

Estimated vitamin intakes of toddlers: predicted prevalence of inadequacy in village populations in Egypt, Kenya, and Mexico¹⁻³

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ABSTRACT Vitamin intakes of 255 toddlers (aged 18-30 mo) were estimated from food consumption recorded during 1 y at sites in Egypt, Kenya, and Mexico. Mean intakes were compared with requirements standards by using a probability approach to estimate the prevalence of inadequate intakes. There were predicted inadequacies for vitamin A (32%) and riboflavin (20%) in Egypt, vitamins A (68%) and C (63%) and riboflavin (52%) in Mexico, and vitamin B-12 (44%) in Kenya. Vitamin E was inadequate in all diets, but in relation to polyunsaturated fatty acids only the intake in Mexico was low. No diet provided the recommended amount of vitamin D, but its dietary requirement is uncertain. Correlations among nutrient intakes suggest factors that may contribute to reported associations of consumption of animal products with improved growth or development among these children: provision of vitamin B-12 and available minerals, displacement of fiber and phytate-rich energy sources, and increased energy density. *Am J Clin Nutr* 1993;58:376-84.

KEY WORDS Dietary surveys, toddlers, vitamin intake, B vitamins, fat-soluble vitamins, vitamin C, niacin-tryptophan, minerals, animal products

Introduction

Malnutrition is a persistent problem among poverty-level populations everywhere (1). Barring famine caused by natural disasters and warfare, however, the majority of people affected experience mild-to-moderate nutritional deprivation, which is reflected more in stunting than in wasting. Currently, international attention has shifted from the broad issue of food sufficiency to that of food quality, focusing predominantly on three micronutrients: vitamin A, iron, and iodine. There are serious deficiencies of each of these nutrients in several locations worldwide: the consequences of deficiency have high individual and societal costs and specific preventive measures are available (1). Although special emphasis on these deficiencies is thus justified, strategies for remediation deserve further thoughtful consideration.

The populations now demonstrably affected by lacks of vitamin A, iron, and/or iodine are generally poor and subsist on limited diets. Such diets almost surely are low in not one but an array of nutrients. Intervention strategies that deliver a single micronutrient are therefore unlikely to be sufficient in that the

effects of associated nutrient deficiencies are unchecked. More efficient strategies could be devised if the risks of deficiency of the wider array of nutrients were known.

Field studies carried out in Egypt, Kenya, and Mexico under a collaborative research support program (the Nutrition CRSP) have provided data that allow examination of diets for the probability of nutrient inadequacies. The design of the multiinstitutional research program has been presented elsewhere (2). Briefly, in each country binational teams of investigators established a study site, one or a cluster of adjacent communities likely to present populations with mild to moderate malnutrition, and with sufficient infrastructure to permit a large study of extended duration. The Egyptian site was Kalama, a village on the Nile delta close to Cairo; several small rural communities were selected in the Embu district of Kenya and in the Solis Valley of Mexico. The projects followed a common overall research protocol adapted to local conditions. Each data set includes information from ≈ 300 households as to anthropometric characteristics, some hematology indexes, morbidity, cognitive scores, and socioeconomic variables. What makes these data sets particularly valuable for the present purpose is that food intake of specified individuals was recorded during 1 y with sufficient frequency to be reasonably representative of habitual intake.

Each of the projects has independently reported associations between some measures of diet and early childhood growth (3) and cognitive development (4, 5). The factor most consistently identified as having positive associations is the amount of animal-source foods in the diet. This finding led us to examine the probability that protein or amino acids were inadequate in diets of toddlers: the predicted prevalence of inadequate intakes was essentially nil in Egypt and Mexico and only 2% in Kenya, leading us to conclude that the reported associations were unlikely to be causally attributable to inadequacy of either (6). A second

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assessment addressed the minerals supplied by these diets (7). High prevalences of iron and zinc inadequacy were predicted in all three locations (respectively, 36% and 10% in Egypt, 13% and 57% in Kenya, and 43% and 25% in Mexico), owing in large part to poor bioavailability characteristics of the diets. Approximately 90% of diets in Egypt and Kenya were predicted to be inadequate in calcium but only 2% were predicted to be in Mexico. Intakes of magnesium and copper were predicted to be adequate. The present paper reports our evaluation of vitamin intakes. We then examine the relationships of intakes of energy and animal protein with vitamins, minerals, and two factors that affect bioavailability, dietary fiber and phytate.

Methods

The methods of data collection, selection, and probability assessment are summarized below. More details are given in a previous paper (6). The University of California at Berkeley Committee for the Protection of Human Subjects approved the protocol.

Subjects

Toddlers were eligible for inclusion in the analytic sample if they were members of studied households and had anthropometric records meeting the following criteria: at least three valid weight measurements taken between 17 and 31 mo of age, one taken before 23.5 mo and one taken after 24.5 mo, with the first and last measurement separated by ≥ 6 mo. The eligible sample numbered 138 in Egypt, 110 in Kenya, and 108 in Mexico.

The nutrient assessment groups (Table 1) were limited to those eligible toddlers whose food records included ≥ 6 valid 1-d intakes, one of which was before 23.5 mo and one after 24.5 mo of age. Individual day records were declared invalid if an invalid food code occurred in the original record or if energy intake was out of range (ie, > 3 SD above the country-specific mean). Days on which breast-feeding was reported were excluded, but breast-fed toddlers whose postweaning intake records met the specified criteria were retained in the assessment groups. The majority of toddlers were weaned by 18 mo (50/96 in Egypt, 79/100 in Kenya, and 53/59 in Mexico) and very few were breast-fed after 24 mo (four in Egypt, three in Kenya, and none in Mexico). The mean age at which the food records were collected is only slightly older than the mean age at which the anthropometry measures were made (Table 1). Median heights and weights and sex distribution of the samples of eligible subjects and the nutrient-assessment groups were virtually identical in all three sites (6).

