Special Article

Vitamin D deficiency and disease risk among aboriginal Arctic populations

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Aboriginal populations living above the Arctic Circle are at particularly high risk of vitamin D deficiency due to limited ultraviolet B exposure (related to geographic latitude) and inadequate dietary intake (recently related to decreased traditional food consumption). Major changes in diet and lifestyle over the past 50 years in these populations have coincided with increased prevalence rates of rickets, cancer, diabetes, and obesity, each of which may be associated with vitamin D inadequacy. This review examines the risk factors for vitamin D inadequacy, the associations between vitamin D and disease risk at high geographic latitudes, and the recommendations for improving vitamin D status particularly among aboriginal Arctic populations. Traditional foods, such as fatty fish and marine mammals, are rich sources of vitamin D and should continue to be promoted to improve dietary vitamin D intake. Supplementation protocols may also be necessary to ensure adequate vitamin D status in the Arctic.

INTRODUCTION

It is currently estimated that 1 billion people worldwide are vitamin D deficient[1] despite vitamin D food fortification in some countries, national dietary intake recommendations for deficiency prevention, and adequate solar ultraviolet B (UVB) in many countries. Breastfed infants, the elderly, those with limited solar UVB exposure (due to protective clothing, high geographic latitude, or insufficient time spent outdoors, for example), and those with dark skin pigmentation are groups believed to be at highest risk of deficiency.[2–4] Although it has long been known that vitamin D deficiency causes rickets and osteomalacia, emerging evidence has implicated hypovitaminosis D [the definition of which is hotly debated, but generally referred to as serum 25(OH)D concentrations <75 nmol/L] in a growing list of nonskeletal chronic diseases that includes several types of cancer, type 1 and type 2 diabetes, obesity, cardiovascular disease, multiple sclerosis, and infectious diseases (such as tuberculosis).[1,4,5] As the relationships between vitamin D and these chronic diseases become clearer, there is increased concern for accurate clinical assessment of vitamin D status, definitions of optimal serum concentrations, revised intake recommendations, and effective strategies to prevent deficiency.[1,6]

Serum 25-hydroxyvitamin D [25(OH)D], or calcidiol, is the principal circulating vitamin D metabolite and the most common measurement of vitamin D status. Although no formal definitions currently exist, most experts define vitamin D deficiency as serum 25 (OH)D levels <20–25 nmol/L[7]; however, <50 nmol/L is

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Key words: Arctic, aboriginal populations, chronic disease, vitamin D

doi:10.1111/j.1753-4887.2011.00406.x

Table 1 **Informal definitions of deficient, insufficient, and optimal serum 25(OH)D concentrations.**

	Range of serum 25(OH)D	Source
Deficiency	<20–25 nmol/L	Hanley and Davison (2005)[7]
Insufficiency	50–80 nmol/L	Hanley and Davison (2005)[7]; Holick (2008)[8]
Optimal	>75 nmol/L,	Garland et al. (2009)[10];
	90–100 nmol/L,	Bischoff-Ferrari et al. (2006)[9];
	100–150 nmol/L	Whiting and Calvo (2005)[6]

Units of nmol/L can be converted to ng/mL by dividing by 2.496.

sometimes defined as deficient (Table 1).[8] The appropriate definition for insufficiency is more controversial; it is often defined as serum levels of 50–80 nmol/L,[7,8] although some studies use lower values. Most evidence suggests better health outcomes are achieved with concentrations >75 nmol/L, while the most optimal range may be 90–100 nmol/L or even 100–150 nmol/L.[6,9,10] It should be noted that some studies report serum concentrations in international system (SI) units, as nmol/L, while others report values as ng/mL (1 ng/mL = 2.496 nmol/L); all values are reported as nmol/L in this review. Assay methods to measure serum 25(OH)D also vary among studies.

The Arctic Circle, located at approximately 66° 33′ N latitude, runs through the northernmost areas of Canada, Denmark (i.e., Greenland), Iceland, Norway, Sweden, Finland, Russia, and the United States (i.e., Alaska). The land within the Arctic Circle is often referred to as the "land of the midnight sun" because the sun does not set for approximately 3 months during the summer. As autumn approaches, the amount of daylight decreases steadily until the sun is no longer visible for up to 2 months in the winter, a phenomenon referred to as "polar night" or "polar twilight." However, any time the sun is present at these latitudes, the solar zenith angle is such that it causes significantly less UVB radiation to reach the earth's surface.[11] Because solar UVB exposure is considered the principal source of vitamin D, the latitude and, thereby, limited UVB exposure in this region of the world play a critical role in the vitamin D status of its inhabitants.

