Special Article

Implications of the nutrition transition for vitamin D intake and status in Aboriginal groups in the Canadian Arctic

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Aboriginal Canadians have low intakes of vitamin D and are shifting away from consumption of traditional foods. Higher body mass index, skin pigmentation, and geographic latitude of residence further predispose Canadian Aboriginal populations to low vitamin D status. Low vitamin D status could compromise bone health and other health outcomes. Studies assessing vitamin D status of different Aboriginal groups are limited. The aim of this review is to examine the literature on vitamin D status and intakes of Canadian Aboriginal populations living in the Arctic. PubMed was searched for relevant articles published from 1983 to 2013. The prevalence of 25-hydroxy vitamin D deficiency ranged from 13.9% to 76.0% among children and adults in the summer. Furthermore, mean vitamin D intakes among all age groups were below the estimated average requirement. As vitamin D deficiency has been recently associated with chronic diseases, and Aboriginal populations living in the Arctic are at high risk for low vitamin D status, their vitamin D status should be assessed regularly across seasons.

INTRODUCTION

Aboriginal and Inuit context in Canada

Aboriginal populations in Canada encompass hundreds of communities with profoundly diverse cultures, languages, ancestry, lifestyle, and eating habits, yet they are united by their Aboriginal status, relationship to the land, and the transition from a traditional lifestyle.[1] Even though the focus of this review is the Inuit population, data assessing the health of different Aboriginal groups were included in the literature review because the number of studies focusing on the Inuit population alone is limited.

Of the 1 172 790 people who identified themselves as an Aboriginal person in the 2006 Statistics Canada Census, 4.4% were Inuit, 34.2% were Métis, and 61.3% were First Nations.[2] Inuit, Dene/Métis, and First Nations make up 3 distinct Aboriginal groups in Canada.[3] The majority of Inuit in Canada (78%) lived in 1 of 4 regions within Inuit Nunaat (Table 1)[2] (ie, the homeland stretching from Labrador to the Northwest Territories and occupying more than one-third of Canada's land mass).[2,3] Inuit are spread over 53 communities, 52 of which are on the coast and 1 of which is an inland community located on the shore of a freshwater lake, Baker Lake, in Nunavut.[4] However, a growing percentage of Inuit live in other parts of Canada, in particular, the southern urban centers of Ottawa–Gatineau, Yellowknife, Edmonton, Montreal, and Winnipeg. In 2006, 22% of Inuit lived outside Inuit Nunaat, 5% of whom lived in rural areas.[2] A smaller proportion of First Nations lived on reserve (40%) than off reserve (60%), and only 1% of Métis lived in 1 of the

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Table 1 **Inuit population in the 4 regions of Nunaat**[2]

Region	Population	Percentage of Inuit population
Nunavut	24 635	49
Nunavik	9565	19
Inuvialuit Settlement Region	3115	6
Nunatsiavut	2160	4

3 Canadian territories. The younger population groups contain considerably larger percentages of Inuit than of non-Aboriginal Canadians. In 2006, more than one-half (56%) of all Inuit were 24 years of age or younger. Of those, 12% were 4 years or younger, which is more than twice the proportion of non-Aboriginal Canadians in that age group (5%).[2] Only 4% of the Inuit population were senior individuals, compared with 13% of the non-Aboriginal population.[2]

Dietary and health transition in Aboriginal populations

For thousands of years, Inuit populations depended exclusively on hundreds of locally harvested animal and plant species, known as traditional foods.[5,6] During the 20th century, however, food use patterns and nutritional status among Inuit changed rapidly.[6–8] Data collected between the years 1993 and 1999 showed that the overall percentage of daily energy from traditional foods was 22% for all ages of Aboriginal Peoples living in the Canadian Arctic, with the lowest intake (17%) being among Yukon First Nations and the highest intake (28%) being among Inuit.[7] Among different age and sex groups of Inuit, consumption of traditional foods accounts for 14.1% to 36.0% of dietary energy, with older age, male sex, and lower body mass index associated with higher intakes.[8] A comprehensive survey carried out in 2007–2008 compared the intake of traditional foods with the consumption of market foods in 18 Inuit communities that had been assessed in 1998–1999. The comparison of food intake data from the 2 surveys (1999 vs 2008) indicated that dietary transition is ongoing. For instance, the overall percentage of energy derived from traditional foods declined from 23.4% in 1999 to 16.1% in 2008 ($P \leq 0.05$).[9]

