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

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Abbreviations used: AI, adequate intake; AMDR, acceptable macronutrient distribution range; AR, average requirement; BMR, basal metabolic rate; DFE, dietary folate equivalents;

DHA, docosahexaenoic acid; DRV, dietary reference value; DYC, drink for young children with added nutrients; EAR, estimated average requirement; EFSA, European Food Safety Authority; EPA, eicosapentaenoic acid; FBDG, food-based dietary guidelines; FUF, follow-up formula; HIC, high-income countries; IOM, Institute of Medicine; LMIC, low- and middle-income countries; NDNS, National Diet and Nutrition Survey; NHANES, National Health and Nutrition Examination Survey; NPNS, National Pre-School Nutrition Survey; PRI, population reference intake; RDA, recommended dietary allowance; RI, reference intake; UK, United Kingdom; UL, tolerable upper level; URs, under-reporters; WHO, World Health Organization

ABSTRACT

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

Objective: To establish a protocol for addressing nutrient shortfalls in 1-5-y-old children (12-60 months) using diet modeling in a population-based sample.

Design: Secondary analysis of the 2010-2011 Irish National Pre-School Nutrition Survey data (*n* 500) was conducted to identify typical food consumption patterns in 1-5-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-day food patterns were developed to assess different milk-feeding scenarios (human milk, whole or low-fat cow's milk and fortified milks) within energy requirement ranges aligned with World Health Organization (WHO) growth standards. FBDG to address nutrient shortfalls were established based on 120 food patterns.

Results: Current mean dietary intakes for the majority of 1-5-y-olds failed to meet reference values (EFSA) for vitamin D (≤100%), vitamin E (≤88%), docosahexaenoic/eicosapentaenoic acid (DHA+EPA; IOM; ≤82%) and fiber (≤63%), while free sugars intakes exceeded recommendations of <10% energy (E) for 48% of 1-3-y-olds and 75% of 4-5-y-olds. 'Human milk + Cow's milk' was the only milk-feeding scenario modeled that predicted sufficient DHA+EPA among 1-3-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 1-3-y-olds (albeit free sugars intakes were estimated at 12%E compared to ≤5%E provided by other scenarios). Iron and vitamin E shortfalls were most prevalent in scenarios for 1-3-y-olds at ≤25th growth percentile.

Conclusions: Using WHO growth standards and international reference values, this study provides a protocol for addressing nutrient shortfalls among 1-5-y-olds, which could be applied in country-specific population health.

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 non-communicable diseases in later-life (4, 5). Malnutrition in children under 5 years typically manifests as micronutrient deficiency both in low- and middle-income countries (LMIC) (4) and high-income countries (HIC) including Ireland (6). This is further complicated, irrespective of region, by excessive or inadequate energy intake, leading to overweight or underweight, wasting and stunting, respectively (3, 4). The World Health Organization (WHO) growth standards characterize how children under 5 years 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 healthcare 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 non-communicable diseases, which highlights the importance of achieving adequacy for some nutrients while limiting others (10). This includes ensuring sufficient intakes of long-chain polyunsaturated fatty acids, namely docosahexaenoic acid (DHA) (11) and eicosapentaenoic acid (EPA) (12, 13), iron and vitamin D (14), whilst 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). While certain nutrient deficiencies are more prevalent in LMIC (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 estimations of inadequacy for given nutrients between countries (21).

