Addressing nutrient shortfalls in 1- to 5-year-old Irish children using diet modeling: development of a protocol for use in country-specific population health

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ABSTRACT

Background: Dietary habits formed in early childhood can track into later life with important impacts on health. Food-based dietary guidelines (FBDGs) may have a role in improving population health but are lacking for young children.

Objectives: We aimed to establish a protocol for addressing nutrient shortfalls in 1- to 5-y-old children (12–60 mo) using diet modeling in a population-based sample.

Methods: Secondary analysis of 2010–2011 Irish National Pre-School Nutrition Survey data ($n = 500$) was conducted to identify typical food consumption patterns in 1- to 5-y-olds. Nutrient intakes were assessed against dietary reference values [European Food Safety Authority (EFSA) and Institute of Medicine (IOM)]. To address nutrient shortfalls using diet modeling, 4-d food patterns were developed to assess different milk-feeding scenarios (human milk, whole or low-fat cow milk, and fortified milks) within energy requirement ranges aligned with the WHO growth standards. FBDGs to address nutrient shortfalls were established based on 120 food patterns.

Results: Current mean dietary intakes for the majority of 1- to 5-y-olds failed to meet reference values (EFSA) for vitamin D ($\leq$100%), vitamin E ($\leq$88%), DHA (22:6n–3) + EPA (20:5n–3) (IOM; $\leq$82%), and fiber ($\leq$63%), whereas free sugars intakes exceeded recommendations of <10% energy (E) for 48% of 1- to 3-y-olds and 75% of 4- to 5-y-olds. "Human milk + Cow milk" was the only milk-feeding scenario modeled that predicted sufficient DHA + EPA among 1- to 3-y-olds. Vitamin D shortfalls were not correctable in any milk-feeding scenario, even with supplementation (5 µg/d), apart from the "Follow-up Formula + Fortified drink" scenario in 1- to 3-y-olds (albeit free sugars intakes were estimated at 12%E compared with $\leq$5%E as provided by other scenarios). Iron and vitamin E shortfalls were most prevalent in scenarios for 1- to 3-y-olds at $\leq$25th growth percentile.

Conclusions: Using WHO growth standards and international reference values, this study provides a protocol for addressing nutrient shortfalls among 1- to 5-y-olds, which could be applied in country-specific population health. *Am J Clin Nutr* 2022;115:105–117.

Keywords: nutrient shortfalls, young children, food-based dietary guidelines, diet modeling, WHO growth standards, food patterns

Introduction

Early childhood represents a window of developmental plasticity whereby the achievement of optimal nutrition and growth is considered paramount for maintaining health and reducing mortality throughout the life-course (1, 2). Malnutrition during early childhood is associated not only with serious adverse health outcomes for the child (2, 3) but also with an increased risk of developing diet-related noncommunicable diseases in later life (4, 5). Malnutrition in children <5 y old typically manifests as micronutrient deficiency both in low- and middle-income

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Supplemental Tables 1–3 and Supplemental Figures 1 and 2 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/ajcn/.

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Abbreviations used: AI, adequate intake; AMDR, acceptable macronutrient distribution range; AR, average requirement; BMR, basal metabolic rate; DRV, dietary reference value; DYC, Drink for Young Children with added nutrients; E, energy; EAR, estimated average requirement; EFSA, European Food Safety Authority; FBDG, food-based dietary guideline; FUF, Follow-Up Formula; HIC, high-income country; IOM, Institute of Medicine; LMIC, low- and middle-income country; NPNS, National Pre-School Nutrition Survey; UL, Tolerable Upper Intake Level; UR, under-reporter.

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countries (LMICs) (4) and in high-income countries (HICs) including Ireland (6). This is further complicated, irrespective of region, by excessive or inadequate energy intake, leading to overweight or to underweight, wasting, and stunting, respectively (3, 4). The WHO growth standards characterize how children <5 y old should achieve optimal growth and provide a yardstick for the identification of malnutrition (7, 8). Growth monitoring, an intrinsic aspect of pediatric care representing substantial health care investment worldwide (8), can identify populations most in need of interventions (3), but countries also have a critical need for nutrition information (9).

Best practice for young child feeding aims to prevent diet-related noncommunicable diseases, which highlights the importance of achieving adequacy for some nutrients while limiting others (10). This includes ensuring sufficient intakes of long-chain PUFAs, namely DHA (22:6n–3) (11) and EPA (20:5n–3) (12, 13), iron, and vitamin D (14), while limiting saturated fat (11, 12) and free sugars intakes (defined as monosaccharides and disaccharides added to foods/beverages by the manufacturer or consumer, and sugars naturally present in honey, fruit juices, and fruit juice concentrates) (15). Although certain nutrient deficiencies are more prevalent in LMICs (14), iron, vitamin D, DHA, and EPA remain nutrients of public health concern worldwide (13, 16–20). Nutrient adequacy needs to be considered within age-related energy requirements in order to support optimal growth and to avoid overweight or stunting (4). Dietary reference values (DRVs) are used globally to identify nutritional shortfalls, but tend to vary considerably across different regions, thus leading to different estimates of inadequacy for given nutrients between countries (21).

Over 100 countries worldwide have published food-based dietary guidelines (FBDGs) but few have addressed the specific nutritional requirements of 1- to 5-y-old children (22). In this age group, a key challenge is the provision of sufficient nutrient intakes within the context of energy requirements for optimal growth and development (4); this is particularly critical during the transition from a predominantly milk-based to a food-based diet (23). In the majority of countries, however, FBDGs for 1- to 5-y-olds are combined with older children, adolescents, and, in some cases, even adults (22). Recognizing the importance of optimal nutrition in young children, the 2020–2025 Dietary Guidelines for Americans were recently updated to include birth to 24 mo (24), as informed by national survey data (NHANES).

Given that dietary habits formed during early childhood can track into later life with impacts on lifelong health (1), FBDGs specifically tailored to addressing nutrient shortfalls in children <5 y old are urgently needed. Diet modeling offers a robust approach for the development of such guidelines (25), as previously shown in Australia (26) and more recently in the United States (24). Therefore, this study aimed to establish a protocol for addressing nutrient shortfalls in 1- to 5-y-old children based on diet modeling in an Irish population-based sample.

Methods

Study sample

The 2010–2011 Irish National Pre-school Nutrition Survey (NPNS) is a nationally representative cross-sectional survey conducted to examine habitual food and drink consumption, health and lifestyle characteristics, and body weight status in preschool children living in the Republic of Ireland (6). A detailed description of the methodology has been reported elsewhere (6). Briefly, 500 children aged 12–59 mo were recruited from "Eumom" (an Irish pregnancy and parenting resource) or randomly selected from childcare facilities in selected locations, representing variety in terms of age, gender, urban/rural location, and socio-demographics. Of note, although the NPNS sample contained a higher proportion of children of professional workers and a lower proportion of children of semiskilled and unskilled workers than the national population, there were no significant differences observed across social class categories for food and nutrient intakes or body weight in the sample. An information letter was sent to the primary caregiver (i.e., parent/guardian of each child). Participation was dependent on the prospective child "opting in." The survey was completed by the caregiver with assistance from a trained researcher. The present study was conducted in accordance with guidelines laid down in the Declaration of Helsinki and ethical approval was obtained from the Clinical Research Ethics Committee of the Cork Teaching Hospitals, University College Cork [Ref: ECM 4 (a) 06/07/10]. Written informed consent was obtained from the parent/guardian of each child before their participation in the survey.

Collection and analysis of dietary intake data

The NPNS study design involved weighed food records completed by the caregiver over a consecutive 4-d period, including 1 weekend day. For this purpose, a trained researcher made 3 home visits to the child and caregiver: an initial training visit to demonstrate how to complete the food diary and use the weighing scales; a second visit 24–36 h into the recording period to review the diary, check for completeness, and clarify details regarding specific food descriptors and quantities; and a final visit 1 or 2 d after the recording period to check the recording from the final days and to collect the diary. Caregivers recorded detailed information on the amounts, types, and brands of foods, beverages, and nutritional supplements consumed by the child over the 4 d and, where applicable, the cooking methods used, the packaging size and type, details of recipes, and leftover foods. In addition, caregivers recorded the time of each eating or drinking occasion, the definition of each eating or drinking occasion, and where the meals or snacks were prepared (6).

Dietary intakes were assessed using WISP© (Tinuviel Software), after customization of the database to in addition include composite dish recipes, nutritional supplements, fortified foods, infant-specific products, and commonly consumed generic Irish foods (6).

