Small Increments in Vitamin D Intake by Irish Adults over a Decade Show That Strategic Initiatives to Fortify the Food Supply Are Needed1–4

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Abstract
Background: Food fortification could be an effective method of increasing vitamin D intakes and preventing deficiency with minimal risk of excessive dosing.

Objective: Secular trends in vitamin D intakes were examined over a 10-y period.

Methods: We compared vitamin D intakes among 18- to 64-y-old adults from the base diet, fortified foods, and supplements in 2 nationally representative dietary surveys in 1999 and 2009 implemented using the same methodology.

Results: There was a slight increase in the median (IQR) intake of vitamin D from 2.9 (3.2) to 3.5 (3.7) µg/d (mean ± SD, 4.3 ± 4.0 to 5.0 ± 6.4 µg). The median (IQR) intake from the base diet was 2.3 (1.6) µg/d in 1999 and 2.1 (1.8) µg/d in 2009. In vitamin D supplement users, median (IQR) intakes were 7.6 (6.7) and 8.7 (7.2) µg/d and the prevalence of inadequacy decreased from 67% to 57% in 2009. Although the consumption of vitamin D–containing supplements was similar in the 2 surveys (17% and 16%), the use of calcium-vitamin D supplements increased from 3% to 10% among women aged 50–64 y. The prevalence of fortified food consumption was also similar at 60%, and median (IQR) vitamin D intakes in consumers were 2.9 (2.2) and 3.7 (2.9) µg/d in 1999 and 2009, respectively. Mathematical modeling of food fortification using modified vitamin D composition data showed that there is potential to increase vitamin D intakes at the lower end of the distribution, without increasing the risk of exceeding the Tolerable Upper Intake Level.

Conclusions: We report small increases in vitamin D intakes among Irish adults over a decade of focus on vitamin D and in the context of a voluntary fortification policy. Strategic management of vitamin D in the food supply is required to yield measurable benefits. J Nutr doi: 10.3945/jn.114.209106.

Keywords: vitamin D intakes, vitamin D fortification, vitamin D supplements, Irish adults, dietary modeling

Introduction
The role of vitamin D in promoting bone growth and maintaining skeletal integrity is well established (1) and there is increasing evidence for an association between low vitamin D status and increased risk of nonskeletal health outcomes (2–4). Despite the well-publicized importance of vitamin D in human nutrition, suboptimal vitamin D status is frequently reported (5–8). At high latitudes north or south, when sunlight intensity during winter months is too low to stimulate dermal synthesis of vitamin D or when skin exposure is limited for any reason, dietary intake is required to maintain adequate vitamin D status (9, 10). Based on bone health outcomes, the Institute of Medicine established an Estimated Average Requirement (EAR) of 10 µg for all ages of >1 y (11).

Vitamin D intakes frequently fall well below this recommendation throughout Europe and internationally (12–15) because it occurs naturally in very few foods—fish, meat, milk, egg yolk, and mushrooms—many of which are consumed episodically. Alternative dietary sources are fortified foods and nutritional supplements. In the United Kingdom and Ireland, foods may be

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2 This article does not necessarily reflect the views of the Commission and in no way anticipates future policy in this area.
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4 Supplemental Tables 1–7 are available from the “Online Supporting Material” link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.
5 Abbreviations used: EAR, Estimated Average Requirement; NCI, National Cancer Institute; RTEBC, ready-to-eat breakfast cereal; UL, Tolerable Upper Intake Level; 25(OH)D, 25-hydroxyvitamin D.
voluntarily fortified, provided that the fortification is not detrimental to health and that the product labeling is not misleading (16), as per the 2006 European Union regulation 1925/2006/EC on the addition of vitamins and minerals to foods (17). In addition, there is historical legislation for the mandatory fortification (vitamins A and D) of margarine, which is a non-dairy vegetable oil-based hard fat originally designed to replace butter but now mainly restricted to use in cooking and baking. We previously reported that voluntary fortification, mainly of ready-to-eat breakfast cereals (RTEBCs), made an important contribution to the low vitamin D intakes seen in Irish adults (18, 19). Over the past decade, the range of foods on the Irish market with added vitamin D has increased to include a wider range of full and low-fat milks, spreading fats, yogurts, beverages, and breakfast cereals. We recently reported that two-thirds of children aged 5-17 y were consumers of fortified foods (mainly breakfast cereals, fat spreads, and milks) and that added vitamin D provided ~25% of vitamin D intakes (20). Children who did not consume supplements but did use fortified foods had mean vitamin D intakes of 3.1 µg/d, almost double those of children who obtained vitamin D from the base diet only (no supplements or fortified foods), at 1.7 µg/d (20).