Over 100 countries worldwide have published food-based dietary guidelines (FBDG) but few have addressed the specific nutritional requirements of 1–5 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 food-based diet (23). In the majority of countries, however, FBDG for 1–5 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 months (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), FBDG specifically tailored to addressing nutrient shortfalls in children <5 years 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 America (24). Therefore, this study aimed to establish a protocol for addressing nutrient shortfalls in 1–5 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 pre-school 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 months were recruited from ‘Eumom’ (an Irish pregnancy and parenting resource) or randomly selected from childcare facilities in selected locations, representing 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 semi-skilled 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 prior to 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-day period, including one weekend day. For this purpose, a trained researcher made three 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 24–36h 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 days after the recording period to check the recording from the final days and to collect the diary. Caregivers recorded detailed information on the amount, type and brand of foods, beverages and nutritional supplements consumed by the child over the 4-days 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, Anglesey, UK), following customization of the database to additionally 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. The protocol for addressing nutrient shortfalls in 1–5 y old children using diet modeling is outlined in **Figure 1**. Where a nutrient shortfall 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 six age groups (1 y (12 months), 1.5 y (18 months), 2 y (24 months), 3 y (36 months), 4 y (48 months) and 5 y (60 months)) 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 FBDG (22). Specifically, the food patterns provided:

predominantly human milk to age 2 years; 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-day food patterns, which aimed to provide sufficient macro- and micronutrients within energy requirements, were modeled using the commonly consumed foods and patterns of consumption, as identified from the NPNS.

Each 4-day 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 was determined by using WHO growth standards (7) and the European Food Safety Authority (EFSA) recommended physical activity levels (30). The 4-day 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, B12 and iodine, and the Average Requirement (AR) for vitamins A, C, B6 and folate, riboflavin, calcium, iron and zinc. The EFSA Recommended Dietary Allowance (RDA) and Tolerable Upper 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-day 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 of <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 years (human milk (~440 mL/day) alone for ≥1–<1.5 y olds and human milk (~170 mL/day) in combination with whole cow's milk (~245 mL/day) for ≥1.5–≤2 y olds). The composition of the human milk used in the diet modeling is outlined in **Supplementary Table 1** (32). In line with common milk-feeding practices, low-fat cow's milk was given from age 2 years (>2–≤5 y olds; ~245 mL/day). After the 4-day 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's milk (≥1–≤5 years); whole cow's milk fortified with vitamin D (≥1–≤5 years); low-fat cow's milk (1.5% fat; ≥2–≤5 years); low-fat cow's milk fortified with vitamin D (1.5% fat; ≥2–≤5 years); Follow-Up Formula (FUF; ≥1–<1.5 years; ~440 mL/day) and Drink for Young Children with added nutrients (DYC; Fortified drink; ≥1.5–≤3 years; ~330 mL/day). In relation to FUF and DYC, an average nutrient content of a variety of these products, available on the Irish market, was calculated and used in the modeling. A daily average intake of 550 mL milk, provided as a mixture of milk, cheese and yogurt (where 200mL milk ≈ 30 g cheese or 125 g yogurt), was modeled across all 4-day food patterns.

Assessing nutritional sufficiency

The 4-day food patterns developed were inputted, and the nutrient content assessed, using nutrition analysis software (Nutritics Research Edition v5.61), 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 re-model 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 FBDG (22). The iterative amendments to the food patterns formed the main basis of the nutrient-driven FBDG developed to address nutrient shortfalls. The protocol established to develop such FBDG in a global context is outlined in **Supplementary Figure 1**. After the non-vegetarian 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 years; 30% for >3 years) were derived from 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 (NDNS) of 1.5–5 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 UK 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 cut-off points, calculated as multiples of BMR (ratio of energy intake to BMR <1.28) (34), were used to identify URs (24% of 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. Armonk, NY: 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 EAR cut-point method was applied and the distribution of intakes was considered by using the mean intake of the 4-day (including one weekend day) food diaries. Differences in predicted daily nutrient intakes from modeling different milk-feeding scenarios were assessed by analysis of covariance (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

Reported daily nutrient intakes from the NPNS are outlined in **Table 1.** The EFSA and IOM DRVs used for assessing nutritional sufficiency are outlined in **Table 2**, along with the proportions of children with nutrient intake shortfalls (additional details are provided in **Supplementary Table 2**). The majority of children failed to meet the DRVs (EFSA AI) for vitamin D (98% of 1–3 y olds; 100% of 4–5 y olds), vitamin E (84% of 1–3 y olds; 88% of 4–5 y olds), DHA+EPA (80% of 1–3 y olds; 82% of 4–5 y olds; IOM AMDR) and fiber (63% of 4–5 y olds), while free sugar intakes exceeded WHO recommendations of <10%E for 48% of 1–3 y olds and 75% of 4–5 y olds (Table 2). Although iron intake shortfalls (EFSA AR) were identified in smaller proportions of 1–3 y olds (18%) and 4–5 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) (additional details are provided in **Supplementary Table 3**).