Diet modeling

For the purposes of the current study, typical nutrient intakes of the NPNS children were firstly compared with regional DRVs (11, 12) in order to identify the proportion of Irish children with nutrient shortfalls. Secondary analysis of the NPNS was subsequently conducted to identify foods consumed by ≥10% of children and typical patterns of consumption (i.e., breakfast, lunch, dinner, and snacks) for use in the diet modeling. **Figure 1** outlines the protocol for addressing nutrient shortfalls in 1- to 5-y-old children using diet modeling. Where a nutrient shortfall

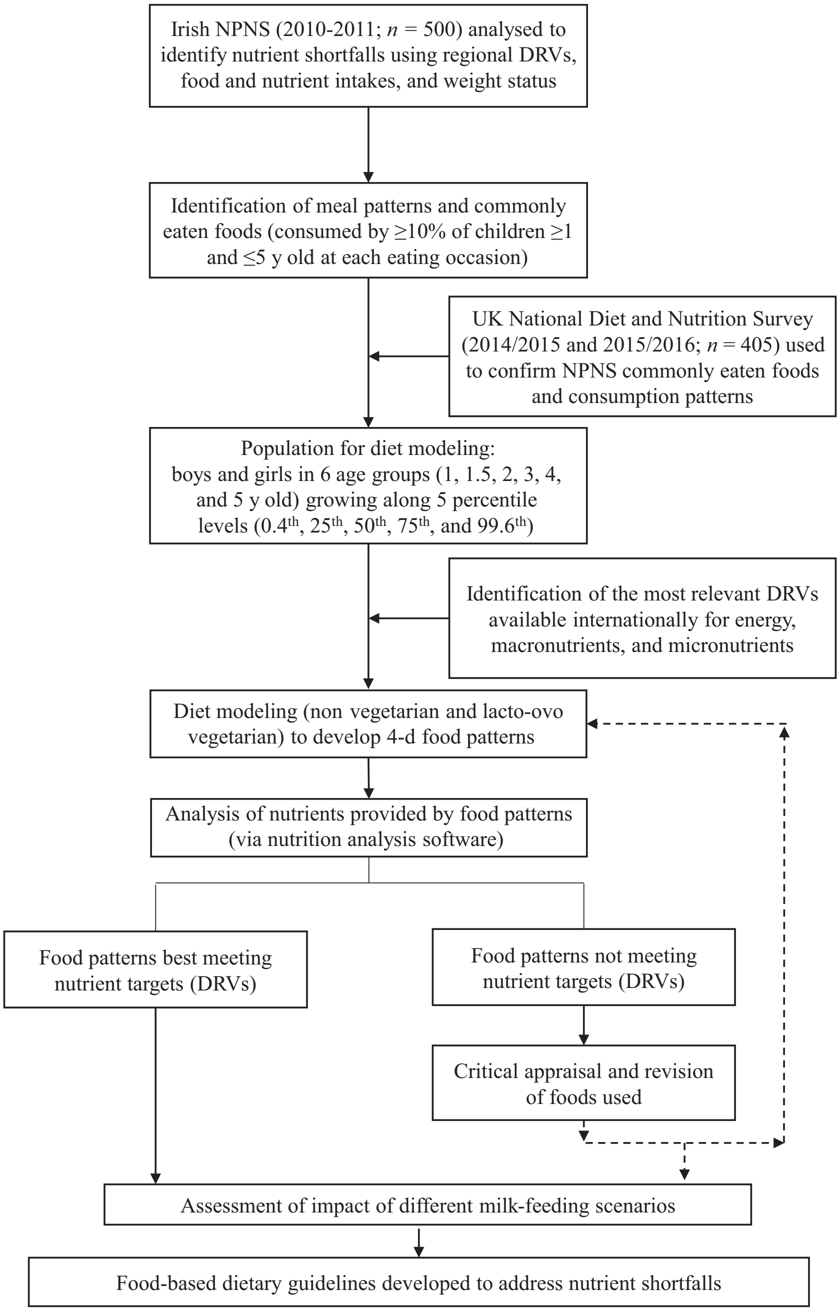

FIGURE 1 Protocol for addressing nutrient shortfalls in 1- to 5-y-old (12–60 mo) children using diet modeling in a population-based sample. DRV, dietary reference value; NPNS, National Pre-school Nutrition Survey.

emerged for ≥10% of children, the key food sources of that nutrient were identified and predicted intakes were assessed in the diet modeling.

General approach to diet modeling.

Diet modeling was conducted for boys and girls in 6 age groups [1 y (12 mo), 1.5 y (18 mo), 2 y (24 mo), 3 y (36 mo), 4 y (48 mo), and 5 y (60 mo)] to address nutrient shortfalls and to assess different milk-feeding scenarios within the range of energy requirements determined by reference body weights and lengths/heights using the WHO growth standards (0.4th, 25th, 50th, 75th, and 99.6th percentile) (7). Four-day food patterns were modeled following best practice guidelines for young child feeding (10) and guiding principles for developing FBDGs (22). Specifically, the food patterns provided predominantly human milk to age 2 y; minimal fat with a progressive reduction in saturated fat as age increased; free sugar intakes < 10% energy (E) or <5%E (15); no added salt or foods considered high in salt; and no processed meats (27, 28). The 4-d food patterns, which aimed to provide sufficient macro- and micronutrients within energy requirements, were modeled using the commonly consumed foods and patterns of consumption identified from the NPNS.

Each 4-d food pattern was modeled to provide the estimated energy requirement for each age, calculated using the Henry equation (29). Body weight and length/height (at the same percentile level) for all body sizes were determined by using WHO growth standards (7) and the European Food Safety Authority (EFSA) recommended physical activity levels (30). The 4-d food patterns were assessed for nutritional sufficiency using the following EFSA DRVs (11): the Population Reference Intake (PRI) for protein; the Recommended Intake (RI) for total fat and carbohydrate; saturated fat as low as possible; the Adequate Intake (AI) for DHA, fiber, vitamins D, E, and B-12, and iodine; and the Average Requirement (AR) for vitamins A, C, and B-6 and folate, riboflavin, calcium, iron, and zinc. The EFSA RDA and Tolerable Upper Intake Level (UL) values, where available, were also considered to improve assessment of adequacy (nutrient intakes relative to the RDA) and safety (nutrient intakes relative to the UL). The Institute of Medicine (IOM) (12) acceptable macronutrient distribution range (AMDR) was used to assess sufficiency of DHA + EPA. Where feasible, nutritional sufficiency of the 4-d food patterns was assessed against equivalent IOM DRVs for comparative purposes. Available information on seasonal differences in the proportions of children with serum 25-hydroxyvitamin D concentrations <30 or <50 nmol/L (17, 31) was used to explore the impact of skin synthesis of vitamin D due to inadvertent sunlight exposure.

Milk-feeding scenarios.

The main milk-feeding scenario used for diet modeling followed best practice, where predominantly human milk was given up to age 2 y [human milk (∼440 mL/d) alone for ≥1- to <1.5-y-olds and human milk (∼170 mL/d) in combination with whole cow milk (∼245 mL/d) for ≥1.5- to ≤2-y-olds]. **Supplemental Table 1** outlines the composition of the human milk used in the diet modeling (32), where human milk data were based on the following 2 sources (33, 34). In line with common milk-feeding practices, low-fat cow milk was given from age 2 y (>2- to ≤5-y-olds; ∼245 mL/d). After the 4-d food patterns were finalized, these milks were substituted with other commonly used milks to assess the impact of different milk-feeding practices on nutrient intakes. The substitute milks were whole cow milk (≥1 to ≤5 y); whole cow milk fortified with vitamin D (≥1 to ≤5 y); low-fat cow milk (1.5% fat; ≥2 to ≤5 y); low-fat cow milk fortified with vitamin D (1.5% fat; ≥2 to ≤5 y); Follow-Up Formula (FUF; ≥1 to <1.5 y; ∼440 mL/d); and Drink for Young Children with added nutrients (DYC; fortified drink; ≥1.5 to ≤3 y; ∼330 mL/d). In relation to FUF and DYC, the average nutrient content of a variety of these products, available on the Irish market, was calculated and used in the modeling. A daily mean intake of 550 mL milk, provided as a mixture of milk, cheese, and yogurt (where 200 mL milk ∼ 30 g cheese or 125 g yogurt), was modeled across all 4-d food patterns.

Assessing nutritional sufficiency.