The Arctic is inhabited by approximately 4 million people, approximately 10% of whom are aboriginal people, including (but not limited to) Inuit, Inuvialuit, First Nations, Metis, Yup'ik, Aleut, and Saami.[12] According to the Arctic Human Development Report published in 2004, aboriginal populations range from approximately 88% in Greenland, 51% in Arctic Canada, 16% in Alaska, 5% in Arctic Norway, Sweden, and Finland, to less than 4% in Arctic Russia.[13] Over the past 50 years, aboriginal Arctic populations have experienced a rapid transition in diet and lifestyle, largely a result of increased acculturation.[13] Particularly, the diet within this population has changed from one based primarily on traditional foods, including caribou, fish, and marine mammals, to a diet consisting mainly of imported non-nutrient-dense foods due to acculturation and, possibly, climate change.[14–16] As a result, widespread dietary inadequacy has become evident, and chronic disease rates are rising among these populations.[15–19]

This review aims to examine the risk factors for vitamin D deficiency and the associations between vitamin D and chronic and infectious diseases among aboriginal populations in the Arctic. Relevant research conducted at northern geographic latitudes (primarily ≥55°), including Norway, Greenland, Finland, Denmark, Estonia, the United Kingdom, and Canada, was reviewed. Key words used for the literature search included the following: vitamin D, Arctic, aboriginal, latitude, UVB, traditional foods, dietary intake, bone, cancer, obesity, diabetes, and infectious disease. The data gathered may be useful in making important decisions for an intervention to improve vitamin D intake and status among aboriginal Arctic populations.

RISK FACTORS FOR ABORIGINAL ARCTIC POPULATIONS

Latitude, season, and sunlight exposure

Upon solar UVB exposure, vitamin D is synthesized in the skin; therefore, geographic latitude and season are critical factors to consider when assessing vitamin D status. It has long been recognized that vitamin D cannot be produced in the skin at latitudes as low as 42° N from November through February due to the increased angle of the sun during these winter months, which decreases the intensity of UVB radiation.[11] As latitude increases, so does the length of the year during which cutaneous vitamin D production is impossible.[11] It is also believed that during summer months, those living at higher latitudes (particularly >60° N) require much longer UVB exposure times than those living at lower latitudes to cutaneously synthesize equivalent amounts of vitamin D.[20] Figure 1 illustrates Webb's[20] model of the effect of latitude on the ability to synthesize vitamin D throughout the year. There are a set of assumptions made in this model (including fixed atmospheric conditions, horizontal skin surface, and skin type), which are further described in the original paper.[20] Dowdy et al.[21] suggest

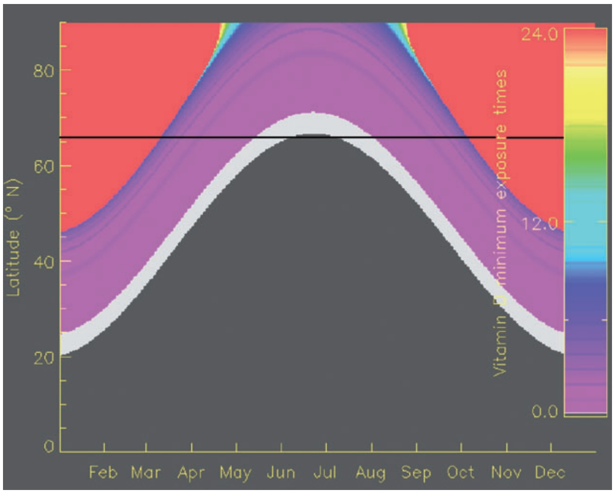

Figure 1 **Minimum exposure time (hours) needed to synthesize the equivalent of 1,000 IU (25 μg) vitamin D with respect to latitude and time of year (assuming a fixed atmospheric state and a horizontal skin surface).** The red areas show where vitamin D synthesis is not possible. The black areas show where vitamin D synthesis occurs in minutes (rather than hours). The horizontal black line at approximately 66 degrees was added to represent the latitude of the Arctic Circle for the purposes of this review. Reproduced from Webb (2006)[20] with permission from Elsevier.

this model overestimates required exposure times; however, the fact remains that exposure times needed to synthesize a beneficial amount of vitamin D (when cutaneous synthesis is possible) are sometimes impractical for those living at high latitudes.