Overweight (BMI >91st ≤98th percentile; boys 17%, girls 16%) and obesity (BMI >98th percentile; boys 8%, girls 5%) were prevalent in this population, while 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 4-day food patterns which were revised, on a trial and error basis, as necessary to form 120 finalized 4-day food patterns (60 4-day non-vegetarian and 60 4-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 FBDG (22). The finalized food patterns were based on the main milk-feeding scenario of predominantly human milk up to and including age 2 and low fat cow's milk from age 2.

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

Predicted vitamin A, folate and calcium intakes were sufficient (relative to EFSA AR) for all scenarios (**Table 4** and **Table 5**). With the exception of the fortified cow's milk feeding scenarios, shortfalls in predicted vitamin E intakes (EFSA AI) were evident in all other scenarios (**Table 4** and **Table 5**), with the greatest shortfalls observed in ≥1–≤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 (**Supplementary 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 plot B**). Inclusion of a daily 5 µg vitamin D supplement increased predicted vitamin D intakes (**Figure 2 plot C**). While 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–≤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 vs ≤5%E provided by other scenarios) (**Table 4**). In the case of ≥4–≤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–≤3 y olds (**Figure 3 plot B**). Including 30 g of unprocessed red meat 2 out of the 4 days modeled (translating into 3 d/week) and 20–30 g of low-sugar iron-fortified breakfast cereals (<18 g sugar/100 g; ≥12 mg iron/100 g) 3 out of the 4 days modeled (translating into 5 d/week), resolved iron intake shortfalls (EFSA AR) in ≥1–≤3 y olds, except those at ≤25th percentile growth level (**Figure 3 plot C**). For these children, an additional 4 mg of iron 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–≤3 y olds modeled on the 'Follow-up Formula + Fortified drink' scenario (**Table 4**) and all scenarios modeled for ≥4–

≤5 y olds (**Table 5**) achieved the EFSA RDA value (7 mg). The lacto-ovo vegetarian scenario provided comparable intakes of iron for ≥1–≤3 y olds (**Table 4**) and significantly higher intakes for ≥4–≤5 y olds (**Table 5**).

Nutrient-driven FBDG for Irish children

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

- Prolonged breastfeeding to age 2 years is optimal for providing DHA+EPA;
- Low-fat cow's milk can be used from 2 years due to the lower content of saturated fat but similar contribution to other nutrient intakes compared to whole cow's 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-recognised poor bioavailability of iron from plant sources, a low-dose iron supplement may be advisable for children consuming vegetarian diets;
- A low-dose vitamin D supplement should be recommended for all 1–5 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. Additionally, high proportions of children had sub-optimal dietary fiber intakes, while 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 dose of 5 µg/d. The current findings also reinforce the critical role of breastfeeding to 2 years in providing sufficient DHA and EPA.

Breastfeeding is essential for protecting against infant infection and mortality (10), particularly in LMIC, but less evidence exists on the benefits of breastfeeding beyond 1 year in HIC (35). Of note, breastfeeding to 2 years 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 HIC (13), is of concern. Breastfeeding beyond 4–6 months is generally an atypical practice in HIC (35, 36), however the current findings show clear benefits of breastfeeding to 2 years, 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-day 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's milk, a major iodine source in Ireland (38) where no iodized salt policy exists, and the low zinc content of human milk beyond 6 months 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 under 5 years 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 under 5 years 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 HIC (19, 45, 46), this study highlights fortified cereals, meat, meat products and DYC as key food sources of 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 1–3 y olds. Iron intake shortfalls in young children are common in HIC, estimated to affect 26% of 12–23 month olds (18) and 10% of 2–5 y olds (45), and deficiency can be exacerbated by enteropathogenic infection in LMIC (47). This is of concern as iron deficiency anemia in young children can impair cognitive development (48). Additionally, whilst the current results show that lacto-ovo vegetarian and non-vegetarian diets can provide comparable iron intakes, the bioavailability of non-heme 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 1–3 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 (1–3 y olds ≤25th percentile level) and using a low-dose supplement, seems prudent (47, 49).

