12] μg/d	I	—	0.3		0.3*	—	—	0.38*	—
	YC	0.4[§]	0.5	0.4	0.5	30	0.5	0.6	5
Folate (DFE), [11,13] μg/d	I	—	80*	—	80*	—	—	80*	—
	YC	133[§]	150	120	150	300[14]	90	120	5
Vitamin B12, [11,15] μg/d	I	—	0.7*	—	0.5*	—	—	1.5*	—
	YC	0.8[§]	0.9	0.7	0.9	400	—	1.5*	—

AI, adequate intake; AR, average requirement; DFE, dietary folate equivalents; DRV, dietary reference value; EAR, estimated average requirement; EFSA, European Food Standards Authority (Nutrition, Dietetics, and Allergies); IOM, Institute of Medicine (Food and Nutrition Board); PRI, population reference intake; RNI, recommended nutrient intake; UL, tolerable upper intake level.

*Indicates an AI.

— Not determinable due to insufficient data.

[‡]I = older infants, corresponding to WHO/FAO and IOM requirements for 7–12 mo; and EFSA for 7–11 mo. YC = young child, characterized by WHO/FAO, IOM, and EFSA as 1–3 y.

[§]The EARs from WHO/FAO were back calculated based on the EAR + 2(SD) = RNI, assuming a normal distribution and a CV of 10.

[1]WHO/FAO (2004) (30).

[2]Vitamin A is expressed as retinol equivalents (RE) by WHO and EFSA and retinol activity equivalents (RAE) by the IOM. The units differ in terms of the conversion of β-carotene (44).

[3]DRIs for vitamin A are from Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, iodine, iron, manganese, molybdenum, silicon, vanadium, and zinc (11).

[4]EFSA DRVs for vitamin A are from Scientific opinion on DRVs for vitamin A (2015) (43).

[5]The UL for vitamin A is only applicable to retinol (13).

[6]DRIs for vitamin D are from Dietary reference intakes for calcium and vitamin D (33).

[7]EFSA DRVs for vitamin D are from Scientific opinion on DRVs for vitamin D (2016) (45).

[8]DRIs for vitamin E and vitamin C are from Dietary reference intakes for vitamin C, vitamin E, selenium, and carotenoids (46).

[9]EFSA DRVs for vitamin E are from Scientific opinion on DRVs for vitamin E (2015) (47).

[10]EFSA DRVs for vitamin C are from Scientific opinion on DRVs for vitamin C (2013) (48).

[11]DRIs for vitamin B6, folate, and vitamin B12 are from Dietary reference intakes for thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, pantothenic acid, biotin, and choline (49).

[12]EFSA DRVs for vitamin B6 are from Scientific opinion on DRVs for vitamin B6 (2016) (50).

[13]EFSA DRVs for folate are from Scientific opinion on DRVs for folate (2014) (51).

[14]The UL for folate is only for folic acid (49).

[15]EFSA DRVs for vitamin B12 are from Scientific opinion on DRVs for vitamin B12 (2015) (44).

than other reference amounts like the EAR/RDA. In the case that a recommendation is based exclusively on the AI, usual intakes for a given population should be greater than or equal to the AI and less than the UL (53). ULs were originally issued because of the increased availability of and concern regarding possible excessive intakes due to the addition of fortificants and dietary supplements to usual diets (49). The derivation of ULs takes into account an uncertainty factor, which involves a considerable amount of judgment, leading some to criticize the value as being arbitrary and potentially too low (55). For example, in the case of zinc, the safety range between the EAR and the UL is only a factor of 4, creating a narrow range between possible adequacy and excess (56). In the case of zinc, the ULs were based on a single clinical trial (41). However, we concluded that zinc should be included to meet the RNI, while avoiding excess as it may impair copper absorption. Therefore, we applied the unrounded ULs as maxima in our study. Apart from zinc, it is unlikely that infants and young children would exceed intakes of most micronutrients on a chronic basis, considering their modest daily energy allowance from complementary foods, unless dietary supplements were being taken. The exception to this is sodium: in most of the studies reviewed, it was consumed to excess, especially among young children.