All valid data for anthropometric measures between 17 and 31 mo of age were used to compute individual regressions of weight and length with age. Weights and lengths at 24 mo estimated from these regressions are very close to observed median values (6); the estimated values are used for the present assessment (Table 1).

Nutrient intake

Nutrient content of foods consumed was calculated from a food-composition database created for this purpose (8). This database includes information on 48 constituents in ≈ 250 major crops and class-representative foods (eg "beef" is used for beef and goat; "kale" for collard greens, sukuma leaf, and "dark"

TABLE 1
Descriptors of sample population

Measurement	Egypt (<i>n</i> = 96)	Kenya (<i>n</i> = 100)	Mexico (<i>n</i> = 59)
Percentage of boys (%)	50.0	50.0	47.5
Median age (mo)	23.6 \pm 1.6*	23.8 \pm 0.9	24.8 \pm 0.9
Predicted 24-mo weight (kg)†	11.1 \pm 1.2	10.3 \pm 1.2	10.6 \pm 1.0
Predicted 24-mo length (cm)†	80.1 \pm 3.4	79.4 \pm 3.2	79.1 \pm 3.2
Weight gain (kg/mo)†	0.23 \pm 0.09	0.16 \pm 0.06	0.16 \pm 0.06
Length gain (cm/mo)†	0.68 \pm 0.24	0.64 \pm 0.16	0.75 \pm 0.17
Food records per child‡	14.9 \pm 4.0	23.7 \pm 3.7	21.3 \pm 3.7
Median age of toddlers for food records	25.0 \pm 1.8	24.4 \pm 0.9	25.1 \pm 1.1

* $\bar{x} \pm$ SD.

† Predicted values = 24-mo intercept of regression lines of recorded weight-by-age; rates are slopes of same individual regression lines. Egyptian toddlers weight and rate of weight gain are greater than the rates for the other two groups and rate of length gain is significantly greater in Mexican toddlers than in the other two groups $P < .05$ (Duncan's range test).

‡ Range, 6–28 per toddler; 0–2 records per toddler in any given month.

leaf). Nutrient values are derived mainly from the US Department of Agriculture (USDA) handbooks (9), supplemented in a few cases with compositional data from other recognized sources. Except for fruits, nutrient entries are for cooked foods as given in the USDA handbooks (9) or, if missing, values for raw products were adjusted by using vitamin retention figures suggested by the USDA (10).

Nutrient-intake values used in analysis are the means for each toddler across all days of observation. Nutrient ratios for each toddler (eg, thiamin/energy) are the ratio of mean values, not the mean of individual-day ratios.

Probability assessment

Estimates of the prevalence of inadequate vitamin intakes were derived by using the probability approach described by a National Research Council committee (11). In application of this method it is assumed that intake and requirement are not correlated and that requirements are symmetrically distributed. (There is no reason, a priori, to reject the first assumption, relative to vitamins, nor evidence that would question the second.) The probability that the reported mean vitamin intake of each toddler is below that toddler's own (unknown) requirement is computed. A vitamin intake that is close to the average requirement figure would have a 50% probability of inadequacy because there is an even chance that the toddler's own requirement is above the average requirement; the probability of inadequacy would reach 100% if the intake were well below the average requirement and, conversely, 0% if the observed intake were comparably higher than the mean requirement. The average of the individual probabilities is the predicted prevalence of inadequacy in the group.

Estimates of mean requirements are those suggested by international agencies (12–14) except for vitamins B-6 (15) and E (16), for which there are no international figures (Table 2). If the SD is not stated in the reference cited, the CV was assumed to be 15%. In generating the estimate of mean requirements

TABLE 2
Estimated values of requirement distribution*

Nutrient	Value
Vitamin A ($\mu\text{g RE} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$)	
Normative	18.6 ± 3.7 (12)
Basal	9.3 ± 1.9 (12)
Vitamin D ($\mu\text{g/d}$)	7.7 ± 1.2 (13)†
Vitamin E ($\text{mg } \alpha \text{ TE/d}$)	4.6 ± 0.7 (16)†
Vitamin C (mg/d)	15 ± 2.3 (13)†
Thiamin	
(mg/1000 kcal)	0.33 ± 0.033 (14)
(mg/MJ)	0.079 ± 0.008
Riboflavin	
(mg/1000 kcal)	0.44 ± 0.044 (14)
(mg/MJ)	0.105 ± 0.010
Niacin	
(mg NE/1000 kcal)	5.5 ± 0.55 (14)
(mg NE/MJ)	1.3 ± 0.13
Vitamin B-6 ($\mu\text{g/g protein}$)	11.5 ± 1.7 (15)
Folate (normative) ($\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$)	2.5 ± 0.38 (12)
Vitamin B-12 ($\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$)	0.03 ± 0.0045 (12)

* $\bar{x} \pm \text{SD}$: reference citation in parentheses. Normative requirement is the amount needed to maintain desirable tissue stores or reserve capacity; basal requirement is the amount needed to prevent clinically detectable signs of impairment. This nomenclature was not used in the past, but recommended intakes of the other vitamins listed may be considered normative. RE, retinol equivalents; TE, tocopherol equivalents; NE, niacin equivalents.

† CV of 15% assumed.

from the published recommended allowances, the recommended figure was assumed to be the required intake plus 2 SD. Two requirements are shown for vitamin A, a "basal" or minimal intake necessary to prevent frank deficiency and a higher "normative" figure judged to be compatible with desirable body stores (12).

