Vitamin D is well known for its role in bone health (24). The fortification of fluid milk with vitamin D began in the 1930s in North America and Europe in an effort to prevent rickets in children (23). Vitamin D supplementation of infants, through cod liver oil first and later as drops, became widespread. Although issues of vitamin D deficiency for infants, particularly those exclusively breastfed, and the relationship between Vitamin D and bone health in older adults, were ongoing issues and research topics, vitamin D fortification and supplementation were thought to have been successful in preventing vitamin D deficiency. However, in recent years, vitamin D deficiency has emerged as a global problem spanning all age groups, from infants to the elderly (19).

Vitamin D3

One of the major factors contributing to global vitamin D deficiency has been our changed attitude toward sun exposure. Previtamin D (dehydrocholesterol) present in the skin, when exposed to ultraviolet B (UVB) in sunlight, forms vitamin D3 (cholecalciferol) (24), hence the name “sunshine” vitamin. Further conversions in the liver and kidney or other tissues produces the active form of vitamin D3 (1,25 dihydroxy vitamin D3) (24). Historically, sun exposure has contributed the majority of vitamin D required for health (3). In recent years, however, public health messages promoting sun avoidance and fears of skin cancer have kept people out of the sun. Sunscreen practices and the use of hats and other clothing to avoid direct sun exposure have become commonplace. An unforeseen consequence of the push for sun avoidance has been the negative impact on vitamin D status (19). Public health messages have failed to highlight the fact that sunscreen can prevent the formation of vitamin D3 (22). In addition, it was once thought that a few minutes of exposure of the hands and face was sufficient for sun-induced vitamin D synthesis, but it is now recognized that full trunk and limb exposure may be needed for adequate skin synthesis of vitamin D3 (24).

Skin color also has been identified as a major limiting factor in the sunlight-induced synthesis of vitamin D due to the UVB absorptive capacity of melanin (24) and may explain, in part, why individuals with darker skin, such as African Americans, are at higher risk for vitamin D deficiency (17). In Northern latitudes, there is insufficient UVB for vitamin D synthesis for much of the year (24). An additional factor is the increasing age of our population. As we age, our ability to synthesize vitamin D3 in the skin diminishes due to less previtamin D being present (24). Cultural and religious practices in which clothing and dress requirements result in significant skin coverage are also factors that significantly limit sunlight exposure and vitamin D production (7).

Current Recommendations

The recommended intake of vitamin D for the United States and Canada is currently under review by the Dietary Reference Intake for Vitamin D and Calcium Committee of the Food and Nutri-
to 100–150 nmol/L may prevent 58,000 new cases of breast cancer and 49,000 new cases of colorectal cancer each year in the United States (5). The development of type 1 diabetes is associated with a low intake of vitamin D and signs of rickets during the first year of life (2). Vitamin D also has direct effects on insulin secretion, and vitamin D deficiency can affect insulin sensitivity, thus vitamin D status may impact the development of type 2 diabetes (1).

Vitamin D status is also related to infectious disease. The antimicrobial role of vitamin D has been elucidated, providing a possible mechanism for the efficacy of “heliotherapy,” the sunlight therapy used for tuberculosis (6) prior to the development of antibiotics in the last century. Vitamin D status is also associated with influenza and viral upper respiratory tract illnesses (25).

With limited skin synthesis, dietary sources of vitamin D are critical to maintain adequate circulating vitamin D levels and optimal health and wellness. However, dietary intakes of vitamin D are inadequate (4). There are few naturally rich sources of vitamin D. Fatty fish, such as salmon and sardines, are excellent sources and contribute significantly to intake (24). Liver and organ meats are high sources, but are not commonly eaten. Eggs and mushrooms (exposed to UVB) are potential, but unpredictable sources.

**Fortification**

When a population-wide need for a vitamin is identified and the current food supply or dietary pattern is limited, food fortification is indicated. Staple foods are targets for fortification. In the United States, fluid milk and breakfast cereals are the main contributors to food-based intake of vitamin D, as most all are fortified (3). Fortification at 400 IU (10 µg) per quart and breakfast cereals at 90 IU per 100 g is permitted. There are many other foods that are eligible for optional vitamin D fortification in the United States. Milk products, such as yogurt, butter, ice cream, sour cream, cream, and cottage cheese, and hard and soft cheeses, are not commonly fortified (3) and thus are not reliable sources of vitamin D. Although fortification is also permitted in margarine, pastas, hot cereals, rice, and conmeal, these foods are not commonly fortified (3). NHANES data confirms that current intakes of most adults in the United States have vitamin D intakes below the recommended adequate intake (AI), even though there is great potential for fortification (3). One can surmise that these low intakes in the United States may be due to inadequate intake of fortified foods such as milk, which is the position of the dairy industry. An alternate view is that the level of fortification is much too low. A third position is that too few foods in the U.S. food supply contain vitamin D due to the limited number of manufacturers that choose to optionally fortify. In a 2009 review by Mithel, et al. (19) of global vitamin D status and determinants of low vitamin D status, the absence of vitamin D fortification is listed as one of the main factors significantly associated with lower 25-hydroxyvitamin D levels.

