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Including Food 25-Hydroxyvitamin D in Intake Estimates May Reduce the Discrepancy between Dietary and Serum Measures of Vitamin D Status[1–3]

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Abstract

The discrepancy between the commonly used vitamin D status measures—intake and serum 25-hydroxyvitamin D [25(OH)D] concentrations—has been perplexing. Sun exposure increases serum 25(OH)D concentrations and is often used as an explanation for the higher population-based serum concentrations in the face of apparently low vitamin D intake. However, sun exposure may not be the total explanation. 25(OH)D, a metabolite of vitamin D, is known to be present in animal-based foods. It has been measured and reported only sporadically and is not currently factored into U.S. estimates of vitamin D intake. Previously unavailable preliminary USDA data specifying the 25(OH)D content of a subset of foods allowed exploration of the potential change in the reported overall vitamin D content of foods when the presence of 25(OH)D was included. The issue of 25(OH)D potency was addressed, and available commodity intake estimates were used to outline trends in projected vitamin D intake when 25(OH)D in foods was taken into account. Given the data available, there were notable increases in the total vitamin D content of a number of animal-based foods when potency-adjusted 25(OH)D was included, and in turn there was a potentially meaningful increase (1.7–2.9 μg or 15–30% of average requirement) in vitamin D intake estimates. The apparent increase could reduce discrepancies between intake estimates and serum 25(OH)D concentrations. The relevance to dietary interventions is discussed, and the need for continued exploration regarding 25(OH)D measurement is highlighted. J. Nutr. 144: 654–659, 2014.

Introduction

Current estimates of total vitamin D intake from foods and dietary supplements suggest that many in the United States consume considerably less vitamin D than the established dietary requirement, and yet serum 25-hydroxyvitamin D [25(OH)D][7] concentrations of the population are higher than would be expected given intakes of the vitamin (1). The Institute of Medicine (IOM) established that, absent sun exposure, the estimated average requirement (EAR) of the population for intake from all dietary sources is 10 μg/d (400 IU/d) and that bone health is assured if the serum 25(OH)D concentrations of the population average 40 nmol/L (1). Data from NHANES 2005–2006, the only survey cycle linking updated vitamin D food composition with food consumption, indicate that total mean vitamin D intakes from foods and supplements for age/gender groups range from 5.0 to 10.7 μg/d (2) (**Supplemental Fig. 1**). Conversely, mean population concentrations of serum 25(OH)D exceed not only the IOM recommendation of 40 nmol/L for the population average but also the 50 nmol/L concentration IOM associated with highest need (1). Taylor et al. (3) analyzed adults aged 19–70 y from NHANES 2005–2006 and found that a statistical probability method resulted in 71% vitamin D inadequacy based on intake but 19% inadequacy based on serum 25(OH)D concentrations.

The discrepancy between 71% and 19% vitamin D inadequacy is considerable. Although the underreporting of dietary intake is likely a partial reason for the difference (4), sun exposure is often cited as a major factor. However, others have commented that sun exposure cannot be a complete explanation because, although

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[3] Supplemental Figure 1 and Supplemental Tables 1–5 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.
[7] Abbreviations used: EAR, estimated average requirement; IOM, Institute of Medicine; *nm*-vitamin D, nonmetabolized vitamin D; SR, National Nutrient Database for Standard Reference; vitamin D-2, ergocalciferol; vitamin D-3, cholecalciferol; 25(OH)D, 25-hydroxyvitamin D.
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winter serum 25(OH)D concentrations decline, they are still higher than is plausibly attributed to food sources (5). Furthermore, sun exposure is not likely to cause such a uniform effect for a highly diverse population. There is the possibility that intake of 25(OH)D—the metabolized form of the vitamin present in foods such as meat, poultry, and eggs—makes a contribution to vitamin D status. Amounts of 25(OH)D in foods generally have not been determined in the United States and, therefore, have not been included when reporting vitamin D content of foods. The omission takes on greater meaning given evidence that 25(OH)D appears to be more potent than the parent vitamin in raising serum 25(OH)D concentrations (6–8). Questions about the amounts of 25(OH)D in animal-based foods warrant a fuller exploration, especially because these foods are consumed frequently in the United States. The question is particularly relevant given calls for greater intake of vitamin D and for additional fortification of the U.S. food supply. The addition of any nutrient to the diet as a national intervention should be preceded by an understanding of the total dietary intake of the nutrient from all sources.