The findings in the current study that the smaller children (1–3 y olds at ≤25th percentile growth level) are more at risk of nutritional shortfalls, suggests that DRVs for this age group should perhaps be derived on a per kg body weight basis rather than by age. In Ireland (6), as in other HIC (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 FBDG exist, such as single- or multi-objective optimization modeling, food pattern modeling and a combination of these (51). In the current study, nutrient shortfalls were addressed by developing FBDG 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 non-communicable diseases (4, 5, 10). The training of health workers in assessment of child growth using WHO standards (8) could be extended to include FBDG, to be developed by applying this protocol to child feeding practices specific to their countries. This would enable health staff to identify and intervene in 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 1–3 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, whilst the FBDG 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 modelled in the current study were based on estimated UK average intakes (32). 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, while similar to values used by the UK and EFSA, are much lower than the values used by 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, while 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 likely to be the case in LMIC), needs to be tested. The main strength of the study was the availability of dietary survey data from a nationally representative cohort of Irish pre-school children, collected by robust methodology involving weighed food records over a consecutive 4-day period, including one 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 ≥1 and ≤5 y based on national dietary intake data and in alignment with WHO growth standards. Notably, the nutrient-driven FBDG established from this protocol have formed the scientific basis to underpin the development of healthy eating guidelines for 1–5 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.

Conflict of Interest Statement: Oonagh C. Lyons, Maeve A. Kerr, Helene McNulty, Fiona Ward, Janette Walton, M. Barbara E. Livingstone, Breige A. McNulty, Laura Kehoe, Pamela A. Byrne, Ita Saul and Mary A. T. Flynn have no conflicts of interest to declare.

Authors' Contributions were as follows: MATF, MAK and HM planned and designed the research and provided supervision to OCL. OCL was primarily responsible for analyzing the data and conducting the diet modeling, with advisory inputs from MATF and IS; FW, MBEL and PAB advised on the protocol development. JW, BAM and LK provided access to the

NPNS database and advised on data analysis. OCL wrote the initial draft of the manuscript, and MATF, MAK and HM had primary responsibility for the final content. All authors contributed revisions to improve the scientific content and approved the final manuscript.

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TABLE 1

Daily dietary intakes in 1–5 year old children from the Irish National Pre-school Nutrition Survey[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 (months)	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 (% Energy)	33 (6)	32 (5)	33 (5)	32 (5)
Saturated Fat (% Energy)	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 (% Energy)	52 (6)	54 (6)	52 (6)	54 (5)
Free Sugar (% Energy)	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 B12 (µg)	4.1 (2.2)	4.3 (2.2)	4.0 (2.0)	3.7 (1.4)
Vitamin B6 (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 National Pre-School Nutrition Survey (2010–2011) (6). Data are expressed as mean (SD).

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

Abbreviations: BW, body weight; DFE, dietary folate equivalents calculated as follows: natural folate (µg) + [folic acid from fortified foods (µg) x1.7]; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; mo, months

TABLE 2

Proportion of Irish children with daily dietary intakes falling outside regional dietary reference values[1]