Vitamin D toxicity is rare (24). The tolerable upper intake level (UL) (highest daily nutrient intake likely to pose no risk of adverse health effects to almost all the general population) of 2,000 IU/day (50 µg/day), set in 1997 (13), is expected to be substantially revised as requirements of some populations may supersede this level. It has been suggested that the safe UL for vitamin D could be set as high as 10,000 IU/day (250 µg/day) (8).

**Opportunities**

There is a significant commercial and altruistic opportunity for manufacturers of cereal-based foods to impact the vitamin D content of the food supply and thereby reduce vitamin D deficiency and insufficiency worldwide. Given the ubiquitous nature of cereal-based foods in the food supply, it may be the optimal food vehicle for the provision of vitamin D. At the present time, bread can be fortified with crystalline vitamin D2 or vitamin D3 at a level of 90 IU per 100 g in the United States. However, a recent Mintel survey indicates that less than 2% of bread products in the United States are fortified with vitamin D (18). As an alternative to fortification, bread can be baked with yeast high in vitamin D. When exposed to UVB, baker’s yeast converts endogenous ergosterol to ergocalciferol (vitamin D2) in a photochemical reaction (16). The resulting bread or other yeast-raised bakery products become a natural source of vitamin D. As the vitamin D originating from the yeast is not declared on the product ingredient list, it is difficult to determine the contribution of the bread to the vitamin D level of the food supply and the intakes of those consuming these foods. Enrichment of yeast-raised bakery products with vitamin D may be an immediate solution to increasing the vitamin D in the food supply in countries that do not permit vitamin D fortification.

In Europe, Optimal Strategy for Vitamin D Fortification (OPTIFORD) is a research project that aims to determine if fortification of foods with vitamin D is a feasible strategy to increase vitamin D intakes, and the objectives specifically highlight a need to develop “a new low-fat food fortified with...”
vitamin D” (21). Cereal-based foods, such as breads, may be the food vehicle needed to achieve the goal of new vitamin D-fortified or -enhanced foods.

Millions of consumers are at risk for vitamin D deficiency or insufficiency. At highest risk are institutionalized elderly, osteoporotic individuals, chronically ill patients, and populations with darker skin pigmentation (24). However, anyone with little sun exposure and that has a low intake of vitamin D is at risk. It is expected that the new North American recommendations for vitamin D intake will be much higher than the AI’s set in 1997, namely 200 IU/day for young adults to 600 IU/day for adults has been suggested (11), and as high as 6,000 IU/day has been estimated as the requirement during pregnancy (12). Current food sources are inadequate to meet even the outdated recommendations and thus will contribute a much smaller percentage of the new recommendations. Thus, there is a serious need for more foods that contain vitamin D and for vitamin D-containing foods to provide higher levels of vitamin D. The fortification of many more cereal-based foods, such as pasta, hot cereals, rice, and cornmeal, is an opportunity to increase vitamin D intakes in the United States, and revised fortification policies to include vitamin D are needed in many countries. Bakery products baked with naturally occurring yeast that is high in vitamin D may be an option for achieving vitamin D fortification policies to include vitamin D in the United States, and revised fortification recommendations. Thus, there is a serious need for more foods that contain vitamin D and for vitamin D-containing foods to provide higher levels of vitamin D. The fortification of many more cereal-based foods, such as pasta, hot cereals, rice, and cornmeal, is an opportunity to increase vitamin D intakes in the United States, and revised fortification policies to include vitamin D are needed in many countries.

Bakery products baked with naturally occurring yeast that is high in vitamin D may be an option for achieving vitamin D fortification policies to include vitamin D in the United States, and revised fortification recommendations. Thus, there is a serious need for more foods that contain vitamin D and for vitamin D-containing foods to provide higher levels of vitamin D. The fortification of many more cereal-based foods, such as pasta, hot cereals, rice, and cornmeal, is an opportunity to increase vitamin D intakes in the United States, and revised fortification policies to include vitamin D are needed in many countries.

References

21. Optiford. Published online at www.optiford.org.

Wendy Dahl is an assistant professor in the Food Science and Human Nutrition Department at the University of Florida where she is active in teaching, extension, and research. Her research program focuses on the efficacy and effectiveness testing of fortified and enriched foods in health and disease. She provides outreach to industry, food retailers, health professionals, and consumers in the development and adoption of wellness-promoting foods and nutrition strategies, with an emphasis on demographics that are most at risk. She can be reached at w Dahl@ufl.edu.