The 4-d food patterns developed were inputted, and the nutrient content assessed, using nutrition analysis software (Nutritics Research Edition version 5.61), based on robust food composition data (32). Where a nutrient shortfall emerged, alternative food patterns providing sufficient intakes were examined to identify key food contributors. These foods were used to remodel the food patterns with nutrient shortfalls on an iterative basis to improve predicted intakes, within the constraints of best practice guidelines for young child feeding (10) and guiding principles for developing FBDGs (22). The iterative amendments to the food patterns formed the main basis of the nutrient-driven FBDGs developed to address nutrient shortfalls. **Supplemental Figure 1** outlines the protocol established to develop such FBDGs in a global context. After the nonvegetarian food patterns were finalized, lacto-ovo vegetarian patterns were modeled by replacing the meat, fish, and poultry with appropriate vegetarian alternatives (eggs, cheese, beans, lentils, tofu), on the main milk-feeding scenario, and adjusted as necessary to meet nutrient targets. The assumptions used for bioavailability of iron (10%), zinc (30%), and calcium (45% for 1–3 y; 30% for >3 y) were derived from the EFSA, where no differences are applied for vegetarians (11).

For validation purposes and to confirm that the foods identified for use in the diet modeling based on the NPNS were still commonly consumed foods (i.e., considering that the NPNS was carried out in 2010/2011), a post hoc secondary analysis was undertaken of more recent British data from the UK National Diet and Nutrition Survey of 1.5- to 5-y-old children (2014/2015 and 2015/2016; $n = 405$) (33). This was considered a suitable approach for validation purposes, given that dietary intakes in the United Kingdom and Ireland are known to be similar.

Identification of under-reporters (URs) in the NPNS cohort has previously been described by Kehoe et al. (20). In summary, basal metabolic rate (BMR) was predicted for each participant from standard equations using body weight (kg) and height (m). Minimum energy intake cutoffs, calculated as multiples of BMR (ratio of energy intake to BMR < 1.28) (34), were used to identify URs (24% of the total sample). URs were not excluded from the current analysis.

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) software (version 25.0; IBM Corp). The NPNS data were analyzed for current daily dietary intakes, and to identify the proportion of children not meeting DRV values and percentage contribution of food groups to intakes of those nutrients where a shortfall was identified in ≥10% of children. In order to assess the prevalence of inadequate intakes, the estimated average requirement (EAR) cutpoint method was applied and the distribution of intakes was considered by using the mean intake of the 4-d (including 1 weekend day) food diaries. Differences in predicted daily nutrient intakes from modeling different milk-feeding scenarios were assessed by ANCOVA after adjustment for age, with Bonferroni post hoc tests. For normalization purposes, variables were transformed before analysis, as appropriate. $P < 0.05$ was considered significant.

Results

Current dietary intakes

Table 1 outlines reported daily nutrient intakes from the NPNS. The EFSA and IOM DRVs used for assessing nutritional

TABLE 1 Daily dietary intakes in 1- to 5-y-old children from the Irish NPNS[1]

	Boys		Girls	
Age category[2]	12–47 mo ($n = 188$)	48–60 mo ($n = 63$)	12–47 mo ($n = 188$)	48–60 mo ($n = 61$)
Age, mo	29.2 ± 10.4	51.7 ± 3.2	29.2 ± 9.9	51.9 ± 3.5
Energy, kJ	4743 ± 1160	5483 ± 1014	4428 ± 883	5138 ± 985
Energy, kcal	1130 ± 276	1304 ± 241	1054 ± 211	1222 ± 234
Protein, g	42.1 ± 11.7	48.1 ± 9.4	40.8 ± 9.7	45.8 ± 11.5
Protein, g/kg BW	3.0 ± 0.9	2.7 ± 0.6	3.0 ± 0.8	2.5 ± 0.5
Total fat, g	41 ± 13	46 ± 12	39 ± 11	43 ± 11
Total fat, %E	33 ± 6	32 ± 5	33 ± 5	32 ± 5
Saturated fat, %E	15 ± 3	14 ± 3	15 ± 3	14 ± 3
DHA, mg	37 ± 59	48 ± 74	40 ± 59	36 ± 51
DHA + EPA, mg	72 ± 99	94 ± 191	74 ± 116	63 ± 76
Carbohydrate, g	148 ± 39	177 ± 41	137 ± 29	164 ± 38
Carbohydrate, %E	52 ± 6	54 ± 6	52 ± 6	54 ± 5
Free sugar, %E	11 ± 6	14 ± 5	10 ± 6	14 ± 5
Fiber, g	11.3 ± 4.1	13.1 ± 4.1	11.3 ± 3.5	12.4 ± 3.6
Micronutrients				
Vitamin A, μg	716 ± 464	652 ± 513	687 ± 564	649 ± 339
Vitamin D, μg	4.0 ± 4.6	3.4 ± 2.9	3.7 ± 3.5	3.0 ± 2.3
Vitamin E, mg	6.5 ± 8.5	6.2 ± 3.4	5.9 ± 4.9	6.3 ± 5.4
Vitamin C, mg	80 ± 58	96 ± 58	84 ± 45	92 ± 47
Folate, μg DFE	221 ± 123	228 ± 102	219 ± 133	236 ± 149
Vitamin B-12, μg	4.1 ± 2.2	4.3 ± 2.2	4.0 ± 2.0	3.7 ± 1.4
Vitamin B-6, mg	1.4 ± 0.7	1.6 ± 0.6	1.4 ± 0.6	1.4 ± 0.5
Riboflavin, mg	1.6 ± 0.7	1.6 ± 0.5	1.5 ± 0.5	1.4 ± 0.5
Calcium, mg	801 ± 313	775 ± 211	762 ± 254	720 ± 252
Iron, mg	7.4 ± 3.4	8.5 ± 3.2	7.1 ± 3.1	7.1 ± 2.0
Zinc, mg	5.4 ± 2.0	5.6 ± 1.5	5.2 ± 1.7	5.3 ± 1.6
Iodine, μg	169 ± 91	146 ± 58	156 ± 80	135 ± 63

[1] Data obtained from the Irish NPNS (2010–2011) (6). Values are means ± SDs. BW, body weight; DFE, dietary folate equivalents calculated as follows: natural folate (μg) + [folic acid from fortified foods (μg) × 1.7]; E, energy; NPNS, National Pre-School Nutrition Survey.

[2] Age groups according to those used by the European Food Safety Authority (11) and the Institute of Medicine (12) dietary reference values.

sufficiency are outlined in **Table 2**, along with the proportions of children with nutrient intake shortfalls (**Supplemental Table 2** provides additional details). The majority of children failed to meet the DRVs (EFSA AI) for vitamin D (98% of 1- to 3-y-olds; 100% of 4- to 5-y-olds), vitamin E (84% of 1- to 3-y-olds; 88% of 4- to 5-y-olds), DHA + EPA (80% of 1- to 3-y-olds; 82% of 4- to 5-y-olds; IOM AMDR), and fiber (63% of 4- to 5-y-olds), whereas free sugar intakes exceeded WHO recommendations of <10%E for 48% of 1- to 3-y-olds and 75% of 4- to 5-y-olds (Table 2). Although iron intake shortfalls (EFSA AR) were identified in smaller proportions of 1- to 3-y-olds (18%) and 4- to 5-y-olds (6%) (Table 2), the main food sources of iron in both groups included high-sugar fortified breakfast cereals and processed meats (**Table 3**), consumed by 49% and 83% of the children, respectively (data not shown). The main food groups contributing to nutrients where a shortfall was identified for ≥10% of children (Table 3) were fish and fish dishes (DHA + EPA); vegetables and vegetable dishes (vitamin A); milks (including fortified; vitamin D, calcium, zinc, and iodine); fruit and fruit juices (vitamin E); and fortified breakfast cereals (folate and iron) (**Supplemental Table 3** provides additional details). Overweight (BMI > 91st and ≤ 98th percentile; boys 17%, girls 16%) and obesity (BMI > 98th percentile; boys 8%, girls 5%) were prevalent in this population, whereas underweight (BMI < 2nd percentile) was uncommon (boys 1%, girls 0%; data not shown) (6).

Predicted dietary intakes from diet modeling

Diet modeling resulted in a total of 640 four-day food patterns which were revised, on a trial and error basis, as necessary to form 120 finalized 4-d food patterns (60 four-day nonvegetarian and 60 four-day lacto-ovo vegetarian). The food patterns were deemed finalized when the energy and the majority of nutrient requirements were met, within the constraints of best practice guidelines for young child feeding (10) and guiding principles for developing FBDGs (22). The finalized food patterns were based on the main milk-feeding scenario of predominantly human milk up to and including age 2 y and low-fat cow milk from age 2 y.