A complex set of circumstances underpin this change, including the introduction of market foods into remote regions,[8] the concern about contaminants in the environment and food supply,[10–13] climate change,[14,15] the increasing number of those with salaried employment,[5] the reduced time available for hunting and fishing,[8] and the increasing costs of harvesting.[15,16] Furthermore, this shift in eating habits is accompanied by increased intakes of energy, refined carbohydrates, fat, and saturated fat.[8,17] The market foods available are low in quality and limited in diversity and freshness,[6] and healthy food choices are often unaffordable.[15] In 2008, the cost of a basket of food for a family of 4 in Igloolik, Nunavut, was more than twice the price of the same basket in large urban centers such as Montreal.[15] Moreover, given the long transportation- and weather-related delays in shipping, fresh fruits and vegetables can be close to spoilage by the time they reach the consumer.[15] Qualitative data indicated that, although younger Inuit in Nunavut might prefer healthy foods, including fruits and vegetables or whole-wheat products, such foods are either not available or differ in quality and cost so substantially that convenience foods are a more tangible choice.[16] All these factors, along with decreased physical activity, contribute to an upward trend in obesity among different age and sex groups in the Inuit population.[18,19] This trend, combined with other social, societal, and environmental factors, has resulted in large health disparities between Aboriginal and non-Aboriginal people in Canada that manifest as shorter life expectancy, increased rates of chronic disease,[20,21] increased rates of fracture,[22] increased prevalence of rickets,[23] and low vitamin D status.[24] On a more positive note, however, secular trends toward increasing height have been reported among Canadian Inuit children.[25] Accordingly, the aim of this review was to examine the literature on vitamin D status and intakes of Canadian Aboriginal populations living in the Arctic.

A search of PubMed for relevant articles published in English from 1983 to 2013 was conducted. Different combinations of the following search terms were used: vitamin D status, vitamin D intake, 25-hydroxy vitamin D (25(OH)D), adults, children, Canadians, Aboriginal populations, indigenous populations, Inuit, First Nations, Cree, traditional foods, North, and Arctic. Eleven manuscripts directly related to the aim of this review were identified.

SOURCES AND SYNTHESIS OF VITAMIN D

The Inuit have adapted to their geographic location by relying on their unique food supply. For example, endogenous synthesis of vitamin D is limited to a few months a year, but traditional foods are rich sources of vitamin D. Humans obtain vitamin D from exposure to UV-B radiation, from their diet, and from dietary supplements.[26] For many populations, it is widely accepted that the major source of vitamin D is endogenous synthesis after exposure to UV-B radiation.[26–28] Solar UV-B radiation, of a wavelength varying between 290 and 315 nm, penetrates the skin and converts 7-dehydrocholesterol in the basal and suprabasal layers of the

Table 2 **Vitamin D content of selected market foods and traditional foods in Canada**

Market foods[a]	μg/100 g	Traditional foods	μg/100 g
Salmon		Game meat: native, ringed seal	
Atlantic, wild: baked or broiled	8.2	Fat[b,c]	75.3
		Liver, raw[a]	10.7
Atlantic, wild: raw	6.4		
Chum (Keta): canned, drained, solids with bone, salted	6.7	Arctic Char	
		Meat and skin, dried[a,c]	44.8
		Meat and skin, raw[a,c]	13.3
Fish oil	4.4		
Tuna, white: canned, with oil, drained, salted	2.0	Beluga[d]	
		Oil, aged[c]	26.7
Egg, chicken: whole, fried	2.2	Blubber[c]	13.3
Egg, chicken: whole, fresh or frozen, raw	1.4	Lake trout flesh, raw[d,e]	19.7
		Cisco eggs, raw[c]	6.5
Margarine: tub, composite	13.2	Arctic cod[b,e]	4.9
Milk: fluid, whole, pasteurized, homogenized, 3.3% milkfat	1.0	Whitefish, lake, native: raw/baked[a]	4.5

[a]Health Canada (2010).[32]
[b]Blanchet et al. (2000).[5]
[c]Two or fewer samples analyzed.
[d]Kuhnlein et al. (2006).[33]
[e]Three or more samples analyzed.

epidermis to previtamin D_3, which is followed by heat-dependent isomerization to vitamin D_3.[29] Even with excessive sun exposure, vitamin D_3 intoxication does not occur, since any previtamin D_3 or vitamin D_3 excess is destroyed by prolonged UV-B radiation.[26] For individuals residing above 52°N, endogenous vitamin D synthesis is believed to be limited to 6 months per year,[30,31] although this has not been confirmed.

Dietary sources and supplements

Vitamin D in traditional food of Aboriginal populations in Canada. Dietary sources of vitamin D are generally limited; however, Aboriginal populations living in the Canadian Arctic have access to a unique diet with a wide variety of natural sources of vitamin D.[5,32,33] Fish, including Arctic char, lake trout, whitefish, and lake or Atlantic salmon, as well as marine mammals such as white whale, ringed seal, and narwhal, are excellent sources of vitamin D[5,32] (Table 2).[5,32,33] Even though the major source of energy intake among Aboriginal populations today is derived from market foods, traditional foods, even in modest amounts, still contribute the major portion of vitamin D intake.[5,8] For instance, vitamin D intakes of older Inuit, Yukon First Nations, and Métis adults (>40 years) were higher than those of younger adults,[7] mainly because of the greater consumption of traditional foods among older adults.