As in our related assessments (6, 7), individual mean intakes were not adjusted for residual within-person variation; these effects were judged to be small in that mean values reflect, on average, 15–24 d of record. The probability approach does not give assurance of reliable estimates of risk for individual children. It does provide a reasonably secure assessment of population risk when it is based on a distribution of habitual intakes in a relatively homogeneous group, such as the present toddler sample populations.

Variations in approach

Probability of nutrient inadequacy is based appropriately on the nutrient requirements as published by recognized international and national bodies. There are, however, valid reasons for considering alternative requirements figures, on the basis of the character of the toddler diets and the uncertainty surrounding some requirement estimates per se.

Requirements for thiamin, riboflavin, and niacin are stipulated in relation to energy. The 1967 FAO/WHO (14) recommendations for these nutrients, relative to energy intake, are uniform for all ages and both sexes. Both US (16) and Canadian (15) nutrient recommendations specify a floor, ie, a minimum daily intake of thiamin, riboflavin, and niacin, for adults who consume < 8.4 MJ (2000 kcal)/d; no floor is stipulated for children. We

devised toddler floor requirements for these vitamins on the basis of the adult figure. The adult floor of 8.4 MJ is $\approx 70\%$ of the adult male energy requirement (16, 17); for toddlers in this series, 3.3 MJ (800 kcal) is $\approx 70\%$ of the FAO/WHO/UNU (17) energy requirement. For children with energy intakes < 3.3 MJ/d, the floor was set as if intake were 3.3 MJ, which yielded values of 0.26 mg/d for thiamin, 0.35 mg/d for riboflavin, and 4.4 mg niacin equivalents (NE)/d for niacin. For toddlers with energy intakes > 3.3 MJ the daily requirement was calculated as a ratio to actual energy intake, by using requirement figures as in Table 2. The floor requirement was assumed to have the same variability as the energy-driven requirement [ie, CV = 10% as specified by FAO/WHO (14)].

On the basis of survey data from China and reexamination of the literature, Campbell et al (18) suggested that the riboflavin requirement is substantially less than the present recommended allowance, but they do not offer an estimate of requirement. We devised two alternative values derived from studies used in setting Canadian, US, and international recommended intakes. Studies of adults dating from the 1940s and 1950s (reviewed in reference 16) recorded the absence of clinical signs of riboflavin deficiency with diets supplying 0.074 and 0.084 mg/MJ (0.31 and 0.35 mg/1000 kcal) and clear evidence of deficiency with a total daily intake of ≤ 0.55 mg (≈ 0.2 mg/1000 kcal), and deficiency symptoms in 1 of 22 men given 0.75–0.85 mg/d (≈ 0.3 mg/1000 kcal). Our first alternative uses 0.081 ± 0.012 mg/MJ (0.34 ± 0.05 mg/1000 kcal) as a mean basal riboflavin requirement. Earlier committees (19), more contemporaneous with the original investigations, were not persuaded that the riboflavin requirement is related to energy and suggested a riboflavin requirement of 0.025 mg/g protein requirement. Because the mean protein requirement for toddlers is 1 g/kg, a second alternative riboflavin requirement is 0.025 mg/kg body wt. For both alternatives, we assumed the CV to be 15%. The probability assessment was repeated by using these alternative requirements figures.

Total NEs in the diet are the sum of preformed niacin plus niacin derived from tryptophan (by using a factor of 1:60). Tryptophan was a limiting amino acid in a small number of diets (6) and toddler gain of protein in growth would remove a small amount of tryptophan (not more than ≈ 30 mg/d) from the pool available for conversion to niacin. The probability assessment was repeated for a worst-case scenario in which no tryptophan is available for conversion to niacin.

Values for preformed niacin in the food-composition table do not take into account the known lower availability of niacin in mature cereal grains (14, 16). Mature maize is the principal staple in Kenya and Mexico but in Mexico maize is lime-treated, which unbinds the niacin. Also, differences in protein (and thus amino acid) digestibility are not reflected in the NEs listed in food tables. The analysis for Kenya was rerun with niacin content of maize reduced to 30%, the accepted availability figure for mature grains (16), and with dietary tryptophan adjusted for estimated protein digestibility of these diets (6).

Because the energy intake of Kenya toddlers was low (see below), it was of interest to know whether or not a Kenyan diet of the existing composition would be adequate if it were consumed in amounts that met the toddler energy requirement of 430 kJ (103 kcal)/kg as suggested by FAO/WHO/UNU (17). The vitamin at highest risk of inadequacy (B-12) was examined. For this analysis a hypothetical requirement distribution was

TABLE 3
Estimated energy and macronutrient intakes of toddlers*

Nutrient	Egypt (n = 96)	Kenya (n = 100)	Mexico (n = 59)
Energy			
(kJ/d)	5003 ± 1237	3540 ± 748	4640 ± 1095
(kcal/d)	1204 ± 295	847 ± 149	1110 ± 262
(% from animal sources)	17.8 ± 5.8	7.6 ± 5.3	13.0 ± 8.7
Protein			
(g/d)	35.8 ± 10.2	23.1 ± 5.5	33.1 ± 7.6
(% from animal sources)	37.2 ± 8.4	16.3 ± 10.3	28.7 ± 14.3
Fat†			
Total (g/d)	22.7 ± 7.6	11.5 ± 4.1	28.9 ± 9.0
Polyunsaturated fatty acids (g/d)	5.9 ± 1.4	3.4 ± 0.6	7.0 ± 2.2
Saturated fatty acids (g/d)	12.0 ± 1.4	3.7 ± 1.9	8.3 ± 3.1
Carbohydrate (g/d)	196 ± 50	171 ± 36	186 ± 48

* $\bar{x} \pm SD$.

† The sum of polyunsaturated and saturated fatty acids is less than total fat because of the presence of monounsaturated fatty acids and small amounts of other lipids.

created as a simulated bivariate distribution of vitamin B-12 and energy requirements [as previously described for protein (6)]. The ratio of animal protein to total energy was also evaluated.