	12–47 months			**48–60 months**		
	Current intakes (*n* 376)	Dietary reference values		Current intakes (*n* 124)	Dietary reference values	
		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)		
n (%) below EFSA AI	*329 (88)*	**100**		-	**N/A**	
DHA+EPA (mg)	73 (108)			79 (147)		
n (%) below IOM AMDR	*300 (80)*		**70**	*102 (82)*		**90**
Free Sugar[6] (% Energy)	10 (6)			14 (5)		
n (%) above 10% Energy	*181 (48)*			*93 (75)*		
n (%) above 5% Energy	*303 (81)*			*124 (100)*		
Fiber (g)	11.3 (3.8)			12.8 (3.9)		
n (%) below EFSA AI	*154 (41)*	**10**		*78 (63)*	**14**	
n (%) below IOM AI	*363 (97)*		**19**	*123 (99)*		**25**
Micronutrients						
Vitamin A (µg)	701 (516)			650 (434)		
n (%) below EFSA AR	*19 (5)*	**205**		*11 (9)*	**245**	
n (%) below IOM EAR	*20 (5)*		**210**	*14 (11)*		**275**
Vitamin D (µg)	3.9 (4.1)			3.2 (2.6)		
n (%) below EFSA AI	*368 (98)*	**15**		*124 (100)*	**15**	
n (%) below IOM EAR	*345 (92)*		**10**	*119 (96)*		**10**
Vitamin E (mg)	6.2 (6.9)			6.2 (4.5)		
n (%) below EFSA AI[7]	*246 (65)*	**6**		*109 (88)*	**9**	
n (%) below EFSA AI[8]	*314 (84)*	**9**				
n (%) below IOM EAR	*209 (56)*		**5**	*72 (58)*		**6**
Vitamin C (mg)	82 (52)			94 (53)		
n (%) below EFSA AR	*6 (2)*	**15**		*3 (2)*	**25**	
n (%) below IOM EAR	*3 (1)*		**13**	*2 (2)*		**22**
Folate (µg DFE)	220 (128)			232 (127)		
n (%) below EFSA AR	*19 (5)*	**90**		*2 (2)*	**110**	

n (%) below IOM EAR	*50 (13)*		**120**	*35 (28)*		**160**
Vitamin B12 (µg)	4.0 (2.1)			4.0 (1.8)		
n (%) below EFSA AI	*24 (6)*	**1.5**		*4 (3)*	**1.5**	
n (%) below IOM EAR	*0 (0)*		**0.7**	*2 (2)*		**1.0**
Vitamin B6 (mg)	1.4 (0.6)			1.5 (0.6)		
n (%) below EFSA AR	*0 (0)*	**0.5**		*0 (0)*	**0.6**	
n (%) below IOM EAR	*0 (0)*		**0.4**	*0 (0)*		**0.5**
Riboflavin (mg)	1.6 (0.6)			1.5 (0.5)		
n (%) below EFSA AR	*2 (1)*	**0.5**		*0 (0)*	**0.6**	
n (%) below IOM EAR	*0 (0)*		**0.4**	*0 (0)*		**0.5**
Calcium (mg)	782 (285)			748 (233)		
n (%) below EFSA AR	*14 (4)*	**390**		*51 (41)*	**680**	
n (%) below IOM EAR	*56 (15)*		**500**	*77 (62)*		**800**
Iron (mg)	7.3 (3.3)			7.8 (2.7)		
n (%) below EFSA AR	*68 (18)*	**5.0**		*7 (6)*	**5.0**	
n (%) below IOM EAR	*9 (2)*		**3.0**	*0 (0)*		**4.1**
Zinc (mg)	5.3 (1.8)			5.5 (1.5)		
n (%) below EFSA AR	*55 (15)*	**3.6**		*36 (29)*	**4.6**	
n (%) below IOM EAR	*5 (1)*		**2.5**	*16 (13)*		**4.0**
Iodine (µg)	163 (86)			140 (60)		
n (%) below EFSA AI	*78 (21)*	**90**		*25 (20)*	**90**	
n (%) below IOM EAR	*42 (11)*		**65**	*8 (7)*		**65**

[1] Data obtained from the Irish National Pre-School Nutrition Survey (6). Data are expressed as mean (SD), except where stated otherwise.

[2] Dietary reference values (DRVs) from both the European Food Safety Authority (EFSA) (11) and the Institute of Medicine (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) (7).