Predicted macronutrient intakes are outlined for ≥1- to ≤3-y-olds (**Table 4**) and ≥4- to ≤5-y-olds (**Table 5**). For ≥1- to ≤3-y-olds, the nonvegetarian "Human milk + Cow milk" scenario provided significantly more DHA than did cow milk alone and, although not quite reaching the EFSA AI for DHA, did achieve the IOM AMDR for DHA + EPA. For ≥4- to ≤5-y-olds, no milk-feeding scenario met the IOM AMDR for DHA + EPA. The EFSA AI for fiber was met by ≥1- to ≤3-y-olds on low-fat cow milk and on FUF and DYC (Table 4), and by ≥4- to ≤5-y-olds (Table 5). Free sugar intakes from the "Follow-up Formula + Fortified drink" scenario exceeded the WHO limit of <10%E, whereas intakes from all other milk-feeding scenarios for ≥1- to ≤3-y-olds were at or below the limit of <5%E and, for ≥4- to ≤5-y-olds, just above this limit at 6%E.

TABLE 2 Proportion of Irish children with daily dietary intakes falling outside regional DRVs[1]

	12–47 mo			48–60 mo		
	Current intakes ($n = 376$)	DRVs		Current intakes ($n = 124$)	DRVs	
		EFSA[2,3]	IOM[2,4]		EFSA[2,3]	IOM[2,4]
Energy, kJ	4586 ± 1041	3167–4753	3217–5786	5313 ± 1011	5807–6180	6117–6473
Energy, kcal	1092 ± 248	757–1136	769–1383	1264 ± 240	1388–1477	1462–1547
DHA,[5] mg	39 ± 59			42 ± 64		
Below EFSA AI, *n* (%)	329 (88)	100		—	N/A	
DHA + EPA, mg	73 ± 108			79 ± 147		
Below IOM AMDR, *n* (%)	300 (80)		70	102 (82)		90
Free sugars,[6] %E	10 ± 6			14 ± 5		
>10%E, *n* (%)	181 (48)			93 (75)		
>5%E, *n* (%)	303 (81)			124 (100)		
Fiber, g	11.3 ± 3.8			12.8 ± 3.9		
Below EFSA AI, *n* (%)	154 (41)	10		78 (63)	14	
Below IOM AI, *n* (%)	363 (97)		19	123 (99)		25
Micronutrients						
Vitamin A, μg	701 ± 516			650 ± 434		
Below EFSA AR, *n* (%)	19 (5)	205		11 (9)	245	
Below IOM EAR, *n* (%)	20 (5)		210	14 (11)		275
Vitamin D, μg	3.9 ± 4.1			3.2 ± 2.6		
Below EFSA AI, *n* (%)	368 (98)	15		124 (100)	15	
Below IOM EAR, *n* (%)	345 (92)		10	119 (96)		10
Vitamin E, mg	6.2 ± 6.9			6.2 ± 4.5		
Below EFSA AI,[7] *n* (%)	246 (65)	6		109 (88)	9	
Below EFSA AI,[8] *n* (%)	314 (84)	9				
Below IOM EAR, *n* (%)	209 (56)		5	72 (58)		6
Vitamin C, mg	82 ± 52			94 ± 53		
Below EFSA AR, *n* (%)	6 (2)	15		3 (2)	25	
Below IOM EAR, *n* (%)	3 (1)		13	2 (2)		22
Folate, μg DFE	220 ± 128			232 ± 127		
Below EFSA AR, *n* (%)	19 (5)	90		2 (2)	110	
Below IOM EAR, *n* (%)	50 (13)		120	35 (28)		160
Vitamin B-12, μg	4.0 ± 2.1			4.0 ± 1.8		
Below EFSA AI, *n* (%)	24 (6)	1.5		4 (3)	1.5	
Below IOM EAR, *n* (%)	0 (0)		0.7	2 (2)		1.0
Vitamin B-6, mg	1.4 ± 0.6			1.5 ± 0.6		
Below EFSA AR, *n* (%)	0 (0)	0.5		0 (0)	0.6	
Below IOM EAR, *n* (%)	0 (0)		0.4	0 (0)		0.5
Riboflavin, mg	1.6 ± 0.6			1.5 ± 0.5		
Below EFSA AR, *n* (%)	2 (1)	0.5		0 (0)	0.6	
Below IOM EAR, *n* (%)	0 (0)		0.4	0 (0)		0.5
Calcium, mg	782 ± 285			748 ± 233		
Below EFSA AR, *n* (%)	14 (4)	390		51 (41)	680	
Below IOM EAR, *n* (%)	56 (15)		500	77 (62)		800
Iron, mg	7.3 ± 3.3			7.8 ± 2.7		
Below EFSA AR, *n* (%)	68 (18)	5.0		7 (6)	5.0	
Below IOM EAR, *n* (%)	9 (2)		3.0	0 (0)		4.1
Zinc, mg	5.3 ± 1.8			5.5 ± 1.5		
Below EFSA AR, *n* (%)	55 (15)	3.6		36 (29)	4.6	
Below IOM EAR, *n* (%)	5 (1)		2.5	16 (13)		4.0
Iodine, μg	163 ± 86			140 ± 60		
Below EFSA AI, *n* (%)	78 (21)	90		25 (20)	90	
Below IOM EAR, *n* (%)	42 (11)		65	8 (7)		65

[1] Values obtained from the Irish National Pre-School Nutrition Survey (6). Values are means ± SDs unless indicated otherwise. AI, adequate intake; AMDR, acceptable macronutrient distribution range; AR, average requirement; DFE, dietary folate equivalents calculated as follows: natural folate (μg) + [folic acid from fortified foods (μg) × 1.7]; DRV, dietary reference value; E, energy; EAR, estimated average requirement; EFSA, European Food Safety Authority; IOM, Institute of Medicine; N/A, not applicable.

[2] DRVs from both the EFSA (11) and the IOM (12) were explored for macronutrients and micronutrients.

[3] DRV for energy calculated from EFSA recommendations (11), applying the weight range according to WHO growth standards (0.4th–99.6th percentiles) (7).

[4] DRV for energy calculated from IOM recommendations (12), applying the weight range according to WHO growth standards (0.4th–99.6th percentiles) (7).

[5] EFSA AI for DHA only applies to children ≥ 1 to ≤ 1.5 y old. There is no EFSA AI for DHA for >1.5 to ≤ 5 y of age.

[6] Free sugars limits of <10%E and <5%E were derived from WHO guidelines (15).

[7] EFSA AI for vitamin E for 1- to 2-y-olds is 6 mg/d.

[8] EFSA AI for vitamin E for 3-y-olds is 9 mg/d.

TABLE 3 Main food sources of key nutrients in 1- to 5-y-old children (12–60 mo)[1]

Key nutrient	Food group[2]	Percentage contribution to nutrient intake
DHA	Fish and fish dishes	30
	Total meat and meat products	27
	Fresh meat[3]	22
	Processed meat[4]	5
	Yogurt and cheeses	14
	Egg and egg dishes	12
DHA + EPA	Fish and fish dishes	34
	Total meat and meat products	20
	Fresh meat[3]	17
	Processed meat[4]	3
	Egg and egg dishes	11
Vitamin A	Vegetables and vegetable dishes	25
	Milks	22
	Total meat and meat products	12
	Fresh meat[3]	10
	Processed meat[4]	2
	Yogurt and cheeses	10
Vitamin D	Milks (fortified)	28
	Total meat and meat products	16
	Fresh meat[3]	6
	Processed meat[4]	10
	Yogurt and cheeses	11
	Nutritional supplements	10
Vitamin E	Fruit and fruit juices	17
	Milks (mainly fortified)	11
Dietary Folate Equivalents	Fortified breakfast cereals	26
	Low-sugar[5]	18
	High-sugar[6]	8
	Fruit and fruit juices	16
	Milks	14
Calcium	Milks	42
	Yogurt and cheeses	18
	Bread and rolls	10
Iron	Fortified breakfast cereals	31
	Low-sugar[5]	21
	High-sugar[6]	10
	Bread and rolls	12
	Total meat and meat products	11
	Fresh meat[3]	7
	Processed meat[4]	4
Zinc	Milks	26
	Total meat and meat products	23
	Fresh meat[3]	15
	Processed meat[4]	8
Iodine	Milks	65
	Yogurt and cheeses	10

[1] Values obtained from the Irish National Pre-School Nutrition Survey (*n* = 500) (6).

[2] The food groups listed are those contributing ≥10% to dietary intakes for a given nutrient.

[3] Fresh meat includes poultry, beef, veal, lamb, and pork.

[4] Processed meat includes bacon and ham, burgers (beef and pork), sausages, meat pies and pastries, and meat products.

[5] Providing <18 g sugar/100 g.

[6] Providing ≥18 g sugar/100 g.

Predicted vitamin A, folate, and calcium intakes were sufficient (relative to EFSA AR) for all scenarios (Tables 4 and 5). With the exception of the fortified cow milk feeding scenarios, shortfalls in predicted vitamin E intakes (EFSA AI) were evident in all other scenarios (Tables 4 and 5), with the greatest shortfalls observed in ≥1- to ≤3-y-olds at ≤25th percentile growth level. Shortfalls in predicted iodine and zinc intakes (EFSA AI and AR, respectively) were evident only in 1-y-olds modeled on human milk, especially those at ≤25th percentile growth level (**Supplemental Figure 2**). Predicted micronutrient intakes in no scenario modeled exceeded relevant EFSA ULs (data not shown).