Excessive exposure to sodium at an early age is potentially harmful as it may facilitate the development of a preference for salt that persists into later life (57) and it is associated with potential to increase blood pressure in salt-sensitive individuals, even in childhood (58). Although sodium may have important technical and food safety functions within many foods, it is desirable that complementary foods and menu plans targeted to early childhood limit unnecessary sodium. This can be achieved by the provision of complementary food with minimal added sodium, which is important considering the relevant amounts of intrinsic sodium occurring in many foods, such as certain vegetables, fish, and milk-based products (59).

A food-based approach for improving micronutrient intakes is generally favored by experts because it ensures the provision of nutrients while teaching children how to consume and enjoy a varied diet (60). The food-based approach requires consideration of the most limiting

TABLE 7 Harmonized reference intake ranges for the micronutrients of concern based on combining recommendations from WHO/FAO, IOM, and EFSA

Nutrient	Infants (6–11 mo)			Young children (12–23 mo)		
	Min[a]	Target[b]	Max[c]	Min[a]	Target[b]	Max[c]
Iron, mg/d	6.9[1]	9.3[2]	40[1]	3[1]	5.8[2]	40[2]
Zinc, mg/d	2.5[1]	4.1[2]	5.8[1]	2.5[1]	4.1[2]	8.4[1]
Calcium, mg/d	260[1]	400[3]	1500[1]	260[1]	500[3]	2500[1]
Magnesium, mg/d	75[4]	—	ND	65[4]	80[4]	ND
Phosphorus, mg/d	275[4]	—	ND	380[4]	460[4]	3000[4]
Potassium, mg/d	750[5]	—	ND	800[5]	—	ND
Sodium, mg/d	200[6]	370[7]	800[7]	200[6]	800[7]	1200[7]
Vitamin A, μg/d	400[2]	—	600[1]	400[2]	—	600[1]
Vitamin D, μg/d	10[3]	—	37.5[3]	10[3]	—	62.5[3]
Vitamin E, mg/d	2.7[2]	—	ND	5[2]	—	200[8]
Vitamin C, mg/d	30[2]	—	ND	30[2]	—	400[8]
Folate (DFE), μg/d	80[2]	—	ND	133[2]	150[2]	300[9]
Vitamin B6, mg/d	0.3[2]	—	ND	0.5[2]	—	30[9]
Vitamin B12, μg/d	0.5[9]	—	ND	0.8[9]	0.9[9]	300[9]

AI, adequate intake; DFE, dietary folate equivalents; DRV, dietary reference value; EAR, estimated average requirement; EFSA, European Food Standards Authority (Nutrition, Dietetics, and Allergies); IOM, Institute of Medicine; ND, not determinable (due to insufficient data); PRI, population reference intake; RNI, recommended nutrient intake; UL, tolerable upper intake level.
*Indicates an AI.
[a]The minimum values correspond to an EAR or an AI.
[b]The target values refers to an RNI/RDA/PRI except for sodium.
[c]The maximum values correspond to a UL.
[1]DRIs for iron and zinc are from Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, iodine, iron, manganese, molybdenum, silicon, vanadium, and zinc (11).
[2]WHO/FAO (2004) (30).
[3]DRIs for calcium and vitamin D are from Dietary reference intakes for calcium and vitamin D (33).
[4]DRIs for magnesium and phosphorus are from Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride (35).
[5]EFSA DRV for potassium is from Scientific opinion on DRVs for potassium (2016) (39).
[6]The minimum requirements for sodium are the infant AI from the recently updated EFSA DRVs (2019) (41).
[7]DRIs for sodium are from Dietary reference intakes for sodium and potassium (38).
[8]DRIs for vitamins E and C are from Dietary reference intakes for vitamin C, vitamin E, selenium, and carotenoids (46).
[9]DRIs for vitamin B6, folate, and vitamin B12 are from Dietary reference intakes for thiamin, riboflavin, niacin, vitamin B6, folate, vitamin B12, pantothenic acid, biotin, and choline (49).

micronutrients in the diet and ensuring the provision of foods naturally rich in those nutrients, such as meat (a source of iron and zinc), and specific fruit and vegetables (sources of potassium, magnesium, folate, and vitamin C) (59). Nevertheless, it is unlikely that nutrient-dense foods can fulfil all requirements, especially in the case of achieving iron adequacy for breastfed infants (61). In such cases, fortificants and dietary supplements must be considered since they add micronutrients without contributing energy. This is particularly important for specific nutrients that are difficult to obtain from contemporary dietary patterns, in particular, vitamin D (62, 63). It also applies to infants who are not exposed to, or have limited access to, adequate dietary variety, such as those from low-resource households (64). The same applies to vitamins A, B6, and B12 in the case of breastfed infants of mothers whose intakes of these vitamins are low or deficient because the breast milk concentrations of these vitamins depend on maternal intake and status, and are known to be highly variable (65). In all cases, the micronutrients of concern for the specific population should be identified using relevant dietary intake surveys. Simulated menu plans could be derived that include naturally nutrient-rich and fortified complementary foods so as to target the micronutrient ranges identified in our review.