Food sources of vitamin D in the United States include some fortified foods, as well as naturally occurring sources, such as meat, poultry, eggs, and fish. As a component of the diet, the nonmetabolized form of vitamin D (*nm*-vitamin D) must be activated before it can function in the body. 25(OH)D is one of the metabolites of the *nm*-vitamin D activation process and, along with *nm*-vitamin D, can be found in animal muscle and adipose tissue (9–11). Most of the *nm*-vitamin D in the U.S. diet is cholecalciferol (vitamin D-3 form) rather than ergocalciferol (vitamin D-2 form), and vitamin D-3 is the form present naturally in animal tissue and fat. Given the history of combining vitamin D-2 with vitamin D-3 for the purposes of estimating overall intake of the vitamin, they are frequently referred to simply as vitamin D.

Lack of information about the amounts of 25(OH)D in foods precludes development of sufficiently detailed scenarios that could predict the changes in reported vitamin D intake if 25(OH)D values were included in the national nutrient database. Given limited resources, it is useful to provide a basis for the continuation of resources to address the omission. Available data can be examined for signals about whether the presence of naturally occurring 25(OH)D in foods could alter understandings regarding the sources of vitamin D in the diet, as well as estimates of vitamin D status based on intake. This study uses previously unavailable preliminary USDA data for 25(OH)D content of a subset of foods to shed light on possible changes to the reported vitamin D content of foods and subsequent intake estimates.

Methods

Food content data: nm-*vitamin D and 25(OH)D.* The United States and other countries publish food composition databases (**Supplemental Table 1**). In the United States, the database is known as the National Nutrient Database for Standard Reference (SR) and is developed by the USDA using primarily food analyses but also package labels, ingredient calculations, and regulatory specifications. Vitamin D in foods is expressed in microgram quantities and international units; 1 μg of vitamin D is equivalent to 40 IU. The content is reported as the sum of vitamin D-3 and vitamin D-2 (i.e., *nm*-vitamin D) or as vitamin D-3 and vitamin D-2 separately when such information is available (12). Updates are incorporated into annual public releases of the SR, most recently in August 2013 as SR26 (12). The SR does not report values for 25(OH)D content of foods.

Beginning in 2007, USDA expanded *nm*-vitamin D content in the SR (12). As part of its exploration of analytical methods for this purpose, USDA generated a limited number of preliminary values for 25(OH)D in meat, poultry, and eggs, as well as several fish items (K. Y. Patterson, unpublished results). The method used was similar to that for *nm*-vitamin D analysis for the SR (13). However, the values have not been published in the SR (14) because of their preliminary nature. Approximately 100 animal-based foods (raw and cooked) were analyzed on the basis of opportunity; therefore, they do not reflect systematic efforts to analyze the most frequently consumed foods or to span representative food products. A number of the values reflect replicate samples, in which case SEs were determined. Ideally, calculations would be made for percentage CV for intra-assay or intra-laboratory outcomes, but the preliminary data lack such information; furthermore, a percentage bias or comparability measure is not possible given the absence of reference materials.