Vitamin D in market foods. For the general Canadian population, only a few natural food sources of vitamin D are available on the market: fatty fish and fish oil are the main sources, followed by organ meats, egg yolk, and some mushrooms. In addition to natural sources, foods fortified with vitamin D are available in some markets, including milk and margarine in Canada, the United States, and the United Kingdom.[34–36] Because of this limited availability, it is difficult for people to rely on dietary sources for adequate vitamin D intake; thus, milk and margarine remain the main sources of dietary vitamin D among the general Canadian population. However, it is important to note that milk consumption is not part of Aboriginal culture and eating habits, and thus milk is not widely consumed among Aboriginal populations.[37,38] Furthermore, evidence suggests a high prevalence of lactose intolerance among Canadian Aboriginal populations.[39,40] Nonetheless, it is important to note that most market foods, including the fortified sources, provide modest amounts of vitamin D compared with traditional foods, which are not consumed by the general Canadian population. For instance, 100 g of milk provides 1 μg of vitamin D,[32] while 100 g of ringed seal fat provides 75.3 μg of vitamin D.[5]

Another source of vitamin D is supplements. Health Canada recommends the intake of a daily vitamin D supplement of 10 μg for all adults over the age of 50 years and for all breastfed healthy term infants, beginning at birth until 1 year of age.[41] Data from Canadian Aboriginal newborns suggest that 60% of Cree children (n = 80) were receiving vitamin D supplements.[42] In general, data from Canadian Aboriginal adults suggest that supplement intake is not a common practice.[7] For instance, the International Polar Year Inuit Health survey of 2007–2008, which represents 1994 Inuit adults, stated that 8.5% of the population were taking vitamins,[38] in contrast to 40.1% of

Canadians, as reported in the Canadian Community Health Survey cycle 2.2.[43]

Factors affecting vitamin D availability. Vitamin D synthesis, whether endogenous or exogenous, is affected by a multitude of factors.[26,29,44,45] The conversion of provitamin D_3 to previtamin D_3 in the skin is affected by skin type (based on pigmentation), age, use of sunscreen, time of day, season, and latitude.[26,29,44,45] Skin type is genetically determined and affects the amount of previtamin D_3 that can be synthesized in the skin for a given dose of UV-B radiation. Skin types range from type I (white skin that readily burns) to type VI (naturally pigmented black skin).[46] Additional work is needed to confirm speculation about whether the skin type of Canadian Inuit is similar to that of American Indians, who have skin type IV.[38] Skin type is closely associated with the amount of melanin pigment in the skin.[30] Melanin is a skin pigment that absorbs UV-B efficiently, acting as a natural sunscreen. Melanin competes with 7-dehydrocholesterol for UV-B, and therefore increased skin pigmentation would reduce the amount of UV-B available for vitamin D_3 synthesis.[30,47]

The amount of UV-B radiation reaching the skin will differ, depending on the latitude, altitude, season, clothing coverage, and time of day.[34,48] People living in Edmonton, at 52°N, are at risk of deprivation of endogenous vitamin D synthesis between October through March because of the larger solar zenith angle.[30,31] It is anticipated that this period would extend at Arctic locations, where Canadian Inuit mainly reside, at latitudes of 52°N or greater. Furthermore, an inverse relationship exists between age and the concentration of 7-dehydrocholesterol in the epidermis.[34] For instance, after exposure to UV-B radiation, the amount of previtamin D_3 produced in the epidermis of young participants (8 and 18 years) was more than 2-fold higher than that produced in older adults (77 and 82 years).[49]

Adiposity is also associated with low serum vitamin D concentrations in adults.[50,51] The reason for this inverse relation is not fully understood, but it is speculated that increased subcutaneous fat could cause a sequestering of this fat-soluble vitamin and would influence the release of vitamin D_3 from the skin into the bloodstream.[52] For instance, serum vitamin D_3 concentration was 57% less in obese than in nonobese subjects after UV-B exposure, despite similar amounts of the vitamin D_3 precursor in the skin.[52] In addition, obesity reduced the increase in serum 25(OH)D in postmenopausal women during vitamin D supplementation for 1 year. For instance, 25(OH)D serum concentrations in normal-weight women were 12.2 nmol/L higher than those in overweight women and 17.7 nmol/L ($P < 0.01$) higher than those in obese women.[53] It is well known that obesity rates among indigenous people are higher than those among the general Canadian population.[54,55] For instance, the Canadian Community Health Survey cycle 2.1 reported that 15.2% of Canadian individuals aged 20 years and older were obese. The rates of obesity varied considerably among the 106 regions assessed: from 6.2% in Vancouver to 47.5% in areas where Aboriginal populations, including Inuit and First Nations, reside.[54]

Other particular cultural practices could also affect vitamin D synthesis. For instance, low vitamin D concentrations among women have been attributed to concealing clothing in Kuwait,[56] Turkey,[57] Saudi Arabia,[58] and the United Arab Emirates.[59] Inuit are known to wear concealing clothing in the summer to protect themselves from insects.[42] Furthermore, sunscreen use has been associated with low vitamin D status.[60,61] Sunscreens with a specific protective factor of 8 or 15 can block UV-B light and reduce vitamin D synthesis by 99%,[60,61] although sunscreen use has not been reported in Inuit.