We accept there are some limitations to our study. First, it is feasible that by restricting our literature search to publications in English (except for 1 article in Russian) we may have missed some dietary intake studies. However, we consider it is unlikely that any additional studies would have revealed new micronutrient deficiencies or excesses not identified by our review.

Second, inconsistent methodologies have been applied in the dietary surveys we considered. Four of the 6 surveys did not consider the use of dietary supplements, which may result in underestimation of some micronutrient intakes. The surveys from China and Russia were based on 1 d of intake only, and therefore the usual intakes of children in those countries could not be assessed. The population sampled for the study in China was not nationally representative, although the remaining 5 studies did claim to be nationally representative. Furthermore, the age ranges reported were not consistently in the age range of 12 to 24 mo; the Mexican study in particular reported intakes for children aged 1 to 4 y (25), which hinders the accuracy of assessment of the micronutrient status in that country. The European CHOP study applied a 3-d weighed food records approach to determine micronutrient intake; the remaining 5 studies applied a 24-h recall, which may have resulted in overestimation of food and nutrient intakes (66). There is generally a lack of recent nationally representative dietary intake surveys among infants and young children. Ideally, a more rigorous assessment of micronutrient status should be carried out, e.g., by applying the European

Micronutrient Recommendations Aligned Network of Excellence (EU-RRECA) method, which enables analysis of aggregated data from multiple studies (67). One study applying the EURRECA method among children aged 1 to 3 y from populous countries (68) reported a prevalence of inadequacy higher than 20% for vitamins A, D, and E, as well as calcium overall, and, specifically in the case of Germany, for folate. Our study results include these micronutrients, but we have extended the list to include vitamins B6 and B12, magnesium, and potassium as at risk of low intakes.

The exclusion of iodine is a third limitation of our study. Iodine has been highlighted as a shortfall micronutrient in specific regions because of different soil quality as well as variability in salt iodization programs (69, 70). Although universal salt iodization is the most practical way to minimize iodine deficiency, it should be recognized that complementary foods should limit added salt (2, 9). The iodine concentration of foods is highly variable within and between countries, and therefore it needs to be dealt with on an individual country/population basis. Based on this rationale – and because our ultimate objective was to apply the micronutrient requirements to universal complementary feeding guidance and menu plans – we decided to exclude iodine from our study. Nevertheless, despite the above limitations in surveys across geographical areas, there was a general consistency in identifying iron, zinc, calcium, folate, and vitamins A and D as commonly underconsumed.

A fourth limitation to our work relates to the fact that the nutrient values and recommendations (from the major organizations) that we used to derive our final results have some level of uncertainty, notably because of their lack of data for infants and young children (71). In many instances, the reference values had been extrapolated from data on adults, who have different micronutrient economies and needs to infants and young children. Furthermore, most of the national and international recommendations for intake are rather dated and need to be revisited and/or revised as more recent and pertinent scientific data becomes available.

Despite the above limitations, we believe our review has particular merit in providing a first set of harmonized nutrient reference ranges for the complementary feeding period, based on the best existing reference values, and for micronutrients of concern, identified from the largest and most extensive dietary intake surveys available. Micronutrient deficits or excesses during the complementary feeding period can be detrimental and may have lifelong repercussions on physical and mental development (72). Our analysis provides a timely summary of existing requirements for the key micronutrients, regardless of the authoritative guideline that is applied. Such micronutrient ranges are critical for the development of practical, science-based dietary guidance to support the health of infants and young children.