Potency of 25(OH)D. Both *nm*-vitamin D and 25(OH)D raise serum 25(OH)D concentrations and initiate bone mobilization, as well as intestinal transport of calcium (9). However, 25(OH)D does so more readily (6–8). Therefore, estimates of vitamin D activity attributable to 25(OH)D in a food require use of a potency factor. A consensus about the potency of 25(OH)D is only beginning to emerge, and, to select a justifiable potency factor, we reviewed available data (**Supplemental Tables 2** and **3**). Biologic assays for anti-rachitic activity ("line tests"), calcium absorption, and calcium transport vary in potency outcomes, but Ovesen et al. (15) summarized this work and concluded that results trend toward support for the potency factor of 5 based on enhanced intestinal calcium absorption. The ability of 25(OH)D to increase serum 25(OH)D concentrations may be more relevant to potency determinations. Early work from Barger-Lux et al. (16), which was based on oral dosing of healthy men and measured serum changes, suggested a potency factor of 8. The Cashman et al. (17) trial in humans is of high quality and demonstrated a potency factor of ~5. It minimized the effect of sun exposure, was large in size, placebo controlled, of sufficient duration, and not confounded by age and growth. Importantly, the supplements were taken with meals to partially mitigate the absence of a food matrix; in contrast, many potency studies are conducted on the basis of administration of a supplement. The outcomes for adults reported by Bischoff-Ferrari et al. (18) trend toward a similar potency as that of Cashman et al. The Bischoff-Ferrari et al. study, designed to examine modalities for administering vitamin D, suggested a potency factor of 3.4 but was limited by lack of a placebo group that could have controlled for increased sun exposure during the study period, which may have resulted in a lower reported potency than would be expected (17). Together, Cashman et al. and Bischoff-Ferrari et al. strengthen support for a potency factor of ~5, which was used for the calculations in this study. A factor of 5 also reflects a midpoint within the array of reported potency factors.

Intake data: animal-based foods. There are insufficient data on the 25(OH)D content of foods to conduct population-based simulations of changes that would occur for vitamin D intake on the basis of food consumption by individuals as reported in NHANES surveys. The best option is to examine the potential changes in vitamin D intake on the basis of mean retail food commodity intakes. Commodity groups are broad and therefore amenable to less detail than is needed to match foods reported in surveys of individuals. The USDA Retail Food Commodity Intakes database (19) provides quantitative national estimates of the amounts of retail-level commodities consumed per person based on the first day of dietary intake data for the 8529 individuals aged ≥2 y in *What We Eat in America*, NHANES, 2007–2008 (19). The intake estimates link to the Food Intakes Converted to Retail Commodities Database, 2007–2008 (19). For each of the 65 retail-level commodities specified, foods within the commodity are converted to a single commodity type, usually the raw form. For example, canned, frozen, and dried carrots consumed in the surveys are converted to a raw carrots commodity. Therefore, all carrot consumption is consolidated into a total amount, expressed as grams per day per person for specific age/gender groups. Commodity intakes (grams per day) for raw beef, pork, chicken, turkey, and egg are available.

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Analyses. Preliminary USDA 25(OH)D data were used to compare *nm*-vitamin D content of a food (i.e., currently reported vitamin D content) with the content potentially attributable to the food if 25(OH)D were taken into account. The foods selected from the preliminary dataset were those generally available to consumers as animal-based food products. For instance, although ground beef is commonly consumed, it was not within the preliminary dataset, so rib eye and chuck steak were the next best choices. The foods selected, in both the cooked and raw forms, included the following: beef rib eye steak, beef chuck steak, pork loin chop, chicken dark meat, turkey dark meat, and whole egg (raw only; cooked not analyzed), as well as beef fat, chicken skin, and turkey skin. We omitted seafood because the amounts of 25(OH)D were extremely low and unlikely to affect outcomes. For each item, the currently reported *nm*-vitamin D content (micrograms per 100 g of food) was identified using the SR. The 25(OH)D content provided by the USDA was adjusted for potency based on a factor of 5. The vitamin D content of the foods was recalculated to include the contribution from 25(OH)D.

To place the recalculated vitamin D content of these foods within the context of food intake and in turn potential increases in vitamin D intake, we used intake information (grams per day) for the beef, pork, chicken, turkey, and egg commodity groups from the USDA Retail Food Commodity Intakes database described above. Values for *nm*-vitamin D and 25(OH)D content of each commodity group were assigned by matching on the basis of the averaged values for the respective raw foods selected for use in this study. Changes in estimated vitamin D intake for the five commodity groups were calculated by multiplying commodity food intake (grams per day) by vitamin D per gram of commodity food (micrograms per gram). Calculations were performed for *nm*-vitamin D alone (i.e., as currently reported) and for *nm*-vitamin D plus potency-adjusted 25(OH)D. These analyses used intake measures for men and women aged ≥20 y for ease of comparison.