Exploration of available information indicates that vitamin D deficiency in this age group almost disappears in summer months (17, 31). Shortfalls in predicted vitamin D intakes (EFSA AI) were evident in the main milk-feeding scenario (**Figure 2**B). Inclusion of a daily 5-µg vitamin D supplement increased predicted vitamin D intakes (Figure 2C). Although the EFSA AI was not achieved, this was deemed sufficient considering inadvertent skin synthesis among children in this age group in Ireland (17, 31). Among ≥1- to ≤3-y-olds, vitamin D shortfalls (EFSA AI) were not correctable, even with supplementation (5 µg/d), apart from in the "Follow-up Formula + Fortified drink" scenario (albeit free sugars intakes were estimated at 12%E compared with ≤5%E as provided by the other scenarios) (Table 4). In the case of ≥4- to ≤5-y-olds, even with supplementation (5 µg/d), no milk-feeding scenario corrected the vitamin D shortfalls (EFSA AI) (Table 5).

Shortfalls in predicted iron intakes (relative to the EFSA AR value), modeled to exclude high-sugar fortified breakfast cereals and processed meat, were evident in ≥1- to ≤3-y-olds (**Figure 3**B). Including 30 g of unprocessed red meat 2 out of the 4 d modeled (translating to 3 d/wk) and 20–30 g of low-sugar iron-fortified breakfast cereals (<18 g sugar/100 g; ≥12 mg Fe/100 g) 3 out of the 4 d modeled (translating to 5 d/wk) resolved iron intake shortfalls (EFSA AR) in ≥1- to ≤3-y-olds, except those at ≤25th percentile growth level (Figure 3C). For these children, an additional 4 mg Fe as either an iron-fortified milk (FUF or DYC) (Table 4) or a supplement (data not shown) resulted in sufficient iron intakes (EFSA AR). Of note, iron intakes in ≥1- to ≤3-y-olds modeled on the "Follow-up Formula + Fortified drink" scenario (Table 4) and all scenarios modeled for ≥4- to ≤5-y-olds (Table 5) achieved the EFSA RDA value (7 mg). The lacto-ovo vegetarian scenario provided comparable intakes of iron for ≥1- to ≤3-y-olds (Table 4) and significantly higher intakes for ≥4- to ≤5-y-olds (Table 5).

Nutrient-driven FBDGs for Irish children

From the diet modeling described here, the following FBDGs were formulated to address nutrient shortfalls in 1- to 5-y-olds in Ireland:

- Prolonged breastfeeding to age 2 y is optimal for providing DHA + EPA.
- Low-fat cow milk can be used from 2 y owing to the lower content of saturated fat but similar contribution to other nutrient intakes compared with whole cow milk.
- Non-vegetarian and lacto-ovo vegetarian food intake patterns are generally comparable in their nutritional contribution, except in the case of DHA + EPA which is limited in vegetarian diets. Furthermore, given the well-recognized poor bioavailability of iron from plant sources, a low-dose iron supplement may be advisable for children consuming vegetarian diets.

TABLE 4 Predicted daily intakes of key nutrients for 1- to 3-y-old (12–36 mo) children arising from modeling of different milk-feeding scenarios[1]

	Nonvegetarian milk-feeding scenarios				Lacto-ovo vegetarian scenario	
	Human milk + cow milk	Whole cow milk	Low-fat cow milk	Follow-up formula + fortified drink	Human milk + cow milk	*P* value[2]
Age, y	1.8 (1.5, 2.0)	1.8 (1.5, 2.0)	2.5 (2.0, 3.0)	1.8 (1.5, 2.0)	1.8 (1.5, 2.0)	
Energy, kJ	3964 (3483, 4222)	3849 (3301, 4171)	4273 (3710, 4722)	3858 (3399, 4418)	3957 (3486, 4240)	0.728
Macronutrients						
Protein, g/kg BW	3.6 (3.3, 3.7)^{a,c}	4.0 (3.8, 4.2)^{b}	3.9 (3.6, 4.5)^{a,b}	3.4 (3.2, 3.7)^{a,c}	3.2 (2.9, 3.5)^{c}	<0.001
Total fat, %E	36 (34, 38)^{a}	36 (34, 37)^{a}	29 (28, 31)^{b}	33 (31, 35)^{b}	36 (35, 37)^{a}	<0.001
Saturated fat, %E	17 (16, 19)^{a}	18 (18, 20)^{b}	13 (12, 15)^{a,c}	14 (13, 15)^{c}	17 (16, 18)^{a}	<0.001
DHA, mg	97 (72, 144)^{a}	6 (4, 113)^{b}	—	24 (21, 125)^{a,b}	63 (44, 93)^{a,b}	<0.001
DHA + EPA, mg	83 (50, 171)	54 (7, 171)	54 (7, 171)	36 (35, 182)	25 (0, 50)	0.567
Carbohydrate, %E	46 (45, 48)^{a}	44 (42, 46)^{b}	52 (49, 53)^{a,c}	49 (48, 51)^{c}	47 (46, 49)^{a,c}	<0.001
Total sugars,[3] %E	23 (21, 25)^{a}	20 (19, 22)^{b}	24 (22, 26)^{a,b}	25 (23, 26)^{a}	24 (22, 25)^{a}	<0.001
Free sugars,[3] %E	4 (4, 5)^{a}	4 (4, 5)^{a}	5 (4, 6)^{a}	12 (11, 14)^{b}	3 (3, 4)^{a}	<0.001
Fiber, g	8.9 (7.8, 11.5)^{a}	9.0 (7.8, 11.5)^{a}	12.1 (9.2, 14.4)^{a,b}	10.6 (9.6, 12.8)^{b}	8.9 (8.0, 11.5)^{a}	0.005
Micronutrients						
Vitamin A, μg	592 (533, 687)^{a}	573 (486, 663)^{a}	561 (443, 591)^{a}	644 (559, 704)^{a}	422 (395, 472)^{b}	<0.001
Vitamin D,[4] μg	6.8 (6.5, 7.0)^{a}	6.8 (6.5, 6.9)^{a}	7.2 (6.8, 7.8)^{a}	17.2 (16.1, 20.0)^{b}	6.7 (6.6, 7.0)^{a}	<0.001
Vitamin E, mg	2.9 (2.7, 3.1)^{a}	2.4 (1.9, 2.9)^{b}	2.8 (2.3, 3.0)^{a,b}	5.2 (4.6, 5.9)^{c}	2.9 (2.4, 3.1)^{a}	<0.001
Folate, μg DFE	151 (143, 162)^{a}	160 (151, 170)^{a}	144 (123, 154)^{a}	194 (187, 203)^{b}	156 (147, 164)^{a}	<0.001
Calcium, mg	663 (618, 756)^{a}	836 (773, 863)^{b}	853 (780, 915)^{b,c}	742 (662, 810)^{a,b}	709 (656, 762)^{a,c}	<0.001
Iron, mg	5.8 (5.4, 6.0)^{a}	5.7 (5.3, 6.0)^{a}	6.0 (5.7, 6.6)^{a}	8.9 (8.2, 9.2)^{b}	6.2 (5.7, 6.5)^{a}	<0.001
Zinc, mg	4.6 (4.2, 5.4)^{a}	5.0 (4.7, 5.6)^{a}	5.4 (4.8, 5.7)^{a,c}	5.8 (5.4, 6.1)^{b}	4.2 (3.8, 4.6)^{c}	<0.001
Iodine, μg	113 (105, 132)^{a}	157 (147, 167)^{b}	144 (137, 170)^{b}	117 (100, 122)^{a}	123 (95, 136)^{a}	<0.001