Acknowledgments

References

1. Pan American Health Organization (World Health Organization). Guiding Principles for Complementary Feeding of the Breastfed Child. Washington (DC): PAHO/WHO; 2003.
2. Fewtrell M, Bronsky J, Campoy C, Domellof M, Embleton N, Fidler Mis N, Hojsak I, Hulst JM, Indrio F, Lapillonne A, et al. Complementary feeding: a position paper by the European Society for Paediatric Gastroenterology, Hepatology, and Nutrition (ESPGHAN) Committee on Nutrition. J Pediatr Gastroenterol Nutr 2017;64:119–32.
3. Motee A, Jeewon R. Importance of exclusive breastfeeding and complementary feeding among infants. Curr Res Nutr Food Sci 2014;2: 56–72.
4. Joint FAO/WHO Food Standards Committee: Codex Committee on Nutrition and Foods for Special Dietary Use. Report of the thirty-sixth session of the Codex Committee on Nutrition and Foods for Special Dietary Use: Review of the Standard for Follow-up Formula. Bali, Indonesia: Codex Alimentarius Commission; 2014. p. 90–107.
5. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on nutrient requirements and dietary intakes of infants and young children in the European Union. EFSA J 2013;11:3408.
6. National Academies of Sciences, Engineering, and Medicine. Review of WIC Food Packages: Improving Balance and Choice: Final Report. Washington, DC: The National Academies Press; 2017.
7. Butte N, Cobb K, Dwyer J, Graney L, Heird W, Rickard K. The start healthy feeding guidelines for infants and toddlers. J Am Diet Assoc 2004;104: 442–54.
8. World Health Organization. Infant and Young Child Feeding: Model Chapter for Textbooks for Medical Students and Allied Health Professionals. Geneva: WHO; 2009.
9. Vossenaar M, Solomons NW. The concept of "critical nutrient density" in complementary feeding: the demands on the "family foods" for the nutrient adequacy of young Guatemalan children with continued breastfeeding. Am J Clin Nutr 2012;95:859–66.
10. McLean E, Cogswell M, Egli I, Wojdyla D, de Benoist B. Worldwide prevalence of anaemia, WHO vitamin and mineral nutrition information system, 1993–2005. Public Health Nutr 2009;12:444–54.
11. Dewey KG, Chaparro CM. Session 4: mineral metabolism and body composition iron status of breast-fed infants. Proc Nutr Soc 2007;66: 412–22.
12. Institute of Medicine (Food and Nutrition Board). Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Washington, (DC): The National Academies Press; 2001.
13. Dewey KG. The challenge of meeting nutrient needs of infants and young children during the period of complementary feeding: an evolutionary perspective. J Nutr 2013;143:2050–4.
14. Greer FR. How much iron is needed for breastfeeding infants? Curr Pediatr Rev 2015;11:298–304.
15. Allen LH, Carriquiry AL, Murphy SP. Perspective: proposed harmonized nutrient reference values for populations. Adv Nutr 2019, doi: 10.1093/advances/nmz096. [Epub ahead of print].
16. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Info Libr J 2009;26(2):91–108.
17. World Population Review. Total Population by Country. Walnut, CA: World Population Review; 2018. Available from: www.worldpopulationreview.com.
18. Bailey RL, Catellier DJ, Jun S, Dwyer JT, Jacquier EF, Anater AS, Eldridge AL. Total usual nutrient intakes of U.S. children (under 48 months): findings from the Feeding Infants and Toddlers Study (FITS) 2016. J Nutr 2018;148: 1557s–66s.
19. Rivera JA, Pedraza LS, Aburto TC, Batis C, Sánchez-Pimienta TG, González de Cosío T, López-Olmedo N, Pedroza-Tobías A. Overview of the dietary intakes of the Mexican population: results from the National Health and Nutrition Survey 2012. J Nutr 2016;146:1851S–5S.
20. Chen C, Denney L, Zheng Y, Vinyes-Pares G, Reidy K, Wang H, Wang P, Zhang Y. Nutrient intakes of infants and toddlers from maternal and child

care centres in urban areas of China, based on one 24-hour dietary recall. BMC Nutr 2015;1:1–23.

21. Denney L, Angeles-Agdeppa I, Capanzana MV, Toledo MB, Donohue J, Carriquiry A. Nutrient intakes and food sources of Filipino infants, toddlers and young children are inadequate: findings from the National Nutrition Survey 2013. Nutrients 2018;10:1730.

22. United Nations Statistics Divison. Infant Mortality Rate, for Both Sexes Combined (infant deaths per 1,000 live births). New York: United Nations; 2019. Available from: http://data.un.org/Data.aspx?d = PopDiv&f = variableID%3A77.