The use of nutritional supplements is increasing in many countries and failure to consider this source of nutrients leads to an underestimation of dietary intakes (21, 22). Unfortunately, nutritional supplements are often omitted from estimates of nutrient intakes, either because supplement intake information is not collected in sufficient detail and/or the nutritional contents of supplements are not included in food composition databases (23, 24). Previously, we have shown that among supplement users, the contribution from supplements to total vitamin D intakes exceeds that of food (25, 26) and for this reason, continuous monitoring of supplement use and habitual intakes are a central component of micronutrient intake risk assessment.

Over the past decade, there has been intense focus, both scientifically and among the public, on the potential role of vitamin D in disease prevention. Although there has not been a targeted public health campaign around vitamin D in adults locally, the surge in the published literature has placed a media spotlight on the field, and public awareness is heightened. The objectives of the present study were to identify and describe the trends in vitamin D intakes and dietary sources of vitamin D in Irish adults between the nationally representative dietary surveys implemented in 1999 and 2009, with particular attention given to the contribution of fortified foods and nutritional supplements. The effect of potential vitamin D food-fortification scenarios on the distribution of vitamin D intakes in Irish adults was assessed using the most recent food consumption data.

Methods

Food consumption data. The North/South Ireland Food Consumption Survey (referred to from now on as the “1999 survey”) was conducted in Irish adults aged 18–64 y in Northern Ireland and the Republic of Ireland (n = 1379), using a 7-d estimated food diary. A detailed description of the sampling procedure, survey design, and methodology for the 1999 survey is available (27, 28). The National Adult Nutrition Survey (referred to from now on as the “2009 survey”) was performed in 1500 adults aged ≥18 y in the Republic of Ireland by the same team and using similar sampling and dietary methodology. Food intake in the 2009 survey was recorded using a 7-d estimated food diary. A detailed description of the sampling procedure, survey design, and methodology for the 1999 survey and at the time of the 2009 survey.

Vitamin D composition data. The procedures to update the vitamin D composition data in both the 1999 and the 2009 surveys have been previously described (20). Briefly, McCance & Widdowson’s The Composition of Foods, 6th edition (29) and supplement editions (30–38), was the core food composition database used. The Composition of Foods is derived primarily from analyzed data, with vitamin D activity calculated from cholecalciferol and 25-hydroxycholecalciferol. The latter is multiplied by a conversion factor of 5, as per Cashman et al. (39). The composition data for vitamin D in foods consumed by participants that were not adequately represented in The Composition of Foods and supplement editions—including data for Irish brands, fortified foods, nutritional supplements, and composite dishes—were updated from manufacturers’ information and recipe analysis, as previously described (40). Quality analytical data for vitamin D were identified using the EuroFIR food composition platform with FoodExPLorer, which is an innovative online interface allowing users to simultaneously search 28 standardized and specialized food composition databases. The foods updated comprised the following: foods for which there were no reported vitamin D values in The Composition of Foods, but which were considered to potentially contain vitamin D (e.g., milk, white fish, and processed meat); mushrooms, which have been found to contain ergocalciferol (41) but for which a value of 0 was assigned in The Composition of Foods; and specific brands of fat spreads particular to the Irish market (26).