Several studies conducted at northern latitudes have confirmed inadequate vitamin D status in both winter and summer seasons. In Estonia, a northern European country located at latitude 57–59° N, vitamin D insufficiency [serum 25(OH)D <50 nmol/L] varied by season and was widespread among the study population ($n = 367$).[22] In winter, the mean serum 25(OH)D concentration was 43.7 ± 15 nmol/L, with 73% of the population having insufficient levels and 8% being deficient (<25 nmol/L). In summer, the mean serum 25(OH)D concentration was 59.3 ± 18 nmol/L; 29% had insufficient levels and less than 1% were deficient. Those who used vitamin D supplements (2%) (5–20 μg of vitamin D per day) had higher 25(OH)D levels in the winter than those who did not take supplements. Additionally, body mass index (BMI) and age were significantly associated with vitamin D status; however, sunbathing habits (i.e., how much of the body was regularly exposed to sun) explained much of the variance caused by these factors. Men had a greater increase in 25(OH)D concentrations after the summer and a lower mean 25(OH)D concentration in the winter compared to women. It should be noted that in Estonia, dairy products are not fortified with vitamin D, few people use supplements, and the typical diet does not contain vitamin-D-rich foods; therefore, this population depends heavily on sunlight exposure for vitamin D. This study concludes that summertime build-up of vitamin D is not adequate to achieve optimal vitamin D status throughout the year at northern latitudes.[22]

Macdonald et al.[23] assessed 25(OH)D status in relation to sunlight exposure, dietary vitamin D intake, bone health, and overweight in 3,113 postmenopausal women living at latitude 57° N in the UK (Aberdeen, Scotland). Mean 25(OH)D concentrations were higher in summer and fall due to greater sunlight exposure compared to winter and spring. However, during each season, between 73% and 84% of the study population had serum 25(OH)D levels of <70 nmol/L, which was considered insufficient. Total dietary vitamin D intake (from food, cod liver oil, and multivitamins) was significantly associated with 25(OH)D concentrations throughout the year. These results suggest dietary intake, especially in the winter and spring, when sunlight is insufficient for cutaneous vitamin D production, can help prevent seasonal variations in vitamin D status in populations living at higher latitudes. Low 25(OH)D was also associated with increased bone loss and turnover as well as with obesity.[23]

In the Norwegian Arctic (latitude 65–71° N), vitamin D status of middle-aged women ($n = 443$) was significantly associated with the time of year and UVB exposure.[24] Between the months of November and June, more women had a serum concentration below 37.5 nmol/L (23%) and below 50 nmol/L (58%) in January and February. Women who spent time in southern latitudes during the summer before their blood was sampled and those who used solariums (tanning beds) had higher serum 25(OH)D concentrations than those who stayed in Norway the entire year. In fact, staying in the Arctic regions of Norway during the summer prior to blood sampling was significantly negatively associated with 25(OH)D concentration. Dietary vitamin D intake also predicted serum 25(OH)D concentrations in this study, emphasizing that traditional marine foods (particularly fish, fish liver, and fish liver oil) can contribute significantly to vitamin D intake in Arctic populations.[24]

For more than half of the year, Arctic populations experience extremely low, if any, UVB radiation, due to the geographic latitude. During this time, residents must wear protective, cold-weather clothing that covers the skin, and they spend less time outdoors due to the extreme temperatures. In the three above-mentioned studies, vitamin D insufficiency was also seen during the summer at high latitudes.[22–24] Research is needed to evaluate the amount of summer sun exposure and summertime vitamin D status in populations living above the Arctic Circle. As long as UVB radiation is inadequate to produce vitamin D cutaneously, these populations are completely dependent on dietary sources from food and/or supplements.

Dietary intake and nutrition transition

The diet and lifestyle transition among Arctic populations has had deleterious effects on diet quality. Recent research by Sharma et al.[15,16] conducted among Inuit and Inuvialuit populations living in Nunavut ($n = 87$) and the Northwest Territories (NWT), Canada ($n = 101$), respectively, found that dietary vitamin D intake was less than the 2010 Dietary Reference Intakes (DRIs).[25] A comprehensive dietary analysis was completed using a validated, culturally appropriate quantitative food frequency questionnaire.[26,27] In Nunavut, the mean daily intake of vitamin D among those aged 19–88 years was 2.25 μg for men and 2.13 μg for women.[15] This is less than a quarter of the current recommended dietary allowance (RDA) for vitamin D in the United States and Canada: 15 μg/day (500 IU) for adults up to 70 years; 20 μg/day (800 IU) for adults >70 years.[25] In the NWT, 83–100% of all age and gender groups did not meet the vitamin D recommendations, with the exception of men between the ages of 51 and 70 years; in this group, 63% did not meet the recommendation.[16] Women in the NWT had a lower mean daily intake of vitamin D than men, 1.9 μg and 6.4 μg, respectively. Further dietary analysis in the same populations confirmed inadequate dietary intake of vitamin D. Among 75 Inuit men and women in Nunavut, more than 60% had low vitamin D intake, with mean daily intakes of 1.9 μg and 3.1 μg, respectively.[28] In the NWT, 84–100% of 64 Inuvialuit women were found to have lower-than-recommended intakes (mean 3.0 μg/day), while most men met the recommendation (mean 7.7 μg/day).[29] It should be noted that some studies report vitamin D intake in international units (IU), while others report vitamin D intake in micrograms (μg) (1 μg = 40 IU); all intake values in this review are reported in micrograms.