Results

Table 1 shows the recalculated vitamin D content of the food types when potency-adjusted 25(OH)D is taken into account and also provides a comparison with the current content (*nm*-vitamin D) as reflected in the SR26. Although not usually considered discrete food items, fat and skin are notable sources of both *nm*-vitamin D and 25(OH)D and are included in the table because they are often consumed as part of a meat or poultry serving. When the presence of 25(OH)D was included, the declared vitamin D content of the food types increased two to 18 times, depending on food type. Limitations of the 25(OH)D data precluded close examination of the contrasts among the values, although it was noted that cooked forms of the foods had greater content of both forms of vitamin D compared with raw forms. Because comparisons were made on a weight basis, the increase is likely primarily due to moisture loss during cooking. There may be some fat loss that could slightly decrease the total amount of vitamin D but apparently not to the extent of the concentration effect from loss of water. Retention data are needed to fully explain the effect of cooking on vitamin D content in foods.

Although the outcomes in Table 1 suggested a considerable increase in declared vitamin D content for at least some animal-based foods if potency-adjusted 25(OH)D were to be included, the commodity intake outcomes in **Table 2** provided a more meaningful context for a signal about the potential impact of 25(OH)D in foods relative to vitamin D status. In the case of men, the recalculated daily vitamin D intake for beef, pork, chicken, and eggs had the potential to be 1.0, 0.6, 0.5, and 2.0 μg/d (~10%, 6%, 5%, and 20% EAR) for these commodity groups,

TABLE 1 Potential increase in vitamin D content due to inclusion of 25(OH)D content in animal-based food types[1]

Food	*nm*-Vitamin D[2]	25(OH)D[3]	Potency-adjusted 25(OH)D[4]	Recalculated vitamin D[5]
	μg/100 g	*μg/100 g*	*μg/100 g*	*μg/100 g*
Beef				
Rib eye steak/roast, meat only, cooked (*n* = 5)	0.10 ± 0.003	0.26 ± 0.009	1.3	1.4
Rib eye steak/roast, meat only, raw (*n* = 5)	0.09 ± 0.01	0.21 ± 0.01	1.0	1.09
Chuck steak, meat only, cooked (*n* = 1)	0.08	0.28	1.4	1.48
Chuck steak, meat only, raw (*n* = 1)	0.07	0.22	1.1	1.17
Beef fat, cooked (*n* = 4)	0.32 ± 0.03	0.39 ± 0.02	1.9	2.22
Beef fat, raw (*n* = 4)	0.30 ± 0.04	0.38 ± 0.01	1.9	2.2
Pork				
Loin chops, meat only, cooked (*n* = 2)	0.77	0.25	1.25	2.02
Loin chops, meat only, raw (*n* = 2)	0.50	0.17	0.85	1.35
Chicken and turkey				
Chicken dark meat, meat only, cooked (*n* = 3)	0.18 ± 0.07	0.22 ± 0.04	1.1	1.28
Chicken dark meat, meat only, raw (*n* = 3)	0.09 ± 0.03	0.14 ± 0.04	0.7	0.79
Chicken skin, cooked (*n* = 2)	0.31	0.39	1.95	2.26
Chicken skin, raw (*n* = 2)	0.30	0.37	1.85	2.15
Turkey dark and light meat, meat only, cooked (*n* = 2)	0.40	0.07	0.35	0.75
Turkey dark and light meat, meat only, raw (*n* = 6)	0.34 ± 0.07	0.07 ± 0.01	0.35	0.69
Turkey skin, cooked (*n* = 1)	1.35	0.28	1.4	2.75
Turkey skin, raw (*n* = 1)	1.14	0.25	1.25	2.39
Egg				
Egg, whole, large, raw (*n* = 12)[6]	2.50 ± 0.7	0.65 ± 0.08	3.25	5.75

[1] Values are shown as means ± SEs or means. *nm*-Vitamin D, nonmetabolized vitamin D; 25(OH)D, 25-hydroxyvitamin D.
[2] From National Nutrient Database for Standard Reference Release 26 (12); reported as vitamin D-3 form.
[3] From preliminary USDA data (K. Y. Patterson, unpublished results).
[4] Adjusted for potency using a factor of 5.
[5] *nm*-Vitamin D content plus 25(OH)D potency-adjusted content.
[6] Observed ranges were 0.73–7.77 μg for vitamin D-3 and 0.43–1.32 μg for 25(OH)D; see also Reference 20.