23. Martinchik AN, Baturin AK, Fatyanova LN, Netrebenko OK, Ukraintsev SE, Bazarova LB, Semenova IA. Infant feeding practices in Russia: Federal State Statistics Service's Analysis. Voprosy Detskoy Dietologii (Pediatric Nutrition) 2017;15:5–11.

24. Zaragoza-Jordana M, Closa-Monasterolo R, Luque V, Ferre N, Grote V, Koletzko B, Pawellek I, Verduci E, ReDionigi A, Socha J, et al. Micronutrient intake adequacy in children from birth to 8 years. Data from the Childhood Obesity Project. Clin Nutr 2018;37:630–7.

25. Piernas C, Miles DR, Deming DM, Reidy KC, Popkin BM. Estimating usual intakes mainly affects the micronutrient distribution among infants, toddlers and pre-schoolers from the 2012 Mexican National Health and Nutrition Survey. Public Health Nutr 2016;19:1017–26.

26. Sanchez-Pimienta TG, Lopez-Olmedo N, Rodriguez-Ramirez S, Garcia-Guerra A, Rivera JA, Carriquiry AL, Villalpando S. High prevalence of inadequate calcium and iron intakes by Mexican population groups as assessed by 24-hour recalls. J Nutr 2016;146:1874s–80s.

27. Pedroza-Tobias A, Hernandez-Barrera L, Lopez-Olmedo N, Garcia-Guerra A, Rodriguez-Ramirez S, Ramirez-Silva I, Villalpando S, Carriquiry A, Rivera JA. Usual vitamin intakes by Mexican populations. J Nutr 2016;146:1866S–73S.

28. Institute of Medicine (Food and Nutrition Board). Dietary Reference Intakes: Applications in Dietary Assessment. Washington, DC: The National Academies Press; 2000.

29. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on principles for deriving and applying dietary reference values. EFSA J 2010;8:1458.

30. World Health Organization and Food and Agriculture Organization of the United Nations. Vitamin and Mineral Requirements in Human Nutrition: Report of a Joint FAO/WHO Expert Consultation. Second edition. Geneva: WHO; 2004.

31. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for iron. EFSA J 2015;13:4254.

32. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for zinc. EFSA J 2014;12:3844.

33. Institute of Medicine (Food and Nutrition Board). Dietary Reference Intakes for Calcium and Vitamin D. Washington (DC): National Academies Press; 2011.

34. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for calcium. EFSA J 2015;13:4101.

35. Institute of Medicine (Food and Nutrition Board). Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride. Washington (DC): National Academies Press (U.S.); 1997.

36. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for magnesium. EFSA J 2015;13:4186.

37. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for phosphorus. EFSA J 2015;13:4185.

38. National Academies of Sciences, Engineering, and Medicine. Dietary Reference Intakes for Sodium and Potassium. Washington (DC): National Academies Press; 2019.

39. EFSA Panel on Dietetic Products, Nutrition and Allergies. Dietary reference values for potassium. EFSA J 2016;14:4592.

40. EFSA Panel on Dietetic Products, Nutrition and Allergies. Dietary reference values for sodium. EFSA J 2019;17:5778.

41. Zlotkin S. A critical assessment of the upper intake levels for infants and children. J Nutr 2006;136:502s–6s.

42. World Health Organization/Food and Agriculture Organization/ International Atomic Energy Association. Trace Elements in Human Health and Nutrition. Geneva, Switzerland: World Health Organization; 1996.

43. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for vitamin A. EFSA J 2015;13:4028.

44. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for cobalamin (vitamin B12). EFSA J 2015;13:4150.

45. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for vitamin D. EFSA J 2016;14: 4547.

46. Institute of Medicine (Food and Nutrition Board). Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium and Carotenoids. Washington (DC): National Academies Press; 2000.

47. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for vitamin E as α-tocopherol. EFSA J 2015;13:4149

48. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for vitamin C. EFSA J 2013;11:3418.

49. Institute of Medicine (Food and Nutrition Board). Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline. Washington (DC): National Academies Press (U.S.); 1998.

50. EFSA Panel on Dietetic Products, Nutrition and Allergies. Dietary reference values for vitamin B6. EFSA J 2016;14:4485.