It has been suggested that the requirement for vitamin E be viewed in relation to the content of polyunsaturated fatty acids (PUFA) in the diet, an acceptable ratio being 0.4 mg α tocopherol equivalents (TE)/g PUFA (16). An assessment was made with all diets that had less than the suggested ratio being assigned a risk of 100%.

Clinical and laboratory measures

Project protocols included physical examination of toddlers for signs of nutritional deficiency, hematologic studies, and examination of stools for ova and parasites (2). Not all of these data sets are complete and linkage of clinical findings with predicted dietary inadequacy at the individual level is not possible. The clinical data are cited to provide context for the dietary risk assessment.

Nutrient relationships

Intakes of energy and nutrients were examined for collinearity. The relationship between animal protein and nutrients was evaluated after energy was controlled. Pearson partial correlation coefficients were computed by using SPSS (20); all associated *P* values are based on two-tailed *t* tests.

Results

Energy and nutrient intakes

Energy intake was much lower in Kenya [346 kJ (83 kcal)/kg] than in Mexico [441 kJ (106 kcal)/kg] and Egypt [454 kJ (109 kcal)/kg] (Table 3). Sources of nutrients also differed between sites. In Egypt, 18% of energy and 37% of protein were from animal products, compared with values of 13% and 29% in Mexico and 8% and 16% in Kenya, respectively. Fat intake was notably lower in Kenya (12% of energy) than in Mexico (23%) and Egypt (24%). PUFA contributed 3.6% of dietary energy

in Kenya, 4.4% in Egypt, and 5.7% in Mexico; all values were above the 2–3% suggested as meeting PUFA requirements (16).

Despite the low energy intake of Kenyan toddlers, the intake of most vitamins (per day or per unit of energy) was as high or higher than in the other groups (Table 4). Kenya ranked lowest only in intakes of nutrients specific to animal products: vitamins B-12 and D, and retinol (but not total vitamin A). Intakes of all vitamins except niacin and vitamins D and B-12 were lowest in Mexico.

Probability of inadequate vitamin intakes

The predicted prevalence of intakes inadequate to meet basal requirements for vitamin A was essentially 0% in Kenya (0.4%), 2% in Egypt, and 20% in Mexico (Table 5). About 68% of toddler intakes in Mexico, 33% in Egypt, and 12% in Kenya were predicted to be insufficient to meet normative storage requirements.

The estimated prevalence of inadequate dietary intake of vitamin D was 100% in all three sites. The extent to which vitamin

TABLE 4
Estimated vitamin intakes of toddlers*

Nutrient	Egypt (n = 96)	Kenya (n = 100)	Mexico (n = 59)
Vitamin A			
($\mu\text{g RE/d}$)	305 ± 192	370 ± 228	203 ± 181
($\mu\text{g RE} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$)	28 ± 16	36 ± 20	19 ± 16
From animal source			
($\mu\text{g RE/d}$)	174 ± 179	50 ± 154	119 ± 162
Vitamin D ($\mu\text{g/d}$)	0.31 ± 0.33	0.06 ± 0.05	0.44 ± 0.29
Vitamin E			
(mg α TE/d)	6.0 ± 1.7	3.3 ± 1.1	2.6 ± 1.1
(mg α TE/g PUFA)	0.8 ± 0.1	1.1 ± 0.3	0.3 ± 0.04
Ascorbic acid (mg/d)	42 ± 21	46 ± 19	14 ± 7
Thiamin			
(mg/d)	0.59 ± 0.20	0.67 ± 0.16	0.46 ± 0.10
(mg/1000 kcal)	0.48 ± 0.07	0.79 ± 0.11	0.42 ± 0.06
(mg/MJ)	0.11 ± 0.02	0.19 ± 0.03	0.11 ± 0.01
Riboflavin			
(mg/d)	0.62 ± 0.22	0.55 ± 0.16	0.54 ± 0.23
(mg/1000 kcal)	0.51 ± 0.08	0.65 ± 0.12	0.49 ± 0.22
(mg/MJ)	0.12 ± 0.02	0.16 ± 0.03	0.12 ± 0.05
Niacin, preformed			
(mg/d)	7.9 ± 2.8	6.1 ± 1.4	6.8 ± 1.8
Niacin, total			
(mg NE/d)†	15 ± 5	10 ± 2	12 ± 3
(mg NE/1000 kcal)	12 ± 1	12 ± 1	11 ± 1
(mg NE/MJ)	2.9 ± 0.2	2.9 ± 0.2	2.6 ± 0.2
Pantothenic acid			
(mg/d)	2.4 ± 0.7	2.0 ± 0.5	1.9 ± 0.5
Vitamin B-6			
(mg/d)	0.75 ± 0.24	0.91 ± 0.22	0.64 ± 0.16
($\mu\text{g/g protein}$)	21 ± 3	40 ± 9	19 ± 2
Folate			
(mg/d)	0.19 ± 0.06	0.19 ± 0.06	0.16 ± 0.05
($\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$)	17 ± 5	18 ± 6	15 ± 5
Vitamin B-12			
($\mu\text{g/d}$)	1.4 ± 1.4	0.61 ± 1.62	1.4 ± 1.7
($\mu\text{g} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$)	0.13 ± 0.14	0.06 ± 0.14	0.13 ± 0.16

* $\bar{x} \pm SD$.

† Preformed niacin + 1/60 tryptophan. Intake of tryptophan was 410 ± 116 mg/d in Egypt, 241 ± 62 mg/d in Kenya, and 336 ± 83 mg/d in Mexico (6).