Data from the USDA National Nutrient Database for Standard Reference Release 23 (42) were used to update vitamin D values for white fish, processed meat (including ham), and mushrooms. Data from the Danish Food Composition Databank, version 7.01 (43), were used to update values for whole, skin-removed, and skinned milk, because the fat contents of milks in Denmark are equivalent to those in Ireland according to Council Regulation (EC) No. 1234/2007 and Danish milk has recently been analyzed for vitamin D. Values for specific fat spreads were updated based on analytical data reported previously (26). Supplemental Table 1 shows the updated vitamin D values (µg/100 g) for foods consumed in the 1999 and 2009 surveys, along with the source of the updated data. The updated composition data were used to recalculate commonly consumed composite dishes and food products, including 109 food codes in the 2009 survey and 132 food codes in the 1999 survey, which constituted ~10% of the vitamin D–containing food codes reported. To reflect the amount of vitamin D added at the time the surveys were conducted, the composition values for fortified foods were not updated. Rather, the vitamin D composition values for fortified foods were obtained from manufacturers at the time of the 1999 survey and at the time of the 2009 survey.

Nutritional supplements and fortified foods. Nutritional supplement intake data were collected from the prospective food diary because participants were requested to record nutritional supplements as consumed and these data were confirmed in a face-to-face interview, as previously described (23). Composition data were transcribed from the product label. This methodology is considered valid for assessing supplement use (25, 43). A participant who consumed a supplement containing vitamin D at any time over the 4-d recording period was considered a vitamin D supplement user.

Foods that were fortified with vitamin D on a voluntary basis, including fat spreads and milk, were considered fortified. Vitamin D is added to hard cooking margarine at a level of 7.5 µg/100 g on a mandatory basis in the United Kingdom and Ireland. This type of margarine, which is used as an ingredient in cooking and baking, was not considered a fortified food because the purpose of vitamin D addition is restoration rather than fortification. The level of vitamin D that would naturally be present in a fortified food was determined based on the composition data for an unfortified equivalent of the food. A participant who consumed a food fortified with vitamin D at any time over the 4-d recording period was considered a vitamin D–fortified food consumer.

Data and statistical analyses. Intake statistics, including mean, SD, median, IQR, and 5th and 95th percentiles, were determined from all sources, from food sources (with and without added vitamin D) and from supplements, using the daily average method: vitamin D intakes from each food and supplement reported were quantified by multiplying the weight of the food (grams) by the vitamin D content (micrograms per...
100 g). Vitamin D intakes were stratified by sex and age group (18–64 y) for the total population, for users of vitamin D–containing supplements (referred to from now on as supplement users), for consumers of vitamin D–fortified foods who did not use vitamin D supplements (referred to from now on as fortified food consumers), and for consumers of vitamin D–unfortified foods only (referred to from now on as base diet consumers). Data were analyzed using PASW, version 21, for Windows (SPSS, Inc.).

Vitamin D intakes in this study were derived from daily average intakes from 4 consecutive recording days. When using repeated short-term measurements of intake, such as 24-h food records, the variance of reported intake is inflated by the day-to-day variation of dietary intake within individuals (44). To estimate usual intakes of a nutrient, the within-subject variation must be eliminated by an appropriate statistical method. Along the lines of the daily average method, the National Cancer Institute (NCI) method (45) was applied to the 2009 survey and a usual intake estimate was calculated for the total population and stratified by sex. The NCI method was not applied to age groups or users of vitamin D–containing supplements because of the small numbers of participants in these subgroups. The NCI method was applied using Crème Nutrition software, which is cloud-based software designed to estimate dietary intakes of foods, chemicals, and nutrients in existing dietary survey populations. In the current analysis, we compared usual intake estimates based on the NCI method with intakes estimated from the daily average method.

Under-reporting of energy intake by self-reported dietary methods is well documented (46, 47). Energy under-reporters in the 2009 survey were identified by calculating basal metabolic rate using the Oxford equations (48) and a Goldberg cut point of 1.1 (49). We chose this cut point on the assumption that the effect of under-reporting on vitamin D intakes would be likely marginal because vitamin D is not generally present in snack foods or desserts, which are known to be more susceptible to misreporting than meats, fish, or dairy foods (46, 47). We examined the impact of energy under-reporting on vitamin D intakes by estimating median intakes when under-reporters were included and excluded.

The EAR cut point for vitamin D, defined by the Institute of Medicine as 10 µg/d (11), was used to estimate the prevalence of inadequate vitamin D intakes. Participants with a mean daily intake below the EAR were considered to have inadequate intakes. This method is considered effective in assessing the prevalence of nutrient inadequacy in a population (50). The Tolerable Upper Intake Level (UL) is the maximum chronic daily intake of a nutrient that is unlikely to pose a risk of adverse health effects to humans (51). The risk of excessive intake of vitamin D was evaluated using the UL of 100 µg/d (11, 51).