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TABLE 2 Vitamin D intake estimates based on retail food commodity intake: U.S. men and women aged >20 y[1]

	Content mean for selected foods		Estimated vitamin D intake based on commodity consumption			
Commodity group	*nm*-Vitamin D[2]	25(OH)D[2]	Intake	*nm*-Vitamin D[3]	Potency-adjusted 25(OH)D[4]	Total: *nm*-vitamin D plus potency-adjusted 25(OH)D
	μg/100 g		*g/d*	*μg/d*	*μg/d*	*μg/d*
Men aged ≥20 y						
Beef, raw	0.08	0.22	81	0.06	0.89	0.95
Pork, raw	0.50	0.17	44	0.22	0.37	0.59
Chicken, raw	0.09	0.14	69	0.06	0.48	0.54
Turkey, raw	0.34	0.07	9	0.03	0.03	0.06
Egg, raw	2.5	0.65	35	0.87	1.14	2.01
Sum[5]			—	1.24 (50 IU)	2.91 (116 IU)	4.15 (166 IU)
Women aged ≥20 y						
Beef, raw	0.08	0.22	45	0.04	0.50	0.54
Pork, raw	0.50	0.17	21	0.11	0.18	0.29
Chicken, raw	0.09	0.14	48	0.04	0.34	0.38
Turkey, raw	0.34	0.07	9	0.03	0.03	0.06
Egg, raw	2.5	0.65	21	0.53	0.68	1.21
Sum[5]			—	0.75 (30 IU)	1.73 (69 IU)	2.48 (99 IU)

[1] From the study by Bowman et al. (19). *nm*-Vitamin D, nonmetabolized vitamin D; 25(OH)D, 25-hydroxyvitamin D.
[2] The content from *nm*-vitamin D and 25(OH)D mean for foods selected for study as shown in Table 1.
[3] Form of vitamin D reported in National Nutrient Database for Standard Reference Release 26 (12).
[4] Adjusted for potency using a factor of 5.
[5] Summation of aggregated data can potentially be misleading but is included here for the purposes of signal generation.

respectively, compared with the current 0.06, 0.22, 0.06, and 0.87 μg/d (~0.6%, 2%, 0.6%, and 9% EAR), respectively. The pattern was similar for women, but, because of lower food intake, the quantitative contributions were less. These findings have the caveat that intakes based on commodity consumption are relatively crude because specificity of individual consumption is missing and data are expressed as average intakes of an aggregated food category.

Summing intake across the commodity groups should be done only for the purposes of signal detection given the aggregated nature of the data. This is because those who consume average amounts of one commodity group may not also consume average amounts of another, and the impact of consumers at either end of the intake spectrum is lost. It would appear, on the basis of summation, that including potency-adjusted 25(OH)D content for these food types could contribute an additional 2.9 μg or 116 IU of vitamin D (~30% EAR) per day for men and perhaps another 1.7 μg or 68 IU (~15% EAR) per day for women. These calculations are based on the IOM determination that available data support a mean reference value of 10 μg/d for adults. IOM reference values have long been the basis for food fortification determinations. Others (21) have concluded that adults require more dietary vitamin D than recommended by the IOM. Should higher requirements be established, the effect of including 25(OH)D in food composition tables would still be evident but would account for less of the requirement.