Conversely, adequate vitamin D intake was reported among Canadian aboriginal and white women ($n = 356$) living in Manitoba (49°–58° N); total mean daily intake from food and supplements was 8.6–18.8 μg/day.[30] Rural aboriginal women obtained significantly more vitamin D from food than urban aboriginal and urban white women, who also used supplements, and older women (≥51 years) consumed more vitamin-D-rich foods than younger women. Despite adequate intake, the prevalence of vitamin D deficiency was higher among Canadian aboriginal women than among Canadian white women. Thirty-two percent of rural aboriginal and 30.4% of urban aboriginal women, compared to 18.6% of urban white women, had a serum 25(OH)D concentration of <37.5 nmol/L, which met the definition of deficiency in this study; 84–95% of aboriginal women and 62% of white women had levels below the optimal level of 75 nmol/L. Vitamin D intake was significantly correlated with vitamin D status only in white women, and the authors indicated this was likely not due to the season in which blood was sampled. Interestingly, fortified milk and margarine were the main sources of vitamin D among these women, which underscores the impact of food fortification in Canada.[30]

It is believed that vitamin D was consumed in adequate amounts in the traditional Inuit diet due to more frequent consumption of vitamin-D-rich foods, such as fatty fish, marine mammals, liver, and other organ meats.[14,18] However, in four recent studies there were no traditional foods (TF) among the top ten foods most frequently consumed in both Nunavut and the NWT, leading researchers to suggest that decreased consumption of TF is likely contributing to current inadequate intake of vitamin D.[15,16,28,29] Receveur et al.[14] also reported decreasing consumption of TF in the Canadian Arctic. Nonetheless, TF (including fatty fish, seal, and whale) still contributed significantly to vitamin D intake: 26.8% in the NWT and 57.7% in Nunavut; therefore, the authors suggested these foods should be promoted to help improve dietary adequacy.[28,29]

Kuhnlein et al.[18,31] evaluated the impact of TF consumption on nutrient intake in Yukon First Nations, Dene/Me'tis, and Inuit adults ($n = 3{,}404$) and in Yukon and Dene children ($n = 98$) residing in Yukon, the NWT, Nunavut, and Labrador. Twenty-four-hour recalls were collected during two seasons to estimate mean vitamin D intake for each group. When a minimum of one TF was consumed in a day, vitamin D intake (and many other nutrients) was significantly higher in all adults. Mean vitamin D intake was three times higher among Inuit (25.1 μg/day) than among Yukon First Nations and Dene/Metis populations (7.3 μg/day and 7.9 μg/day, respectively) when TF were consumed. Older adults (>40 years) in all groups consumed significantly more TF than younger adults, and older Inuit (≥61 years) consumed the most TF of any group.[18,31]

Rejnmark et al.[32] measured various plasma indicators of calcium homeostasis and bone metabolism in Inuit Greenlanders and Danes ($n = 188$) consuming a traditional Inuit diet (defined as including seal and/or whale at least once a week) or a Westernized diet (defined as including seal and/or whale 3 times or less per month) and living in Greenland (at 64° N), and Denmark (55° N). These data showed decreased vitamin D plasma concentrations related to a diet that included less TF. Inuit Greenlanders consuming a traditional diet had higher 25(OH)D concentrations (53 nmol/L) than the other Inuit groups living in either Greenland or Denmark