DIETARY RECOMMENDATIONS

A growing body of knowledge compiled over the past 10 years supports the role of vitamin D in extraskeletal functions,[62] and numerous high-quality studies have become available, which prompted the Institute of Medicine (IOM, now the National Academy of Medicine) in 2010 to assess the current data on health outcomes associated with vitamin D intake.[63] A committee evaluated more than 1000 reports on skeletal and extraskeletal outcomes in relation to vitamin D status, but only evidence from bone studies was consistent and strong enough to release an estimated average requirement (EAR) of 10 μg/d (400 international units per day) for all age groups and different stages of the life cycle and a recommended dietary allowance (RDA) for all age groups except infants under 1 year of age (Table 3).[63] The IOM recommendations are based on the assumption of minimal sun exposure. In addition,

Table 3 **Dietary reference intakes of vitamin D for different age groups**[63]

Age group	RDA (μg/d)	UL (μg/d)
0–6 mo	–[a]	25
6–12 mo	–[a]	38
1–3 y	15	63
4–8 y	15	75
9–70 y	15	100
>70 y	20	100

Abbreviations: RDA, recommended dietary allowance; UL, tolerable upper intake level.
[a]For infants (0–12 months), the adequate intake is 10 μg/d.

although there was not enough evidence of extraskeletal benefits to make recommendations at that time, there is ongoing research that may shed light on extraskeletal outcomes. For instance, the VITamin D and OmegA-3 TriaL (VITAL) is an ongoing study in the United States examining whether taking daily dietary supplements of vitamin D_3 (50 μg/d) or n-3 fatty acids (1 g) decreases the risk of cancer, heart disease, and stroke among 20 000 men and women 50 years and older who have no history of these illnesses.[64] Interestingly, traditional foods are rich sources of both of these nutrients. However, as Canadian Aboriginal populations move away from the consumption of traditional foods and the nutrition transition progresses, the incidence of chronic diseases has been increasing.[8,20,65]

Function of vitamin D in skeletal and nonskeletal tissues

The beneficial role of vitamin D in bone health has been known for centuries.[26,34,45] The direct consequence of vitamin D deficiency is osteomalacia in adults and rickets in children.[26,34,45] In addition to its role in bone metabolism, vitamin D may play an important role in extraskeletal health[62] and prevention of chronic diseases such as hypertension,[66] diabetes,[67–69] cardiovascular disease,[70,71] and different types of cancer.[72] Moreover, vitamin D has been associated with several autoimmune conditions, including type I diabetes,[73] multiple sclerosis,[74] and psoriasis.[75] In contrast to the findings of the studies cited above, results from vitamin D intervention trials are still controversial with regard to the role of vitamin D supplementation in improving extraskeletal health, particularly in decreasing hypertension,[76] diabetes,[77] risk of cardiovascular disease,[78] and risk of cancer.[79] Accordingly, randomized controlled trials are required to fully understand the role of vitamin D in extraskeletal health. This interrelationship between vitamin D deficiency and chronic diseases has not yet been explored in the context of Canadian Aboriginal populations living in remote regions. However, 2 studies assessed the relationship between 25(OH)D and extraskeletal indicators such as glucose control[80] and blood pressure[81] in off-reserve participants. Weiler et al.[80] showed that both 25(OH)D and osteocalcin were involved in glucose control among Aboriginal and white women (n = 368) in Winnipeg. Sulistyoningrum et al.[81] reported an inverse relationship between 25(OH)D levels and blood pressure, independent of adiposity, among a multiethnic sample (n = 687) that included 151 Aboriginal participants living in Vancouver.