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

[5] EFSA AI for DHA only applies to children ≥1–≤1.5 years. There is no EFSA AI for DHA for >1.5–≤5 years.

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

[7] EFSA AI for vitamin E for 1–2 year olds is 6 mg/day.

[8] EFSA AI for vitamin E for 3 year olds is 9 mg/day.

Abbreviations: 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) x1.7]; DRV, dietary reference value; DHA, docosahexaenoic acid; EAR, estimated average requirement; EFSA, European Food Safety Authority; EPA, eicosapentaenoic acid; IOM, Institute of Medicine; N/A, not applicable.

TABLE 3

Main food sources of key nutrients in 1–5 year old children (12–60 months)[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

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

[2] The food groups listed are those providing ≥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.

Abbreviations: DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid.

TABLE 4

Predicted daily intakes of key nutrients for 1–3 year old (12–36 months) children arising from modeling of different milk-feeding scenarios

	Non-vegetarian milk feeding scenarios				Lacto-ovo vegetarian scenario	
	Human milk + Cow's Milk[1]	Whole Cow's Milk[2]	Low-fat Cow's Milk[3]	Follow-Up Formula + Fortified drink[4]	Human milk + Cow's Milk[5]	*P* value[6]
Age (years)	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)[a]	3849 (3301, 4171)[a]	4273 (3710, 4722)[a]	3858 (3399, 4418)[a]	3957 (3486, 4240)[a]	0.728
Macronutrients						
Protein (g/kg BW)	3.6 (3.3, 3.7)[ac]	4.0 (3.8, 4.2)[b]	3.9 (3.6, 4.5)[ab]	3.4 (3.2, 3.7)[ac]	3.2 (2.9, 3.5)[c]	<0.001
Total Fat (% Energy)	36 (34, 38)[a]	36 (34, 37)[a]	29 (28, 31)[b]	33 (31, 35)[b]	36 (35, 37)[a]	<0.001
Saturated Fat (% Energy)	17 (16, 19)[a]	18 (18, 20)[b]	13 (12, 15)[ac]	14 (13, 15)[c]	17 (16, 18)[a]	<0.001
DHA (mg)	97 (72, 144)[a]	6 (4, 113)[b]	-	24 (21, 125)[ab]	63 (44, 93)[ab]	<0.001
DHA+EPA (mg)	83 (50, 171)[a]	54 (7, 171)[a]	54 (7, 171)[a]	36 (35, 182)[a]	25 (0, 50)[a]	0.567
Carbohydrate (% Energy)	46 (45, 48)[a]	44 (42, 46)[b]	52 (49, 53)[ac]	49 (48, 51)[c]	47 (46, 49)[ac]	<0.001
Total Sugar[7] (% Energy)	23 (21, 25)[a]	20 (19, 22)[b]	24 (22, 26)[ab]	25 (23, 26)[a]	24 (22, 25)[a]	<0.001
Free Sugar[7] (% Energy)	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)[ab]	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[8] (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)[ab]	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)^{bc}	742 (662, 810)^{ab}	709 (656, 762)^{ac}	<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)^{ac}	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

Data are expressed as median (95% CI).

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 predominant milk source (including four different non-vegetarian milk-feeding scenarios and one lacto-ovo vegetarian scenario) as follows:

[1] Human milk + cow's milk: modeled on human milk alone (≥1–<1.5 years; ~440 mL/day; 10 percentile levels) or human milk in combination with unfortified whole cow's milk (≥1.5–≤2 years; ~170 mL/day human milk and ~245 mL/day unfortified whole cow's milk; 20 percentile levels) or unfortified low-fat cow's milk alone (>2–≤3 years; ~195 mL/day; 10 percentile levels) based on 376 children from the National Pre-school Nutrition Survey (NPNS) (6).

[2] Whole cow's milk: modeled on unfortified whole cow's milk (≥1–≤3 years; 40 percentile levels) based on 376 children from the NPNS (6). Whole cow's milk fortified with vitamin D was also modeled with the only notable difference being a significantly higher amount of vitamin D (data not shown).