Table 2 **Dietary vitamin D intake among aboriginal Canadian populations.**

Author (year)	Population	Reported mean daily vitamin D intake†
Sharma et al. (2010)[16]	Inuit adults (in Nunavut)	2.3 μg for men 2.1 μg for women
	Inuvialuit adults (in NWT)	6.4 μg for men 1.9 μg for women
Hopping et al. (2010)[28]	Inuit adults (in Nunavut)	1.9 μg for men 3.2 μg for women
Erber et al. (2010)[29]	Inuvialuit adults (in NWT)	7.7 μg for men 3.0 μg for women
Kuhnlein et al. (2004)[18]	First Nations adults (in Yukon)	7.3 μg with traditional foods 2.1 μg without traditional foods
	Dene/Metis adults (in NWT)	7.9 μg with traditional foods 3.5 μg without traditional foods
	Inuit adults (in NWT, Nunavut, and Labrador)	25.1 μg with traditional foods 8.6 μg without traditional foods
Weiler et al.(2004)[30]	Rural aboriginal women (in Manitoba)	13.9 μg from food 13.9 μg from food + supplements
	Urban aboriginal women (in Manitoba)	7.8 μg from food 10.8 μg from food + supplements
	Urban white women (in Manitoba)	6.0 μg from food 10.6 μg from food + supplements

† 1 μg = 40 IU.
Abbreviation: NWT, Northwest Territories.

and consuming a Westernized diet (32 nmol/L and 44 nmol/L, respectively). In addition to diet, this study found ethnicity, age, and season were also significant independent determinants of vitamin D status, while latitude was not. This study suggests ethnicity should be considered in future research of similar populations, as genetic differences in calcium and vitamin D metabolism may exist between Inuits and Caucasians.[32]

In contrast, a recent study that investigated vitamin D status and its determinants among elderly subjects ($n = 669$) in the Faroe Islands (latitude 62° N) indicated that high intake of marine foods may not be enough to protect high-latitude populations from vitamin D inadequacy.[33] The subjects were from a fishing population that regularly consumes fish and pilot whale blubber; since vitamin D fortification is not mandated, these food items comprise their primary source of vitamin D. However, approximately 54% of the study population had serum 25(OH)D levels <50 nmol/L, while only 10.3% had serum 25(OH)D levels >80 nmol/L, with median values being higher in the summer than in the winter. Overall fish intake was not significantly correlated with vitamin D status; however, the most frequently consumed fish were cod and haddock, which are not as high in vitamin D as more fatty fish. Whale blubber intake, at least once a month, increased the odds of 25(OH)D levels being above 80 nmol/L by 56%. BMI, female gender, and summer season were also positively associated with higher vitamin D status. Finally, these authors raised the concern that a traditional diet also increases exposure to environmental contaminants (e.g., methylmercury) and suggest that supplementation is warranted in this population.[33]

Further investigation of possible genetic differences in vitamin D metabolism will provide valuable data to help determine appropriate dietary approaches to preventing vitamin D inadequacy. Evidence of dietary vitamin D intake among aboriginal Arctic populations is summarized in Table 2.

VITAMIN D AND DISEASE

Bone health

Recognized in 1645, rickets was the first observed health effect of vitamin D deficiency.[34] Since food (and infant formula) fortification, sunlight exposure, and supplementation were identified as appropriate treatments for rickets, the focus on vitamin D subsided. However, the persistence or re-emergence of rickets in children and osteomalacia in adults, along with more recent associations between vitamin D and bone health, has placed vitamin D back in the spotlight in recent years.

Vitamin D deficiency rickets continues to be reported among children throughout the world, including the United States, Canada, and the United Kingdom.[35,36] In Canada, Ward et al.[36] confirmed 104 cases of rickets in children between 2002 and 2004, reporting an overall annual incidence of 2.9 cases per 100,000. The incidence was greater among children over 1 year of age living in the North (Yukon Territory, the NWT, and Nunavut). By ethnicity, 13% of the children were First Nations and 12% were Inuit. Overall, 89% of the children were classified as having intermediate or darker skin, and 94% were breastfed. Maternal factors were low sun exposure and low intake of vitamin D (from diet or supplements) during pregnancy and lactation. This study highlighted the need for increased attention to maternal and infant vitamin D status, particularly in people with darker skin and in aboriginal women and children living in Canada's northern territories.[36] The Canadian Paediatric Society acknowledges the health issues related to vitamin D status in mothers and children and has confirmed that deficiency is especially common among aboriginal people, many of whom live in the Arctic. A position statement on the topic recommends routine vitamin D supplementation for children and pregnant and lactating women living in the northern regions of Canada.[37]