[1] Values are medians (95% CIs) unless indicated otherwise. Dietary modeling conducted for different milk-feeding scenarios informed by international best practice (as regards salt, fat, free sugars, and processed meat) and to provide energy intakes in alignment with the WHO growth range (7) and address dietary shortfalls. Five food pattern scenarios were modeled based on the predominant milk source (including 4 different nonvegetarian milk-feeding scenarios and 1 lacto-ovo vegetarian scenario) as follows. Human milk + cow milk: modeled on human milk alone (≥1 to <1.5 y; ~440 mL/d; 10 percentile levels), human milk in combination with unfortified whole cow milk (≥1.5 to ≤2 y; ~170 mL/d human milk and ~245 mL/d unfortified whole cow milk; 20 percentile levels), or unfortified low-fat cow milk alone (>2 to ≤3 y; ~195 mL/d; 10 percentile levels) based on 376 children from the NPNS (6). Whole cow milk: modeled on unfortified whole cow milk (≥1 to ≤3 y; 40 percentile levels) based on 376 children from the NPNS (6). Whole cow milk fortified with vitamin D was also modeled with the only notable difference being a significantly higher amount of vitamin D (data not shown). Low-fat cow milk: modeled on unfortified low-fat cow milk (≥2 to ≤3 y: 20 percentile levels) based on 250 children from the NPNS (6). The EFSA DHA AI applies to children ≥1 to ≤1.5 y old; no DHA data are shown for this scenario because this milk is only recommended for children ≥2 y old. Low-fat cow milk fortified with vitamin D was also modeled with the only notable difference being a significantly higher amount of vitamin D (data not shown). Follow-up formula + fortified drink: modeled on Follow-Up Formula products (≥1 to <1.5 y; ~440 mL/d; 10 percentile levels) or Drink for Young Children with added nutrients products (≥1.5 to ≤3 y; ~330 mL/d; 30 percentile levels) based on 376 children from the NPNS (6). Human milk + cow milk: modeled on the same milks as human milk + cow milk, but meat, poultry, and fish were replaced with vegetarian alternatives. BW, body weight; DFE, dietary folate equivalents calculated as follows: natural folate (μg) + [folic acid from fortified foods (μg) × 1.7]; E, energy; NPNS, National Pre-school Nutrition Survey.

[2] $P < 0.05$ was considered significant. Differences between groups were analyzed by ANCOVA adjusting for age, with Bonferroni post hoc tests. Values in a row without a common superscript letter are statistically significantly different.

[3] There is no recommended daily intake for total sugars because, as well as including sugars naturally present in staple foods such as milk and fruit, total sugar also includes free sugars. Daily intakes of free sugars should be limited where possible to <5%E and not exceed 10%E (15).

[4] Predicted vitamin D intakes include a daily 5-μg vitamin D supplement.

- A low-dose vitamin D supplement should be recommended for all 1- to 5-y-olds.

Discussion

Assessment of dietary intakes in this representative sample of Irish children revealed shortfalls in DHA + EPA, vitamin D, and vitamin E, relative to current DRVs. In addition, high proportions of children had suboptimal dietary fiber intakes, whereas free sugars intakes exceeded WHO recommendations. Using best practice international guidelines, we identified intervention scenarios to correct shortfalls in intakes of key nutrients, albeit vitamin D shortfalls were generally not correctable, even with supplementation at a dosage of 5 μg/d. The current findings also reinforce the critical role of breastfeeding to 2 y in providing sufficient DHA and EPA.

Breastfeeding is essential for protecting against infant infection and mortality (10), particularly in LMICs, but less evidence exists on the benefits of breastfeeding beyond 1 y in HICs (35). Of note, breastfeeding to 2 y was the only milk-feeding scenario modeled in this study that provided sufficient DHA and EPA intakes. Given that DHA is essential for visual and cognitive development in young children (11–13), the shortfalls in DHA intakes identified here in Irish children, in common with other HICs (13), are of concern. Breastfeeding beyond 4–6 mo is generally an atypical practice in HICs (35, 36); however,

TABLE 5 Predicted daily intakes of key nutrients for 4- to 5-y-old (48–60 mo) children arising from modeling of different milk-feeding scenarios[1]

	Nonvegetarian milk-feeding scenarios				Lacto-ovo vegetarian scenario	
	Low-fat cow milk	Whole cow milk	Fortified low-fat cow milk	Fortified whole cow milk	Low-fat cow milk	*P* value[2]
Age, y	4.5 (4.0, 5.0)	4.5 (4.0, 5.0)	4.5 (4.0, 5.0)	4.5 (4.0, 5.0)	4.5 (4.0, 5.0)	
Energy, kJ	5838 (5544, 6205)	6102 (5776, 6503)	5838 (5544, 6224)	5992 (5560, 6273)	5850 (5579, 6211)	0.717
Macronutrients						
Protein, g/kg BW	3.6 (3.4, 4.0)	3.6 (3.4, 4.0)	3.6 (3.4, 4.0)	3.6 (3.4, 4.0)	3.4 (3.2, 3.5)	0.138
Total fat, %E	27 (26, 29)^{a}	31 (29, 32)^{b}	27 (26, 29)^{a}	31 (29, 32)^{b}	29 (27, 30)^{a,b}	<0.001
Saturated fat, %E	13 (12, 14)^{a}	15 (14, 16)^{b}	13 (11, 14)^{a}	15 (14, 16)^{b}	13 (12, 13)^{a}	<0.001
DHA + EPA, mg	83 (10, 203)^{a}	83 (10, 203)^{a}	83 (10, 203)^{a}	83 (10, 203)^{a}	0 (0, 0)^{b}	<0.001
Carbohydrate, %E	54 (53, 56)^{a}	52 (50, 54)^{b}	55 (53, 57)^{a}	52 (51, 54)^{b}	55 (54, 56)^{a}	<0.001
Total sugars,[3] %E	29 (28, 31)^{a,b}	28 (26, 29)^{a}	30 (28, 31)^{a,b}	28 (26, 29)^{a}	29 (28, 31)^{b}	0.001
Free sugars,[3] %E	6 (5, 7)	6 (5, 7)	6 (5, 7)	6 (5, 7)	6 (5, 6)	0.707
Fiber, g	18.6 (17.0, 21.1)	18.6 (17.0, 21.1)	18.6 (17.0, 21.1)	18.6 (17.0, 21.1)	19.1 (16.4, 19.8)	0.999
Micronutrients						
Vitamin A, μg	600 (533, 790)^{a,b}	659 (605, 849)^{b}	605 (533, 790)^{a,b}	659 (605, 849)^{b}	499 (428, 570)^{a}	0.001
Vitamin D,[4] μg	7.6 (7.2, 9.0)^{a,d}	7.3 (7.0, 8.7)^{a}	11.3 (10.5, 12.6)^{b}	14.2 (13.8, 15.4)^{c}	8.4 (8.3, 9.1)^{d}	<0.001
Vitamin E, mg	4.4 (3.8, 4.8)^{a}	4.5 (3.9, 4.9)^{a}	12.7 (10.3, 13.1)^{b}	11.1 (9.1, 11.7)^{b}	4.5 (3.9, 5.4)^{a}	<0.001
Folate, μg DFE	218 (203, 236)^{a}	243 (230, 263)^{b}	593 (524, 612)^{c}	447 (389, 461)^{d}	227 (214, 248)^{a,b}	<0.001
Calcium, mg	1092 (1065, 1203)^{a}	1092 (1065, 1203)^{a}	1148 (1107, 1259)^{a,b}	1243 (1185, 1363)^{b}	1138 (1079, 1271)^{a,b}	0.002
Iron, mg	8.9 (8.3, 9.4)^{a}	8.9 (8.3, 9.4)^{a}	8.9 (8.3, 9.4)^{a}	8.9 (8.3, 9.4)^{a}	9.5 (9.4, 9.8)^{b}	0.005
Zinc, mg	7.3 (6.8, 7.9)^{a,b}	7.6 (7.2, 8.3)^{a}	7.3 (6.8, 7.9)^{a,b}	7.6 (7.2, 8.3)^{a}	6.6 (6.3, 7.4)^{b}	<0.001
Iodine, μg	218 (187, 237)	222 (190, 240)	218 (187, 237)	222 (190, 240)	233 (201, 242)	0.346

[1] Values are medians (95% CIs) unless indicated otherwise. Dietary modeling conducted for different milk-feeding scenarios informed by international best practice (as regards salt, fat, free sugars, and processed meat) and to provide energy intakes in alignment with the WHO growth range (7) and address dietary shortfalls. Five food pattern scenarios were modeled based on the predominant milk source (including 4 different nonvegetarian milk-feeding scenarios and 1 lacto-ovo vegetarian scenario) as follows. Low-fat cow milk: modeled on unfortified low-fat cow milk (≥4 to ≤5 y; 20 percentile levels) based on 124 children from the NPNS (6). Whole cow milk: modeled on unfortified whole cow milk (≥4 to ≤5 y; 20 percentile levels) based on 124 children from the NPNS (6). Fortified low-fat cow milk: modeled on low-fat cow milk fortified with vitamin D (≥4 to ≤5 y; 20 percentile levels) based on 124 children from the NPNS (6). Fortified whole cow milk: modeled on whole cow milk fortified with vitamin D (≥4 to ≤5 y; 20 percentile levels) based on 124 children from the NPNS (6). Low-fat cow milk: modeled on the same milk as low-fat cow milk, but meat, poultry, and fish were replaced with vegetarian alternatives. BW, body weight; DFE, dietary folate equivalents calculated as follows: natural folate (μg) + [folic acid from fortified foods (μg) × 1.7]; E, energy; NPNS, National Pre-school Nutrition Survey.