Vitamin D metabolism

As a fat-soluble vitamin, dietary vitamin D (D_2 or D_3) is absorbed in the small intestine in the presence of bile salts and free fatty acids, after which it is incorporated into chylomicrons and taken into the lymphatic system and, subsequently, into venous blood. Both dietary and endogenous vitamin D are transported to the liver bound to the vitamin D–binding protein (60%) or to lipoprotein (40%); however, some vitamin D is deposited in body fat reserves.[82] Once in the liver, vitamin D is converted by the enzyme vitamin D-25-hydroxylase (CYP27A1) to 25(OH)D, also known as calcidiol.[82,83] A second hydroxylation of 25(OH)D occurs in the kidney by the enzyme 25(OH)D-1-α-hydroxylase (called P450C1 or CYP27B1) to become the hormonally active 1,25-dihydroxyvitamin D_3 (1,25$(OH)_2D_3$, or calcitriol). Calcitriol induces its own destruction by stimulating the 24-hydroxylase enzyme (known as CYP24A1). CYP24A1 catalyzes out a 5-step inactivation pathway that results in the production of calcitroic acid from calcitriol excreted through the bile into the feces; a minor amount is eliminated through the urine. In a series of biliary metabolites similar to those of vitamin D_3, the active forms of vitamin D_2 are catabolized by CYP24A1.[82–85]

Measurement of vitamin D status

Measurement of the serum 25(OH)D concentration remains the best indicator to assess vitamin D status, since it reflects both endogenous vitamin D synthesis and dietary vitamin D intake.[86] Serum 25(OH)D is a better indicator of vitamin D status than serum 1,25$(OH)_2D$ for several reasons: (1) the concentration of 1,25$(OH)_2D$ is 1000 times less than that of 25(OH)D; 1,25$(OH)_2D$ has a shorter half-life than 25(OH)D, ie, 4 to 6 hours vs 21 days; and (3) the production of 1,25$(OH)_2D$ is tightly regulated and could be normal or even high in vitamin D insufficiency.[87,88]

Measurement of 25(OH)D is technically challenging because 25(OH)D is hydrophobic and has a strong protein-binding affinity.[89] The methods available for assessment of 25(OH)D status can be categorized in 3 groups: competitive protein-binding assays, immunoassays, and chromatographic methods. The comparison of these different methods is beyond the scope of this review, although several other reviews are available.[25,90]

Targets for vitamin D status

Opinions differ when it comes to defining optimal vitamin D status. The definition depends mainly on the health outcome considered. The Food and Nutrition

Board of the IOM considers 25(OH)D concentrations <30 nmol/L to be associated with a risk of deficiency, a concentration of 40 nmol/L to be consistent with the EAR, and a concentration of 50 nmol/L to be consistent with the RDA.[63] Osteoporosis Canada defines vitamin D deficiency and insufficiency in adults by a 25(OH)D concentration of <25 nmol/L and <75 nmol/L, respectively.[91] The IOM recommends a 25(OH)D concentration of ≥50 nmol/L for good bone health, while Osteoporosis Canada recommends a concentration of ≥75 nmol/L for musculoskeletal benefits. In a recent position statement of the International Osteoporosis Foundation, the majority of working group members estimated that 75 nmol/L is the appropriate target concentration for older adults, whereas the remaining members opted for a lower target of 50–75 nmol/L[92] to protect against fracture. Furthermore, serum 25(OH)D concentrations in excess of 75 nmol/L are advised for multiple health outcomes.[93,94]

Similarly, there is a lack of consensus about optimal concentrations for the pediatric population. The Canadian Paediatric Society defines vitamin D deficiency (25(OH)D <25 nmol/L) on the basis of decreased calcium absorption from the gut and a tendency toward hypocalcemia, while optimal concentrations (25(OH)D ≥75 nmol/L) are defined on the basis of normal parathyroid hormone production and minimal calcium resorption from bone as well as stabile intestinal calcium absorption.[95] On the other hand, the American Academy of Pediatrics defines vitamin D deficiency (25(OH)D <27.5 nmol/L) with the aim of preventing rickets, while optimal concentrations (25(OH)D ≥50 nmol/L) are considered foundational to good bone health.[96]

VITAMIN D STATUS AND INTAKES IN CANADA

General Canadian population

Low vitamin D status has been observed among Canadians of different age groups. For instance, in a representative sample (n = 1753) of Quebec youth (9–16 years), the assessment of vitamin D status showed that 6.6% had a 25(OH)D concentration <27.5 nmol/L, 25.3% had a 25(OH)D concentration <37.5 nmol/L, and 97.3% had a 25(OH)D concentration <75 nmol/L in winter and spring.[28] Within a smaller sample (n = 48) of children (0–14 years) who presented to the children's hospital in Labrador and Newfoundland, 35.4% had a 25(OH)D concentration <50 nmol/L and 77.1% a concentration <75 nmol/L over the entire year.[97] Furthermore, seasonal variation was observed in this study, as the mean summer vitamin concentration was significantly higher (67.7 ± 17.7 nmol/L) than the winter concentration (52.6 ± 14.3 nmol/L). Better vitamin D status was reported among preschool children attending daycare facilities in Montreal, with 88% of preschoolers having a 25(OH)D concentration >50 nmol/L over the entire year.[98] Similarly, national data from the 2009–2011 Canadian Health Measures Survey show that preschool children had the highest prevalence of 25(OH)D >50 nmol/L (89%) compared with other age groups (6–79 years) over the entire year.[99] In addition, the Survey shows that vitamin D status among older children was better than previously reported,[28,97] with 76% of children aged 6 to 11 years and 71% of children aged 12 to 19 years having a 25(OH)D concentration ≥50 nmol/L.[99]