TABLE 5
Estimated prevalence of inadequate intakes of vitamins (% of individuals)

Nutrient	Egypt (n = 96)	Kenya (n = 100)	Mexico (n = 59)
Vitamin A			
Normative	32.5	12.3	67.6
Basal	2.2	0.4	19.5
Vitamin E	21.5	85.1	91.8
Vitamin C	3.1	1.2	62.7
Thiamin			
(mg/unit energy)*	1.4	0	5.9
With floor†	1.7	0	7.9
Riboflavin			
(mg/unit energy)*	20.4	1.9	51.7
With floor†	20.6	9.0	51.9
Niacin, total			
(mg/unit energy)*‡	0	0	0
With floor†	0	0.2	0
Vitamin B-6 (μg/g protein)	0.02	0	0.5
Folate (μg/kg)	0	0	0
Vitamin B-12 (μg/kg)	3.2	44.2	8.0

* Unit energy is energy intake within guidelines for study populations.

† Diets with intake < 3.3 MJ (800 kcal/d) calculated with fixed minimum daily intake of 0.26 mg thiamin, 0.35 mg riboflavin, 4.4 mg niacin equivalents; diets with ≥ 3.3 MJ calculated as: intake (kcal)/1000 × requirement/1000 kcal.

‡ Preformed niacin + 1/60 tryptophan intake, not adjusted for availability.

D nutriture was dependent on diet is unknown; there was opportunity for endogenous synthesis with adequate exposure to sunlight in all locations but exposure was not recorded.

Inadequate intakes of vitamin E were predicted to be highly prevalent, especially in Mexico and Kenya, when assessed against a normative requirement unrelated to PUFA intake. When vitamin E intakes were evaluated according to the suggested requirement ratio of 0.4 mg α-TE/g PUFA, predicted inadequacy fell to zero in Egypt and Kenya but remained high in Mexico. Indeed, among Mexico toddlers, only 1 in 59 had an intake that met this criterion. Intake of vitamin C was predicted to be inadequate in nearly two-thirds of toddler diets in Mexico but was generally adequate elsewhere.

Of the three B vitamins whose requirement is stipulated in relation to energy intake, only riboflavin was estimated to be at some risk of inadequacy in all sites. The predicted prevalence of inadequate intake of riboflavin was only 2% in Kenya as assessed by the riboflavin-energy ratio, but it was 20% in Egypt and 52% in Mexico. Intakes were reevaluated with a floor of 0.35 mg/d applied to all diets with energy intake < 3.3 MJ (800 kcal)/d. Intakes of 41 of 100 toddlers in Kenya were below the energy cut-off point, but only 8 of 59 toddler diets in Mexico and 3 of 96 in Egypt were below that amount. Thus, introduction of the floor had almost no effect in Egypt and Mexico; the predicted prevalence of inadequate intake of riboflavin increased, but only to 9%, in Kenya because the concentration of riboflavin in the diets was generally high.

The analysis was repeated by using alternative requirements for riboflavin. Lowering the requirement per unit of energy to

a basal amount [0.08 mg/MJ (0.34 mg/1000 kcal)] decreased predicted inadequacy from 52% to 22% in Mexico, from 20% to 1.5% in Egypt, and from 2% to 0.1% in Kenya. When requirement was related to body weight (0.025 mg/kg) and divorced from energy intake, the predicted prevalence of inadequate diets was 6% in Mexico and ≈ 1% in Egypt and Kenya.

Thiamin intakes appeared to be adequate in Kenya and mostly adequate in Egypt irrespective of the basis of calculation. The predicted prevalence of inadequacy was ≈ 6% in Mexico as conventionally estimated or 8% estimated with a floor requirement.

With NE derived from tryptophan included in the calculation, the predicted prevalence of niacin inadequacy was essentially zero in all three groups with or without a floor allowance. If tryptophan were not available for conversion and the adequacy of niacin intake were judged on the basis of preformed niacin only, 5% of diets in Kenya would have been rated inadequate, 21% in Egypt, and 28% in Mexico.

Adjustment of dietary preformed niacin intake to reflect its 30% availability in mature maize reduced the estimated niacin intake in Kenya from 1.7 ± 1.1 mg/MJ (7.2 ± 4.6 mg/1000 kcal) to 1.1 ± 0.8 mg/MJ (4.8 ± 3.3 mg/1000 kcal); the predicted prevalence of inadequate intakes, based on preformed niacin only, increased to 78%. With "available" (corrected for protein digestibility) tryptophan equivalents added to available niacin, the effective intake was 2.2 ± 1.6 mg NE/MJ (9.1 ± 6.8 mg NE/1000 kcal) and the predicted prevalence of inadequacy remained low, 0.05% without and 2.6% with a floor.

There was negligible risk of inadequacy of vitamin B-6 intake and folate intake was predicted to be fully adequate in all three sites. The predicted prevalence of inadequacy of vitamin B-12 intake was high (44%) in Kenya; a moderate risk of inadequacy was predicted in Mexico (8%) and a low risk (3%) in Egypt. If energy intakes from existing diets were increased to amounts that would satisfy the estimated energy requirements of Kenya toddlers, predicted prevalence of inadequacy of vitamin B-12 intake would decrease but only to 33%. Requirements for pantothenic acid have not been quantified but a "safe and adequate dietary intake" for toddlers, which would presumably be a population mean estimate, is stated to be 3 mg/d (16). Mean intake of pantothenic acid was below this in all three groups.

Clinical findings

Physical examination records of 78 Egyptian toddlers (81% of the nutrient assessment sample) list one case of xerosis, but are otherwise negative for nutritional deficiency signs. Records of all 59 Mexican toddlers are negative. In Kenya two cases of glossitis were noted and 40 of the 100 toddlers were judged anemic by physical examination; there were no cases of rickets.