The mean percentage contribution of specific food groups to the total vitamin D intake population was estimated by summing the amount of vitamin D from a particular food group for all participants and dividing this value by the sum of the vitamin D from all foods for all participants (52). A descriptive comparison between the 1999 and 2009 surveys was conducted. To compare the 7-d 1999 survey with the 4-d 2009 survey, data from 4 survey days only were included from 1999 survey. The first 4 recording days were chosen to avoid any bias relating to diary duration (e.g., fall off in recording because of fatigue). Ages 18–64 y only were compared, because the 1999 survey did not include participants >64 y old. We have not reported statistical significance in the current article, because the survey sample sizes are sufficiently powerful to consistently observe statistically significant results even with marginal differences from a vitamin D intake perspective.

We conducted a simple modeling exercise to assess the potential impact of food-fortification scenarios by recalculating the distribution of vitamin D intakes following hypothetical modifications to the food composition data of vitamin D in the 2009 survey. Because this was a secondary aim of the current study and because a complete analysis of fortification is planned across the population, these were deterministic calculations only and the percentages of consumers and intakes of individual products and food groups were not modeled. The foods modified (100% of products stipulated in the 3 scenarios described) were milk/alternatives (vitamin D at 2 µg/100 mL), yogurt (2 µg/100 g), cream (2 µg/100 g), cheese (2 µg/100 g), fruit juice/drinks (2 µg/100 g), bread/rolls (2 µg/100 g), RTEBCs (5 µg/100 g), and fat spreads (8 µg/100 g). Currently, cream, cheese, fruit juice, and bread are not fortified with vitamin D; some milks are at 0.5–2 µg/100 mL; a few yogurts are at various concentrations <5 µg/100 g and most breakfast cereals are at various concentrations <5 µg/100 g. Potential scenarios presented increased the numbers of products fortified to 100% of the following foods: 1) reduced-fat milk, yogurt, fat spreads, orange juice, and RTEBCs; 2) reduced-fat milk, yogurt, fat spreads, orange juice, RTEBCs, milk and yogurt alternatives, and bread; and 3) all milk and alternatives, vitamin D and alternatives, cream, cheese, fat spreads, all fruit juice and drinks, RTEBCs, and all breads and rolls.

Results

Prevalence of consumption of vitamin D–containing supplements and fortified foods. The prevalence of vitamin D–containing supplement use was similar in 18- to 64-y-old adults in 1999 and 2009 (17% and 16%, respectively). However, there were changes in the type of supplements consumed: the use of multivitamins/minerals increased from 6% to 8% in men, the use of cod liver oil decreased from 10% to 5% in women, and the use of calcium–vitamin D supplements increased from 3% to 10% in women aged 50–64 y (Table 1). Between 1999 and 2009, the consumption of vitamin D–fortified fat spreads decreased from 47% to 38%, vitamin D–fortified milk increased from 5% to 17%, and vitamin D–fortified RTEBCs increased from 13% to 27% in men (Table 1). There were some changes in the availability of vitamin D–fortified foods. In 1999, no whole milk, cheese, or yogurts were fortified with vitamin D, whereas in 2009, 1 whole milk product, 1 cheddar cheese product, and 4 yogurt products were fortified with vitamin D. The number of fortified fat spreads increased from 10 in 1999 to 17 in 2009, while the number of fortified breakfast cereals remained similar between 1999 and 2009 (18 and 19 products, respectively).

Table 1

Vitamin D intakes. Median (IQR) vitamin D intakes increased from 2.9 (3.2) µg/d in 1999 to 3.5 (3.7) µg/d in 2009 in the total population of 18- to 64-y-old adults (Table 2) and from 7.6 (6.7) to 8.7 (7.2) µg/d in supplement users. Intakes in base diet consumers were similar between 1999 and 2009 [2.3 (1.6) and 2.1 (1.8) µg/d, respectively]. Supplemental Tables 2–7 show complete details of vitamin D intakes in the 1999 and 2009 surveys in the total populations and are stratified by supplement users, fortified food consumers, and base diet consumers by sex, age group, and source of vitamin D (all sources, food sources, food sources excluding the added vitamin D component, the added vitamin D component only, and supplements).