Similar to findings in children, seasonal variation in vitamin D status was observed in Canadian adults. Among a sample of 1912 adults (≥35 years) randomly selected from 7 cities across Canada, the strongest predictors of low 25(OH)D status for both men and women were winter and spring season and nonwhite ethnicity. Within the sample, 2.3% had a 25(OH)D concentration <27.5 nmol/L and 18.1% had a concentration in the range of 27.5–50 nmol/L over the entire year.[100]

In addition to all these studies, a report representing the first national data on the vitamin D status of Canadians available in over 35 years was published recently. The Canadian Health Measures Survey assessed the vitamin D status of Canadian individuals (n = 5306) living in metropolitan regions within 50 km of urban centers over the entire year. The mean serum 25(OH)D concentration for the entire sample was 67.7 nmol/L (95%CI, 65.3–70.1). Of the sample, 4% had a 25(OH)D concentration <27.5 nmol/L, 10% had a concentration <37.5 nmol/L, and 64.6% had a concentration <75 nmol/L. Nonwhite racial background and low milk consumption were significantly associated with lower vitamin D concentration.[101] Canadians of all age groups who consumed milk more than once a day had a vitamin D concentration that was, on average, 12 nmol/L higher than the concentration among those consuming milk less than once a day. Even though milk is fortified with vitamin D, Canadians do not currently meet the number of milk servings recommended by Canada's Food Guide. Data from the 2004 Canadian Community Health Survey showed that 37% to 84% of Canadians across different age groups do not meet the recommendation for the number of servings of milk products, with the lowest percentage being among children aged 4 to 9 years and the highest percentage being among adults aged 71 years and older.[102] Even though milk consumption decreases with increasing age, milk products still contribute 49% of vitamin D intake of

Canadians, with the highest contribution (75%) being among children aged 1 to 8 years. According to the 2004 Canadian Community Health Survey, the mean vitamin D intake of Canadians across all age groups (1 to ≥70 years) ranged from 5.1 to 7.3 μg/d, which meets the adequate intake[103] set by the IOM in 1997[86]; however, no age group has met the new RDA of 15 μg for individuals (1–70 years) or 20 μg for older adults (≥71 years).[63]

In conclusion, several important findings are confirmed by these studies, which report a high prevalence of low vitamin D status among the Canadian population. First, even though milk is fortified with vitamin D, the food fortification practices in Canada seem to be ineffective in reducing the prevalence of vitamin D insufficiency through the consumption of fortified milk, particularly since milk consumption is inadequate among certain age groups. In addition, the high prevalence of low vitamin D status in the Canadian population may be attributable to vitamin D intakes that are well below the new RDA. Furthermore, seasonality seems to affect vitamin D status across all age groups: vitamin D concentrations are higher in summer, a result of endogenous vitamin D synthesis that does not occur in winter. Lastly, ethnicity seems to have a significant effect on serum 25(OH)D concentrations in adults over a range of latitudes and in different seasons.

Aboriginal Canadian population

Children. Vitamin D in Canadians has been widely assessed in the literature; however, data on the assessment of vitamin D status in Aboriginal Canadians is still very limited. For instance, the most recent assessment of vitamin D status in Canadians, as measured in the 2007–2009 Canadian Health Measures Survey, excluded residents of Indian reserves, Crown lands, the Arctic, and other remote regions.[101] Aboriginal populations with the lowest risk of vitamin D deficiency include those with low body mass index,[55] high socioeconomic status, frequent use of vitamin D supplements,[7] and high consumption of traditional foods.[8]

The historic and ongoing nutrition transition noted among Canadian Aboriginal populations, characterized by reduced reliance upon traditional foods rich in vitamin D,[5,64] raises concerns about the current vitamin D status of northern Aboriginal populations. While a few studies with small sample sizes that varied between 10 and 88 subjects have assessed the vitamin D status of Canadian Aboriginal newborns and infants (0–24 months),[42,104,105] only 1 study assessed preschoolers,[37] and none assessed older children; these studies are presented in Table 4.[37,42,104,105] Among newborns and infants, the lowest vitamin D concentration (26.2 ± 10.9 nmol/L) was observed among First Nations infants in the summer, with only 57% of children having a 25(OH)D concentration >25 nmol/L, 60% of whom were taking vitamin D supplements.[42] The highest vitamin D concentration (34.7 ± 12.6 nmol/L) was observed among Inuit infants assessed over the entire year.[104] This concentration is above the cutoff for deficiency (25 nmol/L) set by the Canadian Paediatric Society.[95] On the other hand, the vitamin D concentration of preschoolers residing in Nunavut (community names within boxes, Figure 1) was higher than that of infants in both summer (54.3 ± 30.1 nmol/L) and winter (42.1 ± 30.8 nmol/L).[37] Among Inuit preschoolers, 48.3% and 27.2% had 25(OH)D concentrations >50 nmol/L in the summer and winter, respectively.[37] It is likely that both sun exposure and dietary vitamin D account for the higher vitamin D concentration observed in the preschoolers than in the infants. In the 2009–2011 Canadian Health Measures Survey, Canadian preschoolers had the highest prevalence