On the basis of hemoglobin concentration, anemia was found to be prevalent among toddlers in all locations: 61% in Egypt, 72% in Kenya, and 69% in Mexico (7). Only part of this could be attributed to iron deficiency (7). Macrocytosis was observed in 18% of the Kenyan toddlers and in 3% of a subsample of Mexican toddlers (n = 36).

Correlations among nutrient intakes

Intakes of all macronutrients were strongly correlated with energy intake ($r = 0.85-0.97$ for carbohydrate and protein, 0.72-0.79 for fat). Intakes of energy from animal sources and total energy intakes were correlated in Egypt ($r = 0.69$) and Kenya ($r = 0.39$), but not in Mexico ($r = 0.19$, $P > 0.15$). Intakes of

energy and micronutrients generally were correlated although there were three exceptions: intakes of vitamins A, C, and B-12 were not significantly related to energy intake in Mexico (Table 6).

To explore further the question of dietary quality as indicated by inclusion of animal products separate from their energy contribution, correlations between animal protein and micronutrient intakes were computed after energy was adjusted for. These relationships are reasonably consistent across countries. In all locations, intakes of riboflavin, vitamin B-12, and vitamin D were positively related to intakes of animal protein. Intake of pantothenate was correlated with animal protein intake in Kenya and Mexico but not Egypt. In Mexico only, vitamin C and vitamin E intakes were correlated with animal protein, implying that plant sources of these nutrients were consumed with diets that also included animal products, because animal products alone supply little of these vitamins. Intake of available zinc was correlated with animal protein in all locations as was calcium intake in Egypt and Kenya (but not in Mexico, where calcium is supplied by lime-processed tortillas). Available iron intake was related to animal protein only in Egypt. Intakes negatively related to animal protein intake were folate in all locations, thiamin in Egypt and Kenya, and preformed niacin in Kenya and Mexico. There was a strong ($P = 0.000$) negative relationship between animal protein intake and phytate and dietary fiber intake in all groups.

Discussion

The predicted prevalence of inadequate vitamin intakes is substantially larger than the clinical evidence of deficiency. This

is to be expected. Clinical signs are manifestations of severe deficiency whereas requirements standards are set at amounts judged to be above the minimum needed to prevent frank deficiency. If, however, requirements were set too high or intakes were significantly underestimated, dietary risks would be exaggerated.

Reliability of estimated vitamin intakes

It is possible that we have underestimated intakes, but that does not seem likely. Food intakes were recorded according to locally established methods and we have no basis for questioning the data beyond the exclusions noted earlier. We have commented previously (6) on the records of the three Kenyan toddlers with the lowest intakes of protein and energy; in only one case did the evidence suggest that the intake was likely to be erroneously low (due, perhaps, to unrecorded intake of breast milk). We have now examined the records of the two Mexican toddlers with exceptionally high intakes of animal foods: these toddlers were the tallest and among the heaviest in the sample population.

Food-composition data are more open to question. There are no (or no modern) analytical data on the vitamin content of many of the foods consumed. Values have been imputed from data for the same or similar foods in the US tables, as prepared by standardized methods of cookery. Comparisons with local food-composition data, where available, did not identify any meaningful differences in vitamin values. Nevertheless, we judge the entries for the macronutrients and energy to be more reliable than for the micronutrients (as is true of all food tables). Food preparation and storage methods in the household could negatively affect the content of vitamins sensitive to heat, oxygen, light, or pH, resulting in overestimation of intakes. There are

TABLE 6
Correlations between toddler intakes of energy and animal protein, vitamins, and minerals

Nutrient	Correlation with energy			Correlation with animal protein†		
	Egypt (n = 96)	Kenya (n = 100)	Mexico (n = 59)	Egypt (n = 96)	Kenya (n = 100)	Mexico (n = 59)
Animal energy	0.69	0.39	0.19‡	—	—	—
Animal protein	0.73	0.41	0.27	—	—	—
Dietary fiber	0.85	0.73	0.70	—	—	—
Phytate	0.80	0.62	0.69	-0.56	-0.64	-0.69
Vitamin A	0.45	0.48	-0.00‡	-0.60	-0.59	-0.84
Vitamin D	0.43	0.35	0.41	0.52	0.17‡	0.62
Vitamin E	0.58	0.61	0.56	0.34	0.88	0.58
Ascorbic acid	0.46	0.45	0.23‡	-0.12‡	-0.17‡	0.27
Thiamin	0.87	0.79	0.83	0.01‡	-0.06‡	0.59
Riboflavin	0.90	0.74	0.30	-0.43	-0.50	0.20‡
Niacin	0.90	0.85	0.88	0.50	0.78	0.93
Pantothenic acid	0.94	0.78	0.88	-0.03‡	-0.62	-0.46
Vitamin B-6	0.87	0.78	0.75	0.17‡	0.45	0.89
Folate	0.79	0.56	0.87	-0.15‡	-0.05‡	-0.03‡
Vitamin B-12	0.29	0.24	0.49	-0.39	-0.34	-0.31
Calcium	0.66	0.52	-0.04‡	0.48	0.38	0.62
Available iron	0.63	0.51	0.83	0.79	0.93	0.23‡
Available zinc	0.51	0.62	0.73	0.70	-0.04‡	0.03‡
			0.42	0.86	0.54	0.61

* All correlations are significant ($P \leq 0.05$) except where otherwise indicated.

† Adjusted for energy.

‡ NS.

also preparatory methods, such as germination and fermentation, that may increase nutrients or their availability. Application of these methods was reported only infrequently in Kenya and is not taken into account because there is no information on the vitamin content of the fermented foods.