Along with the daily average method, the NCI method (45) was applied to the 2009 survey, with intakes stratified by sex, and vitamin D intakes were compared with the daily average method (Table 3). As expected, intakes differed only marginally by 0.2 µg between the 2 methods and there was a marked reduction in the SD using the NCI method. The greatest difference was seen in the 95th percentile of intakes in women, for which the usual intake was 5.5 µg lower than the daily average intake.

Basal metabolic rate was available for 1412 participants in the 2009 survey and 31% of these were identified as under-reporters. When under-reporters were included, median vitamin D intake was 3.7 µg/d; when excluded, the intake was 4.0 µg/d. The equivalent intakes were 9.1 µg/d vs. 10.1 µg/d in supplement users, 3.9 µg/d vs. 4.1 µg/d in fortified food consumers, and 2.2 µg/d vs. 2.5 µg/d in base diet consumers.

Prevalence of inadequate intakes. The percentage of adults in 1999 with inadequate intakes decreased with age: 98% for 18- to 24-y-old adults, 95% for 25- to 34-y-old adults, 92% for 35- to 49-y-old adults, and 89% for 50- to 64-y-old adults (Table 4). Compared with 1999, the prevalence of inadequate intake was

Vitamin D intakes and fortification 3 of 8
slightly lower in 2009 for most age groups: 95% for 18- to 24-y-old adults, 92% for 25- to 34-y-old adults, 93% for 35- to 49-y-old adults, and 81% for 50- to 64-y-old adults. In supplement users, the proportion of participants with inadequate intakes decreased for 67% in 1999 to 57% in 2009.

**Food sources of vitamin D.** The major food groups contributing to total intake of vitamin D in 1999 were nutritional supplements (22%), fish/fish dishes (22%), meat/meat products (19%), butter/fat spreads (8%), milk/yogurts (7%), and breakfast cereals (5%). In supplement users, the contribution of nutritional supplements was 61%, followed by fish/fish dishes (13%), meat/meat products (8%), and milk/yogurts (3%). In adults aged 18–64 y in the 2009 survey, the major food groups contributing to total intake of vitamin D were nutritional supplements (24%), fish/fish dishes (20%), meat/meat products (16%), milk/yogurts (10%), butter/fat spreads (8%), and breakfast cereals (8%). In supplement users, the contribution of nutritional supplements was 64%, followed by fish/fish dishes (11%), meat/meat products (6%), and milk/yogurts (6%). The mean percentage contributions of food groups to total dietary vitamin D intake were largely similar between 1999 and 2009; however, differences were evident in specific population groups. In female supplement users, the mean percentage contribution of cod liver oil decreased from 26% to 8% and the contribution of calcium-vitamin D supplements increased from 5% to 20%. In male fortified food consumers, the mean percentage contribution of RTEBCs increased from 6% to 15%. In base diet consumers, the mean percentage contribution of fish increased from 28% to 34%.

In quantitative terms, the contribution of foods to vitamin D intakes did not vary between supplement users and nonusers or between fortified food consumers and base diet consumers. For example, fish contributed 1.4, 1.0, and 1.1 μg/d in supplement users, fortified food consumers, and base diet consumers, respectively. Meat contributed ~0.8 μg/d and eggs contributed 0.3 μg/d, regardless of whether supplements or fortified foods were additional sources of vitamin D.

**Food-fortification modeling.** On the basis of modifying the food composition data only, without any changes to consumption patterns, median intakes in 18- to 64-y-old adults participating in

### TABLE 1 Percentage of participants using vitamin D–containing supplements and consuming vitamin D–fortified foods in the 1999 and 2009 surveys, stratified by sex and age