[2] $P < 0.05$ was considered significant. Differences between groups were analyzed by ANCOVA adjusting for age, with Bonferroni post hoc tests. Values in a row without a common superscript letter are statistically significantly different.

[3] There is no recommended daily intake for total sugars because, as well as including sugars naturally present in staple foods such as milk and fruit, total sugar also includes free sugars. Daily intakes of free sugars should be limited where possible to <5%E and not exceed 10%E (15).

[4] Predicted vitamin D intakes include a daily 5-μg vitamin D supplement.

the current findings show clear benefits of breastfeeding to 2 y, to some extent validating in a national context the benefits of international recommendations. This study also shows the importance of fish for DHA + EPA intakes, although this was included only once in each 4-d pattern, in line with Irish healthy eating advice which limits oily fish to once per week owing to concerns regarding potential exposure to contaminants. To address widespread DHA and EPA shortfalls, especially among vegetarians, supplements (13) or fortified foods (37) could also be recommended, but further research is needed to assess the effectiveness of these approaches on childhood nutrition and growth (13). The smallest breastfed children (1-y-olds at ≤25th percentile growth level) had shortfalls in predicted intakes of iodine and zinc, presumably owing to the absence of cow milk, a major iodine source in Ireland (38) where no iodized salt policy exists, and the low zinc content of human milk beyond 6 mo postpartum (39). The current findings thus not only show the benefits for DHA + EPA intakes of breastfeeding for longer periods, but also highlight those children at greatest risk of iodine and zinc shortfalls owing to small size who could be identified through child growth monitoring.

The provision of sufficient vitamin D through foods in this study was particularly challenging, as shown elsewhere (19, 40). In Ireland, just 29% of children <5 y old consume vitamin D–fortified foods, whereas only 20% consume vitamin D supplements (17). The effectiveness of micronutrient-fortified young-child formula products in improving intake and status of vitamin D has been previously reported in the current cohort of Irish children (20) and in other European, and New Zealand and Australian, children (41, 42). It is noteworthy that current requirements for vitamin D (the EFSA AI and IOM EAR) assume no skin synthesis of vitamin D from sunlight exposure (11, 43). Irrespective of dietary intakes, however, inadequate vitamin D status in children <5 y old in Ireland was previously reported to disappear in summer months (17), a seasonal variation that has also been observed in Danish children (44), emphasizing the importance of skin synthesis.

As in other HICs (19, 45, 46), this study highlights fortified cereals, meat, meat products, and DYC as key food sources of

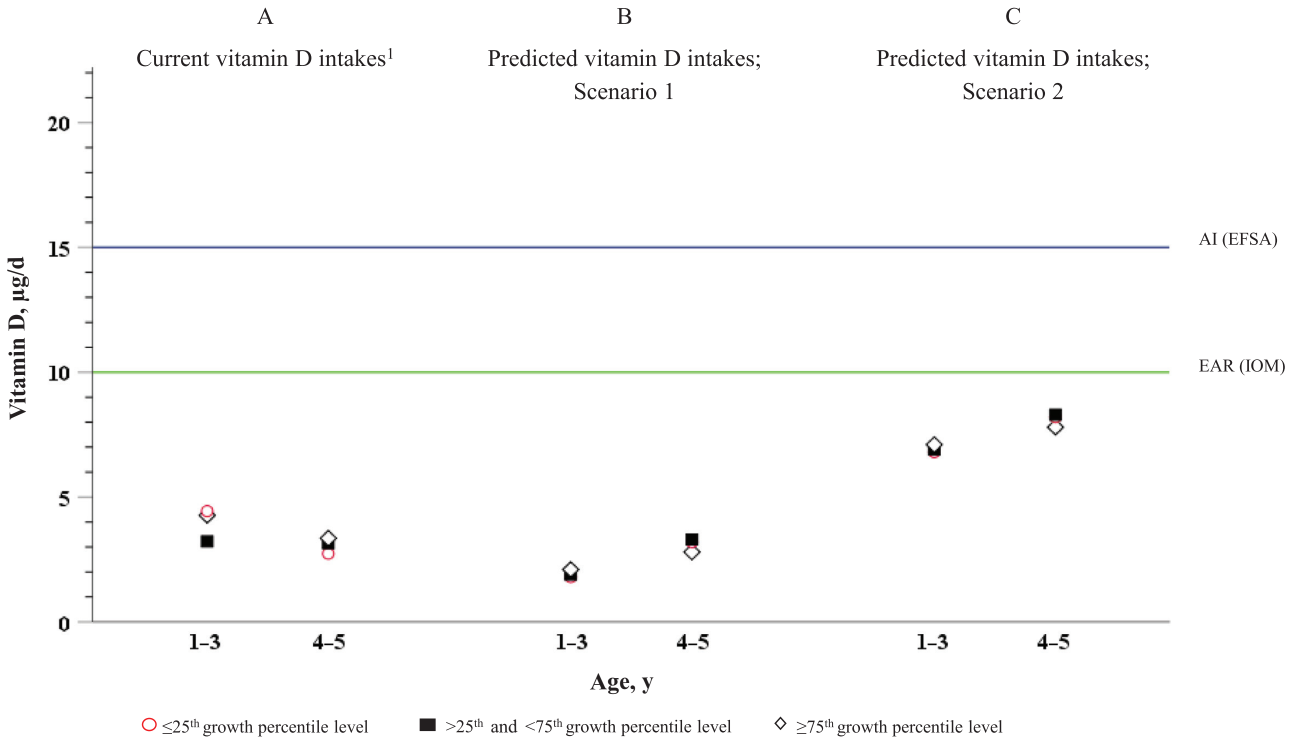

FIGURE 2 Diet modeling to address vitamin D shortfalls in 1- to 5-y-old (12–60 mo) children. (A) Current mean vitamin D intakes (µg/d). (B) Predicted mean vitamin D intakes (µg/d) based on the main milk-feeding scenario: predominantly human milk up to and including age 2 y [human milk (~440 mL/d) alone for ≥1- to <1.5-y-olds and human milk (~170 mL/d) in combination with whole cow milk (~245 mL/d) for ≥1.5- to ≤2-y-olds] and low-fat cow milk from age 2 y (~295 mL/d), excluding all high-sugar cereals and processed meats. (C) Predicted mean vitamin D intakes (µg/d) as for (B), with the addition of a daily 5-µg vitamin D supplement. [1]For details of current dietary intakes, see Tables 1 and 2. AI, adequate intake; EAR, estimated average requirement; EFSA, European Food Safety Authority; IOM, Institute of Medicine.

iron in the diets of young children. Although current dietary iron intakes were found to be generally sufficient, certain foods contributing to iron (high-sugar iron-fortified cereals and processed meat) were not aligned with best practice guidelines. Diet modeling which excluded all high-sugar cereals and processed meat thus resulted in shortfalls in predicted iron intakes in 1- to 3-y-olds. Iron intake shortfalls in young children are common in HICs, estimated to affect 26% of 12- to 23-mo-olds (18) and 10% of 2- to 5-y-olds (45), and deficiency can be exacerbated by enteropathogenic infection in LMICs (47). This is of concern because iron deficiency anemia in young children can impair cognitive development (48). In addition, although the current results show that lacto-ovo vegetarian and nonvegetarian diets can provide comparable iron intakes, the bioavailability of nonheme iron (i.e., that from plant-based foods) is known to be considerably lower than that of heme iron from a meat-based diet (11, 12). In the current study, shortfalls in predicted iron intakes among 1- to 3-y-olds were addressed by FUF and DYC or an iron supplement—approaches shown to be effective elsewhere (41, 42, 49). Given concerns regarding potential adverse effects of iron supplementation, however, targeting only children identified at risk (1- to 3-y-olds at ≤25th percentile level) and using a low-dose supplement seems prudent (47, 49).

The findings in the current study, that the smaller children (1- to 3-y-olds at ≤25th percentile growth level) are more at risk of nutritional shortfalls, suggest that DRVs for this age group should perhaps be derived on a per kilogram body weight basis rather than by age. In Ireland (6), as in other HICs (19, 40, 50), intakes of saturated fat and free sugars exceed recommendations in this age group. In this study, energy requirements related to body size in the children prompted the use of lower-fat foods in the diet modeling. Nevertheless, predicted saturated fat intakes remained high, indicating the challenges of achieving low saturated fat intakes in young children. Notably, the more stringent free sugars target of <5%E (15) was shown in this study to be achievable except within the "Follow-up Formula + Fortified drink" milk-feeding scenario, perhaps detracting to some extent from benefits provided by these milks in terms of micronutrient intakes.