Discussion

Discrepancy between vitamin D status measures. Clarifying differences between the measures of vitamin D status—intake estimates vs. serum concentrations—is a public health priority because they factor into decisions about fortification and supplementation. Also, although different types of status measures are not expected to necessarily align, wide discrepancies can call one or both measures into question. The current population-based estimates suggesting low vitamin D intake, even when food and supplement intakes are combined, are puzzling in view of reported serum 25(OH)D concentrations. An important step before intervention is to ensure that the intake estimates reflect true intake to the extent possible and that the estimates are not artificially low. The existing U.S. food composition dataset underlying the estimation of dietary intake does not take into account the 25(OH)D content of animal-based food products. This may cause an underestimation of intake given that these animal-based foods are consumed frequently by the U.S. population. Recently, Heaney et al. (5) considered 25(OH)D in foods by estimating nonsupplemented vitamin D intake via a back-calculation technique using existing and unpublished data on the relation between vitamin D intake and serum concentrations. Additionally, these authors examined seasonal serum changes when estimating the contribution of skin synthesis to basal status. The study appeared to have made use of a limited dataset but overall concluded that dietary intakes of vitamin D from nonsupplement sources must be higher than the current estimates indicate. The authors posited the unrecognized contribution of 25(OH)D in foods as a likely explanation. Cashman et al. (17) highlighted the potential yet generally unrecognized contribution of 25(OH)D to the diet in Europe.

The ability to obtain previously unavailable data specifying the 25(OH)D content of a subset of U.S. animal-based foods presented the unique opportunity to explore the potential additive effect of 25(OH)D on the reported vitamin D content of these foods and its possible impact on intake measures. The outcomes suggested that an additional 15–30% of the EAR for vitamin D (1.7–2.9 μg) could be added to estimates of U.S. intake if the vitamin D composition of the food products took into account the presence of 25(OH)D adjusted for potency. The use of data for raw food items may have underestimated the impact, whereas the use of commodity-based intake data attenuated outcomes and muted differences due to individual consumption patterns. Additionally, the measurement of the 25(OH)D

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content of the foods reflected preliminary work, involved relatively few analyses, and may not be consistent with values reported internationally (**Supplemental Table 4**). In short, our data are limited, and the outcomes should be considered indicative of a trend rather than as quantitative realities. However, because there are no immediate plans to pursue additional or more final values for 25(OH)D, they remain the best available U.S. data.

Conclusions about the potency of 25(OH)D for the purpose of estimating total vitamin D intake would benefit from additional studies, including those that address bioavailability in food matrices and those that make use of pharmacokinetics. Furthermore, attention should be given to calculations based on areas under the dose–response curve because they provide good indicators of relative potency. Overall, although support trends toward a potency factor of ~5 compared with *nm*-vitamin D, not all agree. Jakobsen et al. (22), commenting in 2007, preferred a factor of 1.7. Barger-Lux et al. (16) reported a potency factor of 8. Depending on the 25(OH)D potency ultimately established, the impact on measures of intake may vary relative to our analyses, which used a factor of 5. For example, the recalculated vitamin D content of the rib eye steak item could vary from 0.54 to 2.1 μg/100 g depending on potency.

Our outcomes indicated that the question of 25(OH)D in foods is worth pursuing. Incorporation of 25(OH)D into food composition databases could result in increases in estimated intakes of vitamin D that would help reduce the disconnect between vitamin D status reflected by intake estimates and that based on serum 25(OH)D concentrations. This, in turn, could help to inform decisions about the extent to which vitamin D is a nutrient of dietary concern. At the same time, the outcomes offer a cautionary tale relative to quantifying a dose–response relation between vitamin D intake and serum 25(OH)D concentrations. Without consideration of the potentially sizable contribution of dietary 25(OH)D to serum 25(OH)D concentrations, current intakes are underestimated. Therefore, higher intakes (i.e., dose) than assumed currently may be associated with observed serum concentrations (i.e., response). Furthermore, because omission of food-derived 25(OH)D from intake estimates is likely to affect nonsupplement users more than supplement users, this source of error would have greater impact at low rather than high dietary intakes. These possibilities are relevant to establishing or revising reference values that identify a specific intake to ensure an appropriate serum 25(OH)D concentration.