[3] Low-fat cow's milk: modeled on unfortified low-fat cow's milk (≥2–≤3 years: 20 percentile levels) based on 250 children from the NPNS (6). EFSA DHA AI applies to children ≥1–≤1.5 years; no DHA data are shown for this scenario as this milk is only recommended for children ≥2 years. Low fat cow's milk fortified with vitamin D was also modeled with the only notable difference being a significantly higher amount of vitamin D (data not shown).

[4] Follow-Up Formula + Fortified drink: modeled on Follow-Up Formula products (≥1–<1.5 years; ~440 mL/day; 10 percentile levels) or Drink for Young Children with added nutrients products (≥1.5–≤3 years; ~330 mL/day; 30 percentile levels) based on 376 children from the NPNS (6).

[5] Human milk + cow's milk: modeled on the same milks as human milk + cow's milk (footnote 1), but meat, poultry and fish were replaced with vegetarian alternatives.

[6] $P<0.05$ was considered significant. Differences between groups were analysed by ANCOVA adjusting for age, with Bonferroni post-hoc tests. Different superscript letters within a row denote statistically significant differences between any two values, whereas the same letters indicate no significant difference.

[7] 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% energy and not exceed 10% energy (15).

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

Abbreviations: BW, body weight; DFE, dietary folate equivalents calculated as follows: natural folate (µg) + [folic acid from fortified foods (µg) x1.7]; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid.

TABLE 5

Predicted daily intakes of key nutrients for 4–5 year old (48–60 months) children arising from modeling of different milk-feeding scenarios

	Non-vegetarian milk feeding scenarios				Lacto-ovo vegetarian scenario	
	Low-fat Cow's Milk[1]	Whole Cow's Milk[2]	Fortified Low-fat Cow's Milk[3]	Fortified Whole Cow's Milk[4]	Low-fat Cow's Milk[5]	*P* value[6]
Age (years)	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)^{a}	6102 (5776, 6503)^{a}	5838 (5544, 6224)^{a}	5992 (5560, 6273)^{a}	5850 (5579, 6211)^{a}	0.717
Macronutrients						
Protein (g/kg BW)	3.6 (3.4, 4.0)^{a}	3.6 (3.4, 4.0)^{a}	3.6 (3.4, 4.0)^{a}	3.6 (3.4, 4.0)^{a}	3.4 (3.2, 3.5)^{a}	0.138
Total Fat (% Energy)	27 (26, 29)^{a}	31 (29, 32)^{b}	27 (26, 29)^{a}	31 (29, 32)^{b}	29 (27, 30)^{ab}	<0.001
Saturated Fat (% Energy)	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 (% Energy)	54 (53, 56)^{a}	52 (50, 54)^{b}	55 (53, 57)^{a}	52 (51, 54)^{b}	55 (54, 56)^{a}	<0.001
Total Sugar[7] (% Energy)	29 (28, 31)^{ab}	28 (26, 29)^{a}	30 (28, 31)^{ab}	28 (26, 29)^{a}	29 (28, 31)^{b}	0.001
Free Sugar[7] (% Energy)	6 (5, 7)^{a}	6 (5, 7)^{a}	6 (5, 7)^{a}	6 (5, 7)^{a}	6 (5, 6)^{a}	0.707
Fiber (g)	18.6 (17.0, 21.1)^{a}	18.6 (17.0, 21.1)^{a}	18.6 (17.0, 21.1)^{a}	18.6 (17.0, 21.1)^{a}	19.1 (16.4, 19.8)^{a}	0.999
Micronutrients						
Vitamin A (µg)	600 (533, 790)^{ab}	659 (605, 849)^{b}	605 (533, 790)^{ab}	659 (605, 849)^{b}	499 (428, 570)^{a}	0.001
Vitamin D[8] (µg)	7.6 (7.2, 9.0)^{ad}	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)^{ab}	<0.001
Calcium (mg)	1092 (1065, 1203)^{a}	1092 (1065, 1203)^{a}	1148 (1107, 1259)^{ab}	1243 (1185, 1363)^{b}	1138 (1079, 1271)^{ab}	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)^{ab}	7.6 (7.2, 8.3)^{a}	7.3 (6.8, 7.9)^{ab}	7.6 (7.2, 8.3)^{a}	6.6 (6.3, 7.4)^{b}	<0.001
Iodine (µg)	218 (187, 237)^{a}	222 (190, 240)^{a}	218 (187, 237)^{a}	222 (190, 240)^{a}	233 (201, 242)^{a}	0.346