Table 4 **Vitamin D status in Aboriginal children and neonates in Canada**

Reference	City and latitude	No. of subjects	Age	Season/ month	Assay	Deficiency in nmol/L (prevalence)	Mean 25(OH)D (nmol/L)
Lebrun et al. (1993)[42]	Manitoba (53°N)	80 FN	3–24 mo	Summer	CPBA	<25 (43.0%)	26.2 ± 10.9
Waiters et al. (1999)[104]	Inuvik (68°N)	37 Indian 51 Inuit	Newborn	Year-round	CPBA	NR	Indian: 34.2 ± 14.3 Inuit: 34.7 ± 12.6
Weiler et al. (2008)[105]	Winnipeg (49°N)	10 FN	0–15 d	Year-round	RIA	<27.5 (70%)	27.0 ± 9.6
El Hayek et al. (2010)[37]	Nunavut (n = 16 communities; 51°N–70°N)	(1) 282 Inuit (2) 52 Inuit	3–5 y	(1) Summer subsample (2) Winter subsample	Chemiluminescent assay	(1) <25 (13.9%) <37.5 (36.3%) (2) <25 (34.1%) <37.5 (51.7%)	(1) 54.3 ± 30.1 (2) 42.1 ± 30.8

Abbreviations: CPBA, competitive protein-binding analysis; FN, First Nations; NR, not reported; RIA, radioimmunoassay.

Figure 1 **Map of communities recruited in the Inuit Health Survey (all communities) and the Inuit Child Health Survey (outlined communities)**

(89%) of 25(OH)D concentrations ≥50 nmol/L when compared with older children.[99] Future studies are needed to confirm whether Inuit preschoolers have a better vitamin D status than their older counterparts.

Few studies have examined vitamin D intake of older Canadian Aboriginal youth.[37,106,107] A recent review that compiled data from 24 cross-sectional studies assessing the diet of school-aged Aboriginal children from urban and remote regions found that vitamin D intake was inadequate.[108] Low vitamin D intakes were mainly attributed to decreased consumption of traditional foods and increased consumption of market foods, combined with low intakes of milk.[37,106,107] For instance, only one-fifth of First Nations children aged 9 to 13 years (n = 201) and one-third of Inuit preschoolers aged 3 to 5 years (n = 275) consumed the 2 or more daily servings of milk recommended by Canada's Food Guide.[37,109] Vitamin D concentrations are significantly higher among Inuit preschoolers who consume 2 or more milk servings per day than among those who do not drink milk at all.[37] Whether milk intake will be still associated with higher 25(OH)D concentrations in children older than 5 years of age still needs to be investigated. Even though the number of milk servings consumed by Aboriginal children living off reserve was not assessed, the frequency of consumption was assessed in Aboriginal preschoolers (2–5 years) in the Statistics Canada's 2006 Aboriginal Children's Survey.[110] The results showed that 84.2% of First Nations children, 85.7% of Métis children, and 69.7% of Inuit children consumed milk or milk products twice or more per day. Accordingly, it is likely that Canadian Aboriginal children living off reserve are drinking more milk, as it could be that dietary habits of Aboriginal populations living in remote communities are influenced by the accessibility and availability of foods.[110] On a positive note, even if Aboriginal preschoolers living off reserve are drinking milk, they are still consuming traditional foods, as 70.3% of First Nations, 62.4% of Métis, and 90.2% of Inuit reported consuming traditional foods in the previous day.[110]

In Aboriginal populations living in remote regions of Canada, market food constitutes the main portion of the diet of children, with traditional food contributing only 4.3% of energy among Yukon First Nations and Dene/Métis aged 10 to 12 years[17] and 8.4% among Inuit preschoolers aged 3 to 5 years.[62] It has also been reported that mean vitamin D intake was below the RDA of 15 μg/d among First Nations children aged 9 to 13 years (3.9 ± 2.7 μg/d),[109] among Inuit children aged 3 to 5 years (6.3 ± 2.9 μg/d),[37] and among Yukon First Nations and Dene/Métis boys and girls aged 10 to 12 years (3.8 ± 2.6 and 4.0 ± 5.0 μg/d, respectively, from November to January).[106] Even though vitamin D intake of Aboriginal children seems to be lower than that recommended, it was comparable to that of preschoolers attending daycare facilities in Montreal. Despite low intakes of vitamin D in Montreal preschoolers, vitamin D status was satisfactory, with 88% of preschoolers having 25(OH)D concentrations ≥50 nmol/L.[98] This suggests that ambient sunlight exposure makes an important contribution to the vitamin D status of Montreal preschoolers. Considering that the latitude at which Aboriginal children grow is a nonmodifiable factor, Aboriginal children should rely more on traditional foods to compensate for limited sun exposure. Several studies among different Canadian Aboriginal groups, including Inuit, Métis, and First Nations, have indicated