Failure to take account of poor bioavailability can lead to low estimates of the prevalence of inadequacy. Niacin in maize is a well-recognized example. Adjustment of the Kenya intakes to correct for bound niacin in mature maize and for tryptophan digestibility is illustrative, albeit the predicted prevalence of inadequate intake remains very low ($\approx 2\%$). The literature on bioavailability of other vitamins is sparse. Evidence on the different forms of folate and on absorption of vitamin B-12 is reviewed in the 1988 FAO/WHO report (12) without any specific advice on its general application. The occurrence of unavailable forms of vitamin B-6 is noted in the RDA text (16) but without comment on its significance. Some requirements studies have used foods as the source of micronutrients so differences in availability may be more or less built into requirements figures. There is still wide scope for research on this neglected topic.

Estimated requirements and prediction of inadequacy

Knowledge of nutrient requirements and their distribution is fundamental to the present assessment. Requirements standards could be higher than true requirements, but they are probably not lower than needs, given the appropriately cautious views of recommending agencies. Recommendations for intakes of vitamins for toddlers have almost no direct experimental support; most represent logical inferences drawn from limited information on adults and very young infants, adjusted for size and rate of growth. Recent international recommendations (12) include consideration of a possible range of requirements, from just enough (basal) to sufficient to maintain body stores (normative). Considering the environmental conditions in the poor communities studied, there is a real possibility that nutrient needs are increased because of disease. On balance the vitamin requirements used in our assessment are not likely to be inappropriately high for existing conditions.

Alternative requirements standards were considered for thiamin, riboflavin, and niacin, in particular the inclusion of a "floor" as has been suggested for adults (15, 16). We are not aware of any evidence that there is or is not a minimum requirement for these vitamins, independent of energy requirement, in toddlers. As noted above, the validity of linking requirements of riboflavin and energy has long been questioned (19). For Egyptian and Mexican intake assessments, the issue is almost irrelevant because energy intakes approximated accepted standards. It made little difference in estimated risk for Kenyan diets because the nutrient density was high. Had the ratios of thiamin and riboflavin to energy been as low in Kenyan diets as in those in Mexico or Egypt, however, the risk-estimate based on a floor would have been much higher and identified a potential area of concern.

Apart from the issue of a floor, the riboflavin requirement merits restudy. As we noted above, the literature cited in establishing standards could justify a much lower recommendation. Our first alternative figure, 0.081 ± 0.012 mg/MJ ($0.34 \pm .05$ mg/1000 kcal), is still above an amount some studies of adults would justify. The second alternative, $0.025 \pm .0038$ mg/kg, is equivalent to 0.057 mg/MJ (0.24 mg/1000 kcal), when the reference toddler energy requirement of 103 kcal/kg is used. Application of either alternative had little impact on the Kenyan

assessment, but virtually eliminated riboflavin from the risk category in Egypt. The first alternative cut the estimated prevalence of inadequate diets in half in Mexico and the second further reduced the prediction to only 6%. There is no evidence to support a judgment about the functional state of riboflavin nutriture in these toddlers.

The fact that the predicted prevalence of vitamin A intakes inadequate to meet basal requirements was 20% in Mexico without there being clinical evidence of deficiency might suggest that the requirement standard is high. On the other hand, the contribution to vitamin A intake from dietary carotene may have been undervalued. The FAO/WHO report (12) suggests that the RE of β -carotene might be 1:4 when carotene intake is low, as for the diets of Mexican toddlers, rather than the conventional 1:6. This modification would increase estimated total vitamin A intake by 20%, to 245 RE/d, in Mexico and would lower but not eliminate the estimated prevalence of inadequacy.

The international requirement estimate for vitamin C is low compared with the US standard (16) but is the same as the Canadian recommendation (15). The estimated mean intake of Mexican toddlers, 14 mg/d, was not greatly above the 6–10 mg/d required to correct scurvy in adults (16). Also, intake of this labile nutrient is more likely to be overestimated than underestimated. As we reported previously (7), one serious consequence of the low vitamin C intake in Mexico was reduced bioavailability of dietary iron.

Vitamin D intake was identified as being potentially inadequate in all three countries. We have no information on actual solar exposure and it is clearly an important variable. Factors that might be considered in Kenya, in addition to the extremely low intake of the vitamin, are skin pigmentation, and perhaps, the very low intakes of fat (11.5 ± 4.1 g/d) and cholesterol (19 ± 15 mg/d) in relation to the precursor pool size, a variable that has not been explored to our knowledge.

Findings for vitamin E are uninterpretable at this juncture. Neither the food-composition data nor the estimated requirements figures are very well grounded. PUFA intake was not far below recommended upper limits (21) in Mexico, owing to frequent use of vegetable oil in cookery (assumed to be soybean oil). The vitamin E intake appeared to be quite low, a point that should be watched over time. The combination in Mexican diets of low intakes of β -carotene, vitamin C, and vitamin E has potentially serious long-term implications for cancer risk (21).

If the requirement for vitamin B-12 is "normative", i.e. includes a storage component, then the hematologic findings suggest that this standard approximates true requirement. In Kenya, predicted prevalence of inadequate diets was 44%; macrocytosis was observed in 18% of a sample of toddlers. The assessment of folate intakes indicated no risk of folate inadequacy that would contribute to macrocytosis. Folate intake and availability may be overestimated, but the error would have to be very large (mean intake was 6–7 times the mean requirement) to suggest that folate was a significant factor in the macrocytic anemia.

Vitamin B-12 is probably a significant factor in blood indexes and may relate to other aspects of toddler development as well. On the other hand, vitamin B-12 intake could be underestimated. In Kenya, consumption of insects was recorded but casual ingestion by toddlers may have gone unnoticed. Also, bacterial vitamin B-12 contaminants and insect fragments may be present in foods. Reinforcing the belief that vitamin B-12 has particular potential for inadequacy in Kenya, however, is the unpublished

finding of very low concentrations of vitamin B-12 in breast milk samples from women in this study, 131 ± 28 ng/L (S Oace, C Neumann, personal communication, University of California, Berkeley, 1992) as compared with ≈ 600 ng/L in the United States (16). Even a toddler who was breast-fed would have received only ≈ 0.07 μ g vitamin B-12/d from breast milk.