Many different approaches for developing FBDGs exist, such as single- or multiobjective optimization modeling, food pattern modeling, and a combination of these (51). In the current study, nutrient shortfalls were addressed by developing FBDGs in the context of energy requirements related to body size. By identifying nutrient shortfalls in this way, our protocol could be used to inform appropriate dietary interventions at the time of routine growth monitoring, which would simultaneously address obesity risk and nutrient deficiency, i.e., the double burden of malnutrition (4). There is growing consensus that such interventions are needed among young children to reduce the long-term risks associated with diet-related noncommunicable diseases (4, 5, 10). The training of health workers in assessment of child growth using WHO standards (8) could be extended to include FBDGs, to be developed by applying this protocol to child feeding practices specific to their countries. This would

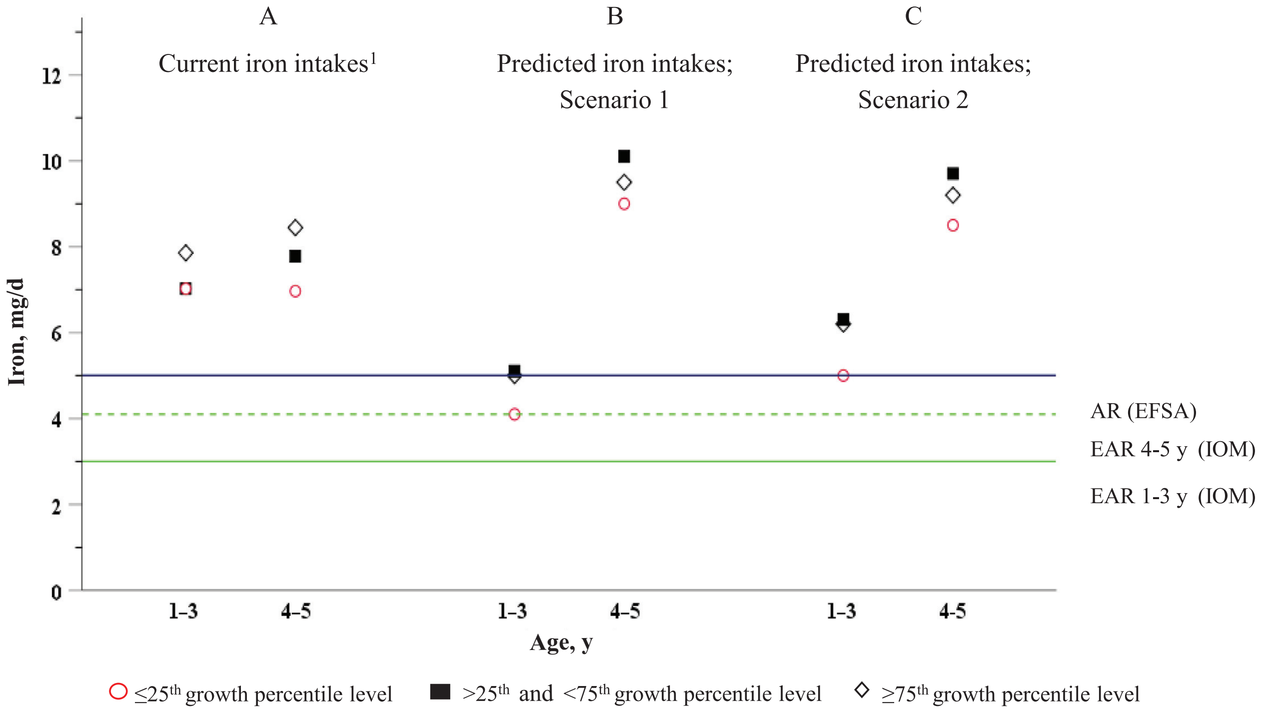

FIGURE 3 Diet modeling to address iron shortfalls in 1- to 5-y-old (12–60 mo) children. (A) Current mean iron intakes (mg/d) including high-sugar (≥18 g/100 g) iron-fortified cereals and processed meat, consumed by 49% and 83% of 1- to 5-y-olds, respectively. (B) Predicted mean iron intakes (mg/d) based on the main milk-feeding scenario: predominantly human milk up to and including age 2 y [human milk (∼440 mL/d) alone for ≥1- to <1.5-y-olds and human milk (∼170 mL/d) in combination with whole cow milk (∼245 mL/d) for ≥1.5- to ≤2-y-olds] and low-fat cow milk from age 2 y (∼295 mL/d), excluding all high-sugar cereals and processed meat. (C) Predicted mean iron intakes (mg/d) as for (B), but with the addition of low-sugar iron-fortified (<18 g sugar/100 g; ≥12 mg Fe/100 g) cereals 5 d/wk and unprocessed red meat 3 d/wk. [1] For details of current dietary intakes see Tables 1 and 2, and for the main food contributors see Table 3. AR, average requirement; EAR, estimated average requirement; EFSA, European Food Safety Authority; IOM, Institute of Medicine.

enable health staff to identify and intervene in cases of children at particular nutritional risk related to specific growth parameters and local foods. By enabling trained health workers to provide more specific dietary guidance, use of this protocol could address concerns regarding the lack of nutrition information provided at the time of growth assessment (9). For example, in the current context, such interventions among Irish children could address the higher risk of vitamin E and iron shortfalls predicted in 1- to 3-y-olds at ≤25th growth percentile, and shortfalls in iodine and zinc in predominantly human milk–fed 1-y-olds at ≤25th growth percentile.

The limitations of the current study are acknowledged. Our protocol used the widest WHO growth range (0.4th–99.6th percentile), although the lower extreme has limited applicability for healthy children in Ireland. Also, although the FBDGs developed here to address nutrient shortfalls are designed to accompany growth monitoring, they are based on patterns where weight and linear growth are aligned and need to be developed further to cover the commonly encountered growth issues of over- or under-nutrition. The serious limitations to the use of estimated human milk data in this as in other similar studies must also be acknowledged. The human milk data modeled in the current study were based on estimated UK average intakes (32–34). However, inconsistencies in protocols used to collect national data on human milk consumption, as well as differences in maternal micronutrient status, can cause substantial variation in the data (52, 53). Of note, the iodine content of human milk used in this study, although similar to values used by the United Kingdom and EFSA, was much lower than the values used by the IOM to set recommendations (53), possibly owing to higher use of iodized salt in the United States and Canada. In addition, the limited evidence available for establishing DRVs for this age group (11, 12) is challenging and the proportions of children shown here to have nutrient shortfalls were dependent on the DRV applied (i.e., EFSA or IOM). Also, whereas the predicted intakes in the modeled scenarios aimed to meet the AR or AI values (depending on the nutrient), the use of the RDA value as the intake goal would result in higher proportions of children with predicted nutrient shortfalls. Finally, although the current study protocol was developed using representative and comprehensive dietary intake data (6), the performance of the protocol using more limited dietary data (as is likely to be the case in LMICs) needs to be tested. The main strength of the study was the availability of dietary survey data from a nationally representative cohort of Irish preschool children, collected by robust methodology involving weighed food records over a consecutive 4-d period, including 1 weekend day. Also, the approach used to address nutrient shortfalls, based on WHO growth standards representing optimal growth for children internationally, enabled assessment of various milk-feeding scenarios in alignment with prevailing food and cultural habits by using local, commonly consumed, age-appropriate foods. Notably, our protocol accommodates international best practice guidelines for young child feeding to prevent diet-related chronic disease.

In conclusion, this study is one of the first to establish a protocol for addressing nutrient shortfalls among children $\geq$1 and $\leq$5 y old based on national dietary intake data and in alignment with WHO growth standards. Notably, the nutrient-driven FBDGs established from this protocol have formed the scientific basis to underpin the development of healthy eating guidelines for 1- to 5-y-old children in Ireland (54). The protocol presented here, although based on Irish data, incorporates international best practice and is applicable for addressing nutrient shortfalls for children elsewhere in country-specific population health.

The authors' responsibilities were as follows—MATF, MAK, and HM: planned and designed the research, provided supervision to OCL, and had primary responsibility for the final content; OCL: was primarily responsible for analyzing the data and conducting the diet modeling, with advisory inputs from MATF and IS, and wrote the initial draft of the manuscript; FW, MBEL, and PAB: advised on the protocol development; JW, BAM, and LK: provided access to the NPNS database and advised on data analysis; and all authors: contributed revisions to improve the scientific content and read and approved the final manuscript. The authors report no conflicts of interest.

Data Availability

Data described in the article, code book, and analytic code will be made available upon request, pending application and approval from the Irish Universities Nutrition Alliance (IUNA) Data Access committee.

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