Although there is limited evidence, it has been reported that aboriginal people may have significantly higher rates of fracture than non-aboriginal people.[38] A study of the First Nations population in Manitoba (latitude 49–58° N) evaluated risk of all fractures and found that First Nations people had a twofold higher incidence of any type of fracture than non-First-Nations people. Vitamin D status and intake were not assessed; however, this study was the first to identify this population as being at higher risk for fracture, suggesting that ethnicity and/or higher prevalence of osteoporosis may be factors in fracture rates in this population.[38]

Low vitamin D status is associated with elevated parathyroid hormone, which is associated with increased bone loss and turnover. In southern Finland (latitude 60° N), the relationships between intact parathyroid hormone (iPTH), serum 25(OH)D, and bone health in young healthy adults aged 31–43 years were assessed.[39] This study reported that one-third of the study population ($n = 328$) was vitamin D deficient [25(OH)D < 25 nmol/L] during the winter despite adequate mean daily vitamin D intake by men and nearly adequate intake by women. Serum iPTH concentrations were found to increase with 25(OH)D levels < 80 nmol/L in women and <40 nmol/L in men; moreover, women had significantly higher iPTH concentrations than men. Significantly lower forearm bone mineral density was seen only in men with higher iPTH concentrations, and no relationship was found between 25(OH)D levels and bone mineral density.[39] Thus, current dietary intake recommendations may not be adequate for healthy young adults at higher latitudes to achieve the optimal vitamin D status needed to maintain normal iPTH concentrations in the wintertime and to prevent decreased bone mineral density.

Vitamin D and calcium supplementation during winter may prevent seasonal changes in vitamin D status and bone loss in some populations[40]; however, there is no consensus on the optimal level or duration of supplementation or on whether supplementation is most effective with calcium alone or in combination with vitamin D for bone health. Several drug therapies also show good efficacy for improving bone density,[41] but the focus of this review is dietary strategies for improving vitamin D status at high latitudes.

Cancer

It is believed the incidence of malignant diseases, including cancer, was exceptionally low among Inuit populations historically, but this is no longer the case.[13] Coinciding with major changes in diet and lifestyle over the past 50 years, a significantly increased incidence of cancer, especially lung, colorectal, breast, and stomach cancer, has been observed among the Inuit.[13] The incidence of colorectal cancer is currently higher in Alaskan Inuit than in whites living in the United States.[13] Furthermore, cancer is now the leading cause of death among Alaska Native people, and cancer mortality rates in Alaska are significantly higher than those in the mainland United States.[42] While environmental, geographical, and genetic factors are important to consider, poor diet quality and lifestyle changes are also plausible contributors to these numbers.

A link between sun exposure, latitude, and cancer mortality was first suggested in 1915.[43] What is referred to as the UVB/vitamin D/cancer theory was proposed in 1980 by Garland and Garland on the basis of an observation that colon cancer rates were lowest in the sunniest parts of the United States,[44] and support for this theory has grown to be scientifically strong enough that vitamin D is currently used in cancer prevention and treatment.[45] To date, evidence has linked UVB exposure with the incidence of approximately 18 types of cancer, including colon, breast, lung, stomach, and prostate cancer.[45–47] Specifically, age-adjusted incidence of breast cancer was higher in countries at higher latitudes (including Iceland and Norway) when incidence rates in 107 countries were compared,[46] while the age-adjusted incidence of lung cancer was also higher in countries at higher latitudes (including Canada, Denmark, and the United Kingdom) in a comparison of incidence in 111 countries.[47] A recent meta-analysis of 63 observational studies that examined vitamin D and cancer risk found that the majority of these studies reported a positive effect of sufficient (>75 nmol/L) vitamin D status on the risk of colon, breast, prostate, and ovarian cancer.[48] Several large epidemiological studies linked lower dietary vitamin D intake with higher risk of colon cancer[48]; lower dietary vitamin

D intake has also been associated with breast cancer.[46] At high latitudes, survival rates of several types of cancer have been associated with season of diagnosis as a result of seasonal variations in UVB irradiance and vitamin D status. In Norway (latitude 58–71° N), Robsahm et al.[49] found a significant variation in prognosis based on the season of diagnosis in 115,096 breast, colon, and prostate cancer patients. Those diagnosed in summer or fall, when serum 25(OH)D levels were highest, had a lower risk of death. There was no difference in prognosis between those living in northern or southern regions of Norway; the authors suggested that dietary intake of fatty fish and cod liver, which are commonly consumed in northern Norway, may explain this finding. This study also suggests that higher vitamin D levels during cancer treatment may improve treatment effects.[49] Further research on the relationships between vitamin D and cancer is warranted among aboriginal Arctic populations.