<table>
<thead>
<tr>
<th></th>
<th>Men and women, all ages, %</th>
<th>Men, %</th>
<th>Women, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>18–24 y 25–34 y 35–49 y 50–64 y</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>All ages</td>
<td>18-24 y</td>
<td>25–34 y</td>
</tr>
<tr>
<td>1999 Survey</td>
<td>n</td>
<td></td>
<td></td>
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<tr>
<td>Supplements</td>
<td>1379</td>
<td>90</td>
<td>146</td>
</tr>
<tr>
<td>All types</td>
<td>17</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Multinutrient</td>
<td>8</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Cod liver oil</td>
<td>9</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Calcium + vitamin D</td>
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<td>0</td>
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<tr>
<td>Fortified foods</td>
<td>n</td>
<td>662</td>
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<tr>
<td>All types</td>
<td>59</td>
<td>60</td>
<td>53</td>
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<tr>
<td>Fat spreads</td>
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<td>49</td>
<td>42</td>
</tr>
<tr>
<td>RTEBCs</td>
<td>19</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Milk</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2009 Survey</td>
<td>n</td>
<td>1274</td>
<td>109</td>
</tr>
<tr>
<td>Supplements</td>
<td>16</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>All types</td>
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<td>8</td>
<td>11</td>
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<td>Calcium + vitamin D</td>
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<td>1</td>
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<td>22</td>
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<tr>
<td>Other</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
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</table>

1 RTEBC, ready-to-eat breakfast cereal.

### TABLE 2 Vitamin D intakes in the total population, supplement users, fortified food consumers, and base diet consumers participating in the 1999 and 2009 surveys

<table>
<thead>
<tr>
<th></th>
<th>Men and women, all ages, μg/d</th>
<th>Men, μg/d</th>
<th>Women, μg/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999 Survey</td>
<td>n</td>
<td>Mean ± SD</td>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Total population</td>
<td>1379</td>
<td>4.3 ± 4.0</td>
<td>2.9 (3.2)</td>
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<tr>
<td>Supplement users</td>
<td>229</td>
<td>9.4 ± 6.0</td>
<td>7.6 (6.7)</td>
</tr>
<tr>
<td>Fortified food consumers</td>
<td>671</td>
<td>3.6 ± 2.6</td>
<td>2.9 (2.2)</td>
</tr>
<tr>
<td>Base diet consumers</td>
<td>479</td>
<td>2.8 ± 2.1</td>
<td>2.3 (1.6)</td>
</tr>
<tr>
<td>2009 Survey</td>
<td>n</td>
<td>Mean ± SD</td>
<td>Median (IQR)</td>
</tr>
<tr>
<td>Total population</td>
<td>1274</td>
<td>5.0 ± 6.4</td>
<td>3.5 (3.7)</td>
</tr>
<tr>
<td>Supplement users</td>
<td>200</td>
<td>11.7 ± 12.8</td>
<td>8.7 (7.2)</td>
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<tr>
<td>Fortified food consumers</td>
<td>650</td>
<td>4.4 ± 2.8</td>
<td>3.7 (2.9)</td>
</tr>
<tr>
<td>Base diet consumers</td>
<td>424</td>
<td>2.7 ± 2.3</td>
<td>2.1 (1.8)</td>
</tr>
</tbody>
</table>
the 2009 survey increased from 3 (at current fortification) to 7 μg/d for scenario A (reduced-fat milk, yogurt, fat spreads, orange juice, and RTEBCs), 9 μg/d for scenario B (reduced-fat milk, yogurt, fat spreads, orange juice, RTEBCs, milk and yogurt alternatives, and bread), and 12 μg/d for scenario C (all milk and alternatives, yogurt and alternatives, cream, cheese, fat spreads, all fruit juice and drinks, RTEBCs, and all breads and rolls; Figure 1). At the 95th percentile, intakes were still well below the UL (100 μg) for all potential food-fortification scenarios.

Discussion

This article presents temporal changes in vitamin D intakes and food sources in 2 nationally representative dietary surveys conducted in 1999 and 2009. The median daily intake of vitamin D increased slightly between 1999 and 2009, but remained well below the EAR of 10 μg. These low intakes are mirrored in other populations, including Europe (12, 13), the United States (14, 53), Canada (15), and Australia (7). The high prevalence of inadequate vitamin D intakes in Irish adults is concerning, because dietary intake is the only source of vitamin D during the long winter in Ireland (lat 51–53°N). Recent analysis of vitamin D status in the 2009 survey found that 18%, 40%, and 60% of participants had serum 25-hydroxyvitamin D concentrations below 30, 40, and 50 nmol/L, respectively, during the winter months (November–March) (54).