The predicted prevalence of dietary vitamin B-12 inadequacy is only 8% in Mexico but Allen et al (3) found low serum vitamin B-12 in 41% of toddlers examined ($n = 32$). Absorption of vitamin B-12 may have been impaired because of intestinal parasitism; *Giardia*, an organism reported to impair vitamin B-12 absorption (22) was present in 40% of Mexican toddlers but in only 3% in Kenya (2). Pantothenic acid intakes may be at some unknown risk. Mean intakes in all sites were lower than the estimated safe intake for this age group.

Animal-source foods and nutrient intakes

Positive relationships between consumption of animal-source foods and indicators of health and growth are commonly observed in developing countries but the mechanism by which the effect is mediated is debatable. Because usage of meat, milk, and eggs is strongly related to income, which is in turn related to many social and economic factors, some argue that consumption of animal products may be a sensitive proxy for the combined effects of, among other things, education, parental competency, housing, and health conditions (see 23). One of our objectives in undertaking the probability analyses was to examine the possibility that the reported positive associations between intake of animal products and size (3) and cognitive performance (4, 5) of children were attributable to nutritional factors. Our analyses cannot prove but strongly suggest that animal products play an important nutritional role based on the likelihood of multiple nutrient deficits and that the role is complex.

The composition of diets was quite different in the three countries. About 12% of energy was derived from protein in Mexico and Egypt and 11% in Kenya as is typical of diets worldwide. The diets otherwise present a gradient from a low of 12% fat energy in Kenya to higher values of 23% in Mexico and 24% in Egypt. The higher values were, of course, lower than those typical of Western developed-country diets, where fat energy is $> 35\%$ of the total (see ref 21). The amount of energy and protein derived from animal products was also low in comparison with usage by more affluent groups: in the United States for example, two-thirds of dietary protein is of animal origin (16) compared with about one-third in Egypt and Mexico and one-sixth in Kenya. The toddlers' diets were remarkably high in fiber [15 g/d in Mexico, 17 g/d in Egypt, and 22 g/d in Kenya (6)] and phytate (0.8 g/d in Egypt, 1.1 g/d in Kenya, and 1.7 g/d in Mexico (7)). We commented previously on the potential difficulty of Kenyan toddlers consuming enough of their energetically dilute diet (if more of the same food were available) to meet energy and nutrient needs (6, 7). [If they could consume enough food to meet the FAO/WHO/UNU recommendation (17), their diets as presently constituted still would not have satisfied requirements for vitamin B-12 (33% prevalence of inadequacy) or for iron (19%) and zinc (30%) (7)]. Animal products generally contain fat and are more concentrated sources of energy than are almost all plant foods as consumed (nuts and oils excepted). They also are more digestible. One benefit of animal products may be to improve overall nutrition by making it possible for

small children to consume enough food to meet their energy needs.

Animal products may contribute to nutritional adequacy in several other ways. Most obvious is the direct contribution of nutrients such as vitamin B-12, which may be present in other foods but is supplied reliably only by animal-source foods. Vitamin A needs may be met more efficiently by retinol than by carotenes in bulky, low-fat diets. Zinc, iron, and calcium are supplied in more readily absorbable forms, if not necessarily in larger amounts by animal than by plant foods.

Animal products also may play an important indirect role in overall bioavailability by displacing coarse plant foods in the diet. If energy intake from animal sources is not correlated with total energy intake [as in Mexico, for example (Table 6)], then it follows that there must be a nearly isoenergetic replacement of plant energy with animal energy as the amount of animal-source foods in the diet rises. Allen et al (24) reported that such substitution did occur in the Mexican diets: the intake of whole-grain maize decreased as consumption of animal foods increased. The resultant lowering of the phytate and fiber content of the diet should improve absorption of nutrients in the total diet.

A close correlation between animal-source and total energy intakes suggests different consumption patterns from that reported in Mexico: either animal products must be a fairly uniform component of the local diet or they must be supplementary to a common base diet. In Egypt, animal products appeared to be a regular component of most diets, and total and animal-source energy intakes were strongly related; still, some displacement of plant foods by animal foods was indicated by the negative correlation between animal protein and phytate and fiber when intake was controlled for energy (Table 6). In Kenya total energy intakes were low and the amount of animal products in the Kenyan diet was quite small [on average, 268 kJ (64 kcal)/d, equal to ≈ 100 mL cow milk]. Animal-source and total energy intakes were correlated; even so, intakes of phytate and fiber fell and that of available zinc rose with increasing animal protein intake.

The significance of such food tradeoffs depends, of course, on the composition of the food exchanged and on the total amount of nutrients and other substances present in the diet. We have noted that intakes of some vitamins were negatively related to animal protein intake [folacin, niacin, and thiamin (Table 6)]. In the present instance these nutrients were not predicted to be inadequate, but they could be in other situations.

The probability analyses suggested that inadequate intakes of several minerals and vitamins believed to be needed for normal growth and development may be present in each of the countries. Nutritional enhancement associated with animal products appears to be due to their contribution of specific nutrients and their higher digestibility, to the replacement of foods that contain interfering substances and, perhaps for small children, increased energy density of the diet. Because of the complexity of the interaction of dietary components and the cooccurrence of nutrients in foods, further analyses should examine multivariate associations of nutrients and food-intake patterns with outcomes such as growth, cognitive development, and morbidity. \square

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