Diabetes

Alaska Native people have the highest rate of increase in diabetes of any people in North America,[50] and the prevalence of diabetes among aboriginal people in northern Canada is also increasing.[17,19] Vitamin D is believed to play a role in glucose intolerance, type 2 diabetes, and metabolic syndrome due to its effects on insulin secretion and sensitivity,[51,52] and it may also be an environmental factor in the development of type 1, or juvenile, diabetes.[53] As diabetes rates continue to rise in Arctic populations, the public health implications of vitamin D status are becoming increasingly significant.

The incidence of type 2 diabetes was associated with low serum vitamin D status in Finland (latitude >60° N) in a pooled analysis of two cohorts (in which similar results were found previously).[52] Men with the highest serum vitamin D concentrations (range, 54–148 nmol/L; mean, 69.1 nmol/L) had an 82% lower risk than those with the lowest concentrations (range, 9–29 nmol/L; mean, 22.3 nmol/L) after adjustment for BMI, physical activity, smoking, and education. Vitamin D insufficiency [serum 25(OH)D < 50 nmol/L or 20 ng/mL] was also reported in the winter among a small cohort with type 2 diabetes in Scotland at approximately 56° N.[54]

Results of randomized controlled trials of vitamin D supplementation related to diabetes, including some trials conducted at higher latitudes, have varied.[55] However, it has been suggested that promoting higher intakes of both vitamin D and calcium may be an inexpensive intervention for prevention of type 2 diabetes.[56]

A birth-cohort study in northern Finland (latitude 65–68° N) showed that regular vitamin D supplementation of ≥2,000 IU/day (or 50 μg/day) in infancy was associated with a reduced risk of developing type 1 diabetes.[57] Stene and Joner[58] also observed a reduced risk of type 1 diabetes in Norway (latitude 58–71° N) in children who were supplemented with cod liver oil (approximately 400 IU/day or 10 μg at least 5 times per week) during the first year of life. In a previous study, the same authors observed a reduced risk of type 1 diabetes in offspring when mothers used cod liver oil during pregnancy, but no significant benefit was found with the use of other vitamin D supplements in this study.[59] The authors suggested the effects could be attributed to the fatty acids in cod liver oil, which are also found in other marine sources of vitamin D consumed by aboriginal Arctic people (such as fatty fish, seal, and whale blubber). Additionally, the authors suggested the bioavailability of vitamin D may be better in cod liver oil than in other supplements; however, Holvik et al.[60] reported no difference in the bioavailability of vitamin D between fish oil capsules and a multivitamin tablet containing the same dose of cholecalciferol.

Infectious disease

Antimicrobial drug resistance, the re-emergence of tuberculosis, and the emergence of HIV and other viruses in Arctic communities has caused increased concern among governments and medical and public health officials.[61] Besides crowded housing, the cold climate, overuse and/or lack of antimicrobial drugs in the Arctic,[61] vitamin D status may also be a determinant of some infectious diseases. Vitamin D deficiency has been associated with increased rates of infection, including respiratory infections, influenza, and active tuberculosis, as reviewed by Gombart.[5] Discussion of the mechanisms by which vitamin D is involved in immunity is beyond the scope of this review.

In 2006, the highest rates of tuberculosis in Canada were reported in Nunavut (155.9 cases per 100,000 people). Overall, rates were higher among Canadian-born aboriginal people than among Canadian-born non-aboriginal people and were higher in the North (Yukon, the NWT, and Nunavut) than in the rest of Canada.[62] A recent meta-analysis found that patients with tuberculosis had lower serum 25(OH)D levels than controls matched on age, sex, ethnicity, diet, and location; however, the authors did not control for sunlight exposure and smoking.[63] Vitamin D, cod liver oil, and sunlight were used to treat patients with tuberculosis before antibiotics were available; although current studies are inconclusive, vitamin D has been suggested as a possible safe, low-cost prophylaxis and supplemental treatment for tuberculosis and other bacterial infections.[64,65] It has also been suggested that higher vitamin D levels may be required for optimal innate immune function,[64] which further brings into question the adequacy of current recommendations, especially for populations with limited UVB exposure.

Implications for public health

When sunlight is not sufficient to meet vitamin D needs, ensuring adequate vitamin D intake is paramount. Mandatory vitamin D fortification policies have been established in Canada, Norway, Sweden, and Finland. While food fortification does contribute to improved vitamin D intake and status,[66,67] whether it is sufficient to improve the health status of a population at a high latitude is unclear. For example, vitamin D fortification of milk products and margarine in Finland has been effective in improving vitamin D status and intake, but the high prevalence of suboptimal vitamin D status during the winter remains a concern in this population.[66,67] Expanding the number of foods to be fortified with vitamin D has been suggested in Canada and Finland.[67,68] Further research is needed to establish an adequate serum 25(OH)D level for optimal health outcomes and the amount of fortification needed to achieve this serum level.