In contrast with reports that suggest an increase in supplement use in European countries (55–57), the prevalence of vitamin D supplement use was similar in Irish adults between 1999 and 2009. However, there was a change in the type of supplements used—most notably an increase in calcium-vitamin D preparations in older women, which is perhaps a result of increasing awareness of the role of calcium and vitamin D in osteoporosis. Despite the low prevalence of vitamin D supplement use, supplements were the major source of vitamin D in both surveys, and supplement users had a substantially higher median intake of vitamin D than the total population. The contribution of supplements was higher in women than in men, particularly in those aged ≥50 y, primarily because of the use of calcium-vitamin D preparations. The Food Safety Authority of Ireland recommends that everyone should take a daily vitamin D supplement of 5 μg (58). However, although supplementation improves vitamin D intake on an individual basis, this approach is likely to have limited efficacy from a population perspective in terms of preventing deficiency, because the majority are not supplement users and rely on dietary vitamin D sources, i.e., the base diet and fortified foods, discussed in detail recently (10, 59).

Excluding supplements, the main food group contributing to vitamin D intake was fish. Indeed, oily fish is the richest natural source of vitamin D and fish is frequently reported to be a major food contributor on a percentage basis (12, 59). However, the actual quantity of vitamin D contributed by fish was relatively small, at ~10% of the EAR. Given that current recommendations are for twice-weekly fish consumption, including oily fish at least once per week (58), it is unrealistic to expect the population to achieve a substantial amount of their daily vitamin D requirements from fish. Meat also contributed considerably to vitamin D intakes in the total population. Although meat contains only small amounts of vitamin D, it is widely consumed by Irish adults. Again, the actual contribution was small relative to the EAR and a healthy intake of meat would provide only a fraction of daily vitamin D requirements.

Because natural dietary sources of vitamin D are limited, the addition of vitamin D to commonly consumed foods could be useful as a public health approach designed to increase vitamin D intake in the general population. More than one-half of adults in the 2009 survey consumed a vitamin D–fortified food, the majority of which were fat spreads, followed by RTEBCs and milk. The overall prevalence of vitamin D–fortified food consumption was similar between 1999 and 2009; however, vitamin D–fortified RTEBCs and milk were more widely consumed in 2009. In 2009, fortified foods provided almost one-third of the mean daily vitamin D intake from food sources, which is equivalent to the contribution of fish. This finding is similar to data from the United States, where fortified foods provide the majority of vitamin D intake from food sources (53). Fortified food consumers had a higher median daily vitamin D intake compared with base diet consumers. The added vitamin D component provided a substantial amount of the total vitamin D intake in fortified food consumers, even at current conservative fortification.

### Table 3
Comparison of vitamin D intakes in adults participating in the 2009 survey using the NCI method and the daily average method

<table>
<thead>
<tr>
<th></th>
<th>NCI method</th>
<th>Daily average</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>1500</td>
<td>1500</td>
</tr>
<tr>
<td>Mean ± SD, μg/d</td>
<td>5.2 ± 4.4</td>
<td>5.4 ± 7.2</td>
</tr>
<tr>
<td>Percentile, μg/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>25</td>
<td>2.4</td>
<td>2.2</td>
</tr>
<tr>
<td>75</td>
<td>6.7</td>
<td>6.3</td>
</tr>
<tr>
<td>95</td>
<td>13.4</td>
<td>14.8</td>
</tr>
</tbody>
</table>

1 NCI, National Cancer Institute.
A limitation of relying on the daily average method, rather than in the contribution of supplements to vitamin D intake in women. The horizontal line represents the EAR cut point of 10 μg/d. (Scenario A) Reduced-fat milk, yogurt, fat spreads, orange juice, and RTEBCs. (Scenario B) Reduced-fat milk, yogurt, fat spreads, orange juice, RTEBCs, milk and yogurt alternatives, and bread. (Scenario C) All milk and alternatives, yogurt and alternatives, cream, cheese, fat spreads, all fruit juice and drinks, RTEBCs, and all breads and rolls. Fortification concentrations are reduced-fat milk and fruit juice/drinks (2 μg/100 mL); yogurt, cream, cheese, bread, and rolls (2 μg/100 g); RTEBCs (5 μg/100 g); and fat spreads (8 μg/100 g). EAR, Estimated Average Requirement; RTEBC, ready-to-eat-breakfast cereal.