Challenges in determining 25(OH)D in foods. Assay methods and reference materials present challenges to the determination of 25(OH)D in foods (**Supplemental Table 5**). Liquid chromatographic separation followed by MS and tandem MS, with its enhanced selectivity, sensitivity, and ability to use isotopically labeled internal standards, is emerging as the preferred method of assessment for foods, similar to methods for serum (23–26), but requires improved chromatographic separation. The ability to address a wide range of food matrices of differing fat content is also a concern and requires standardization of sample preparation steps. Moreover, reference materials for the measurement of vitamin D in foods are lacking yet are critical to the validation of the measurements. Developing reference materials will require resources and time. Furthermore, unlike analytical efforts for serum 25(OH)D, for which a broad-based coalition has been established to standardize measurement and ensure comparable results for use in research (27,28), methodologies for *nm*-vitamin D and 25(OH)D in foods are not currently the subject of joint discussions about standardization.

Importantly, as made clear in a review by Schmid and Walther (29), there are also non-analytical differences among the reported 25(OH)D content of foods. For instance, the muscle concentrations of *nm*-vitamin D and 25(OH)D differ according to cattle type. Also, some values can be inexplicably high, and, although they may be based on a single measurement, they may also have been derived from animals that received vitamin D supplementation. The practice of vitamin D supplementation to beef, pork, and chickens is not well documented and could vary widely. Reasons for supplementing animals may include perceptions about improved muscle tenderness (30), special feeding protocols, and even interest in making a food label claim about the nutrient content of the product. Likewise, fish products show noteworthy variation in amounts of *nm*-vitamin because of diet (29). The vitamin D content of dairy products is subject to variables such as fodder, exposure to sunlight, production time of year, and animal breed (29). The USDA reported that variability in egg production practices creates the potential for variability in the composition of eggs in the retail market (30). These observations signal challenges in determining the representative amount of any form of vitamin D in an animal-based food.

Finally, the way in which national databases currently report vitamin D content is not standardized and can be confusing, particularly in regard to the inclusion of 25(OH)D content (Supplemental Table 1). Standardization efforts are needed and could encompass international collaborations, conferences, and standard-setting agreements. Without such activities, the available food composition datasets have the potential to become more confusing over time, undercutting their combined utility for estimating intakes and exploring the relation between vitamin D and health outcomes.

Vitamin D fortification and supplementation. The issues identified in this study are relevant to questions about vitamin D food fortification and use of vitamin D supplements. On one hand, interest in ensuring that vitamin D is available as needed in the U.S. diet is appropriate. To that end, the knowledge that animal feeding practices and management can increase vitamin D in the final food product opens another avenue for consideration beyond the familiar approaches of adding the vitamin to grains and cereals or encouraging supplement use. On the other hand, understanding current status and adequately simulating the impact of modifying the nutrient content of the food supply is an essential task before dietary interventions. Simulations should target not only the amounts and vehicles for fortification but should also provide a basis for safety given the diverse nature of food consumption patterns (31). Furthermore, there is the need to more actively monitor the effects of discretionary vitamin D fortification, which is increasingly evident among cereals and grain products (32). These additions, which may be performed to allow a nutrient content claim, can rapidly and significantly affect estimates of intake. Moreover, the possible decision in the future to require the mandatory declaration of vitamin D on food labels may stimulate the addition of vitamin D to foods on the part of food manufacturers. Whether this is a desirable outcome relative to increased intakes (33) or whether it leads to a questionable fortification race is yet to be determined.

The folate fortification experience exemplifies the nature of the preparation and considerations that should underpin decisions to fortify or supplement. In anticipation of implementing federal regulations regarding the addition of folate to certain cereals and grain products, the FDA performed simulations that required extensive modifications to food composition tables coupled with the use of nationally representative survey data reflecting individuals'

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food consumption (34,35). Existing baseline intake of the nutrient from all sources was identified and then followed by modeling changes in the intake of the vitamin given various scenarios. In considering dietary interventions for vitamin D, a similar analysis would be needed before devising specific strategies. However, there are currently insufficient data about the vitamin D content of foods. Overcoming this limitation to characterizing measures of vitamin D intake is an important goal for ensuring adequate vitamin D status and a safe food supply.

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