In addition to fortification, many researchers and health professionals support the need for oral vitamin D supplementation at northern latitudes.[30,37,67,68] Supplementation is believed to be an inexpensive and well-tolerated intervention and may help prevent expensive medical treatment for deficiency-related problems if the population is agreeable[9,48,69]; however, the optimal dose and frequency are still debated. In Denmark, four strategies were considered to promote increased vitamin D intake among the high-risk segments of the population, and supplementation was found to be the most preferred method to accomplish this.[70] An assessment to determine the optimal method for increasing vitamin D intake among aboriginal Arctic populations is warranted.

Furthermore, many studies have raised concerns that current intake recommendations in many countries are too low to prevent vitamin D deficiency and associated health problems for many population groups. Experts have suggested that recommendations be substantially increased and tailored to specific populations, considering the variety of factors that affect vitamin D status.[69,71–73] As a result, in 2004, the Nordic Nutrition Recommendations (which serve as dietary recommendations for all Nordic countries: Denmark/Greenland, Finland, Norway, Sweden, and Iceland) were revised with increased vitamin D recommendations – from 5 μg/day to 7.5 μg/day – for ages 2–60 years, based on accumulating evidence of significant seasonal variation in vitamin D status.[74] In 2010, the Institute of Medicine of the National Academies also revised the Dietary Reference Intakes (DRIs) for vitamin D (and calcium) in collaboration with US and Canadian governments. The recommendations for vitamin D increased to 15 μg/day (600 IU) for all individuals 1 to 70 years of age and 20 μg/day (800 IU) for adults <70 years.[25]

These authors and others strongly urge that culturally appropriate nutrition education and intervention programs continue and expand throughout Arctic communities to improve dietary intake and reduce chronic disease rates related to nutrient insufficiency.[14–16,18] Healthy Foods North is an example of a comprehensive nutrition intervention aimed at reducing dietary and lifestyle risk factors for chronic diseases in aboriginal Canadian Arctic populations.[75–77] This program has identified several nutrient deficiencies in Nunavut and the NWT and has shaped nutrition intervention strategies based on these deficiencies.[15,16] This program emphasizes traditional foods, such as fatty fish and marine mammals, to improve vitamin D intake. Although there is a continued need to improve data on contaminants in fish by regions, as well as on vitamin D values in fish (and marine mammals) by region, a recent joint consultation of the Food and Agriculture Organization of the United Nations and the World Health Organization affirmed that fish is an important source of food and nutrition for many cultural groups.[78] This report further affirms that fish consumption is beneficial for reducing cardiovascular disease and enhancing neurodevelopment of fetuses of pregnant women, and it indicates that establishing a healthy diet that includes fish is important, especially among vulnerable populations, such as those in the Arctic, where fish (and marine mammal) consumption is a critical source of vitamin D in winter months.[78]

CONCLUSION

In summary, aboriginal Arctic populations are among those at highest risk of vitamin D deficiency due to low UVB exposure, inadequate vitamin D intake as a result of decreased consumption of traditional foods, and darker skin pigmentation. Despite limited health research on aboriginal Arctic people, this brief review of current evidence related to populations at high latitudes suggests it is imperative for nutrition, medical, and public health professionals to focus on strategies to maintain adequate vitamin D status in these populations in order to help reduce the risk and economic burden of numerous chronic and infectious diseases.

Continued research is needed to further understand the role of vitamin D in the etiology and treatment of chronic and infectious diseases among aboriginal, national, and global populations at differing latitudes. In light of the known risk factors for Arctic populations, accurate assessment of the extent of vitamin D inadequacy and its health consequences in this area should be a priority. Finally, research that further examines the role and safety of marine products and other traditional foods within food systems is essential to determine sustainable approaches to improving health in the Arctic. A better understanding of these matters will guide researchers and health professionals in developing appropriate, evidenced-based recommendations and effective interventions for Arctic populations.

Acknowledgments

The authors thank the members of the Healthy Foods North team for their tireless efforts and their dedication to improving the health of aboriginal Arctic populations.

Funding. This work was supported by the American Diabetes Association Clinical Research award (1-08-CR-57).

Declaration of interest. The authors have no relevant interests to declare.

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