Data are expressed as median (95% CI).

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 predominant milk source (including four different non-vegetarian milk-feeding scenarios and one lacto-ovo vegetarian scenario) as follows:

[1] Low-fat cow's milk: modeled on unfortified low-fat cow's milk (≥4–≤5 years; 20 percentile levels) based on 124 children from the National Pre-school Nutrition Survey (NPNS) (6).

[2] Whole cow's milk: modeled on unfortified whole cow's milk (≥4–≤5 years; 20 percentile levels) based on 124 children from the NPNS (6).

[3] Fortified low-fat cow's milk: modeled on low-fat cow's milk fortified with vitamin D (≥4–≤5 years; 20 percentile levels) based on 124 children from the NPNS (6).

[4] Fortified whole cow's milk: modeled on whole cow's milk fortified with vitamin D (≥4–≤5 years; 20 percentile levels) based on 124 children from the NPNS (6).

[5] Low-fat cow's milk: modeled on the same milk as low-fat cow's milk (footnote 1), but meat, poultry and fish were replaced with vegetarian alternatives.

[6] $P<0.05$ was considered significant. Differences between groups were analysed by ANCOVA adjusting for age, with Bonferroni post-hoc tests. Different superscript letters within a row denote statistically significant differences between any two values, whereas the same letters indicate no significant difference.

[7] 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% energy and not exceed 10% energy (15).

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

Abbreviations: BW, body weight; DFE, dietary folate equivalents calculated as follows: natural folate (µg) + [folic acid from fortified foods (µg) x1.7]; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid.

FIGURE 1. Protocol for addressing nutrient shortfalls in 1–5 year old (12–60 months) children using diet modeling in a population-based sample.

Abbreviations: DRVs, dietary reference values; NPNS, National Pre-school Nutrition Survey; UK, United Kingdom

FIGURE 2. Diet modeling to address vitamin D shortfalls in 1–5 year old (12–60 months) children.

A. Current mean vitamin D intakes (µg/d)

B. Predicted mean vitamin D intakes (µg/d) based on main milk-feeding scenario (predominantly human milk up to and including age 2 [human milk (~440 mL/day) alone for ≥1–<1.5 y olds and human milk (~170 mL/day) in combination with whole cow's milk (~245 mL/day) for ≥1.5–≤2 y olds] and low-fat cow's milk from age 2 [~295 mL/day]) 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.

Abbreviations: AI, adequate intake; EAR, estimated average requirement; EFSA, European Food Safety Authority; IOM, Institute of Medicine

FIGURE 3. Diet modeling to address iron shortfalls in 1–5 year old (12–60 months) 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 1–5 year olds, respectively.

B. Predicted mean iron intakes (mg/d) based on main milk-feeding scenario (predominantly human milk up to and including age 2 [human milk (~440 mL/day) alone for ≥1–<1.5 y olds and human milk (~170 mL/day) in combination with whole cow's milk (~245 mL/day) for ≥1.5–≤2 y olds] and low-fat cow's milk from age 2 [~295 mL/day]) and 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 iron/100g) cereals 5 d/week and unprocessed red meat 3 d/week

[1] For details of current dietary intakes see Tables 1 and 2, and for main food contributors see Table 3.

Abbreviations: AR, average requirement; EAR, estimated average requirement; EFSA, European Food Safety Authority; IOM, Institute of Medicine