51. EFSA Panel on Dietetic Products, Nutrition and Allergies. Scientific opinion on dietary reference values for folate. EFSA J 2014;12:3893.

52. Butte NF, Fox MK, Briefel RR, Siega-Riz AM, Dwyer JT, Deming DM, Reidy KC. Nutrient intakes of US infants, toddlers, and preschoolers meet or exceed dietary reference intakes. J Am Diet Assoc 2010;110(12 Suppl): S27–37.

53. Barr SI. Applications of dietary reference intakes in dietary assessment and planning. Appl Physiol Nutr Metab 2006;31:66–73.

54. Trumbo PR, Yates AA, Schlicker-Renfro S, Suitor C. Dietary reference intakes: revised nutritional equivalents for folate, vitamin E and provitamin A carotenoids. J Food Comp Anal 2003;16:379–82.

55. National Academies of Sciences, Engineering, and Medicine. Global Harmonization of Methodological Approaches to Nutrient Intake Recommendations: Proceedings of a Workshop. Washington (DC): National Academies Press; 2018.

56. Dwyer JT, Wiemer KL, Dary O, Keen CL, King JC, Miller KB, Philbert MA, Tarasuk V, Taylor CL, Gaine PC, et al. Fortification and health: challenges and opportunities. Adv Nutr 2015;6:124–31.

57. Stein LJ, Cowart BJ, Beauchamp GK. The development of salty taste acceptance is related to dietary experience in human infants: a prospective study. Am J Clin Nutr 2012;95:123–9.

58. Lava SA, Bianchetti MG, Simonetti GD. Salt intake in children and its consequences on blood pressure. Pediatr Nephrol 2015;30:1389–96.

59. U.S. Department of Agriculture, Agricultural Research Service. FoodData Central. Beltsville: USDA; 2019. Available from: fdc.nal.usda.gov.

60. Allen LH. To what extent can food-based approaches improve micronutrient status? Asia Pac J Clin Nutr 2008;17:103–5.

61. Dube K, Schwartz J, Mueller MJ, Kalhoff H, Kersting M. Iron intake and iron status in breastfed infants during the first year of life. Clin Nutr 2010;29: 773–8.

62. Braegger C, Campoy C, Colomb V, Decsi T, Domellof M, Fewtrell M, Hojsak I, Mihatsch W, Molgaard C, Shamir R, et al. Vitamin D in the healthy European paediatric population. J Pediatr Gastroenterol Nutr 2013;56: 692–701.

63. Golden NH, Abrams SA. Optimizing bone health in children and adolescents. Pediatr 2014;134:1229–43.

64. Kirby M, Danner E. Nutritional deficiencies in children on restricted diets. Pediatr Clin 2009;56:1085–103.

65. Dror DK, Allen LH. Overview of nutrients in human milk. Adv Nutr 2018;9(suppl.1):278S–94S.

66. Fisher JO, Butte NF, Mendoza PM, Wilson TA, Hodges EA, Reidy KC, Deming D. Overestimation of infant and toddler energy intake by 24-h recall compared with weighed food records. Am J Clin Nutr 2008;88(2): 407–15.

67. Roman Viñas B, Ribas Barba L, Ngo J, Gurinovic M, Novakovic R, Cavelaars A, de Groot LCPGM, van't Veer P, Matthys C, Serra Majem L. Projected prevalence of inadequate nutrient intakes in Europe. Ann Nutr Metab 2011;59(2–4):84–95.

68. Hilger J, Goerig T, Weber P, Hoeft B, Eggersdorfer M, Carvalho NC, Goldberger U, Hoffman K. Micronutrient intake in healthy toddlers: a multinational perspective. Nutrients 2015;7(8):6938–55.

69. Zimmermann MB. Iodine deficiency in industrialized countries. Clin Endocrinol 2011;75:287–8.

70. Muthayya S, Rah JH, Sugimoto JD, Roos FF, Kraemer K, Black RE. The global hidden hunger indices and maps: an advocacy tool for action. PLoS One 2013;8:e67860.

71. National Academies of Sciences, Engineering, and Medicine. Harmonization of Approaches to Nutrient Reference Values: Applications to Young Children and Women of Reproductive Age. Washington (DC): National Academies Press; 2018.

72. Bailey RL, West KP, Jr, Black RE. The epidemiology of global micronutrient deficiencies. Ann Nutr Metab 2015;66:22–33.