We have recently shown in a systematic review and meta-analysis of food-based randomized controlled trials that vitamin D–fortified foods are effective in increasing intakes and serum concentrations of 25-hydroxyvitamin D [25(OH)D] (60). Despite the widespread consumption of vitamin D–fortified foods in the 2009 survey, almost all fortified food consumers still had inadequate vitamin D intakes. This finding is consistent with other studies that report that although fortification increases vitamin D intake and/or vitamin D status, the increments are not sufficient to achieve recommended intakes (15, 53, 61–63). Thus, to develop an effective vitamin D fortification strategy, modeling of food consumption data is required to optimize both types of food that should be fortified and the concentration of vitamin D that should be added. In deterministic modeling of food-fortification scenarios using dietary intake data from the 2009 survey, the hypothetical addition of vitamin D to milk/alternatives, yogurt/alternatives, cream, cheese, fat spreads, fruit juice/drinks, RTEBCs, and bread/rolls at relatively low increments increased median daily intakes from 3 to 12 μg, which is above the EAR of 10 μg/d. With this fortification scenario, there was no risk of excessive intakes at the 95th percentile. This was a preliminary analysis and probabilistic modeling experiments, which include modification of the proportion of consumers of different products containing varying concentrations of vitamin D in successive iterations, are planned, but it is important to note that food composition data must accurately reflect current fortification practices for these experiments to be of value.

The greatest difference between intakes calculated using the daily average method and the NCI method was in women at the 95th percentile, which was probably caused by the large variation in the contribution of supplements to vitamin D intake in women. A limitation of relying on the daily average method, rather than usual intakes, is the possible overestimation of the prevalence of individuals below the EAR. However, mean vitamin D intake estimates differed only marginally between the daily average method and the NCI method. Almost one-third of participants in the 2009 survey were identified as under-reporters; however, the inclusion or exclusion of under-reporters made a relatively minor difference to the estimated median daily vitamin D intakes.

Strengths of the current study were the analysis of 2 nationally representative surveys with high-quality dietary intake data collected over multiple days of recording using similar methodology and standard operating procedures. A limitation of our analysis, which is common to all dietary intake assessments of vitamin D, was the lack of internationally standardized methods for the analysis of vitamin D composition of foods. Although we made every effort to include high-quality analytical food composition data, we await further updates and developments to develop standard reference methods for food analysis including the 25(OH)D component of animal products (42, 64). Given that 25(OH)D in meat, fish, and other animal products may have 5 times the potency of vitamin D in the same foods (39), the accurate measurement of this metabolite will be a valuable step to improving the accuracy of intake estimates (65).

To conclude, we found that vitamin D intakes in Irish adults increased marginally between 1999 and 2009 and remain well below recommendations. Clearly, natural vitamin D sources do not provide adequate vitamin D for Irish adults and current fortification practices are haphazard and ineffective in terms of achieving adequate intakes in the population. Judging by the current low prevalence of supplement use and trends over the last 12 y, it is unlikely that supplement use will become more widespread. In contrast, our introductory modeling experiment showed that well-designed food-fortification policies may have the potential to increase vitamin D intakes across the population, without compromising safety. Given the gap between current intakes and recommendations, sustainable food-based strategies to increase intakes in the population and minimize the prevalence of serum 25(OH)D concentrations below 30 nmol/L are urgently required. Investigations to food-based approaches that may be of value in terms of preventing vitamin D deficiency without increasing the risk of excessive intakes are currently being undertaken as part of the food-based solutions for optimal vitamin D nutrition and health through the life cycle (EC Contract 613977), which commenced in November 2013.

Acknowledgments

LJB analyzed the food consumption data and updated the food composition data for vitamin D; LJB and MK wrote the paper; JW and MK conducted the 2009 and 1999 surveys, respectively; AF is the director of the national dietary surveys and KDC was a grant holder for the 2009 survey; MK designed the research and had primary responsibility for final content. All authors read and approved the final manuscript.

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