Table 5 **Vitamin D status, concentration, and intake of Aboriginal adults in Canada**

Reference	City and latitude	No. of subjects	Season/ month	Assay	Deficiency in nmol/L (prevalence)	Insufficiency in nmol/L (prevalence)	Mean 25(OH)D (nmol/L)	Mean vitamin D intake (μg/d)
Lebrun et al. (1993)[42]	Manitoba (53°N)	80 FN pregnant women	Late June and July	CPBA	<25 (76%)	NR	19.8 ± 7.7	NR
Waiters et al. (1999)[104]	Inuvik (68°N)	37 Indian 51 Inuit pregnant women	Year-round	CPBA	Cutoff NR Indian: 52.8% Inuit: 45.0%	NR	Indian: 52.1 ± 25.9 Inuit: 48.8 ± 14.2	Indian: 7.9 ± 6.0 Inuit: 8.2 ± 5.0
Weiler et al. (2007)[24]	Winnipeg (49°N)	26 rural, 183 urban Aboriginal women ≥25 y	Year-round	RIA	<37.5 (rural, 32%; urban, 30.4%)	<75 (rural, 96% rural; urban, 84%)	Rural: 41.8 ± 14.5 Urban: 53.8 ± 25.5	Rural: 13.9 ± 14.6 Urban: 10.8 ± 12.3
Rejnmark et al. (2004)[112]	Greenland Nuuk (64°N) and Denmark (55°N)	A: 46 Inuit on TF B: 45 Inuit on MF C: 54 Inuit on MF (22–62 y)	Year-round	RIA	NR	<40 nmol/L Winter: A: (42%) B: (81%) C: (77%) Summer: A: (23%) B: (74%) C: (47%)	Winter: A: 41 ± 3 B: 29 ± 2 C: 30 ± 2 Summer: A: 53 ± 3 B: 32 ± 2 C: 44 ± 2	NR
Von Westarp et al. (1981)[113]	Arctic Bay (73°N)	61 Inuit	Spring	CPBA	<25 (1.6%)	NR	64.6 ± 33.9	NR
El Hayek et al. (2011)[38]	Inuvialuit Settlement Region, Nunavut, Nunatsiavut n = 36 communities (54°10′ N to 74°43′ N)	2168 Inuit adults ≥18 y	Summer	Chemiluminescent assay	<37.5 (27.2%)	<50 (42.2%) <75 (67.4%)	58.8 ± 32.6	6.1 ± 8.2
Riverin et al. (2013)[114]	Eastern James Bay (49°N to 55°N) n = 7 communities	944 adults ≥15 y	Spring and summer	RIA	<30 (5.8%)	<50 (48.4%) <75 (88.3%)	Spring: 48.1 (46.5–49.8) Summer: 51.6 (50.3–52.9)	NR

Abbreviations: CPBA, competitive protein-binding analysis; FN, First Nations; MF, market foods; NR, not reported; RIA, radioimmunoassay; TF, traditional foods.

that micronutrient nutrition, including vitamin D status, is improved when traditional foods are consumed.[7,64]

Adults. According to a recent review of studies assessing the vitamin D status of Canadians, the mean vitamin D concentration was near 50 nmol/L in winter and 60 nmol/L in summer; in First Nations or subpopulations with dark skin color, it was 40 nmol/L.[111] Only limited data examining the vitamin D status of Canadian Aboriginal adults are available (Table 5[24,38,42,104,112–114]), with only a few studies assessing status in Canadian Aboriginal men,[38,112–114] particularly Inuit.[38,112,113]

Even though Aboriginal women and white women had similar vitamin D intakes that were below the RDA of 15 μg/d, Aboriginal women had significantly lower vitamin D concentrations (by 15–17 nmol/L) than white women. Furthermore, one-third of all Aboriginal women had a vitamin D concentration below 37.5 nmol/L and 96% of rural and 84% of urban Aboriginal women had a concentration below 75 nmol/L[24] (Table 5). Despite supplementation in pregnancy, 24% of First Nations mothers, 48% of native Indian mothers, and 55% of Inuit mothers were vitamin D sufficient[42,104] (Table 5).

The highest 25(OH)D concentration (64.6 ± 33.9 nmol/L) was observed among Inuit adults (n = 61) living in Arctic Bay (73°N) in late March to early April of 1981, most likely reflecting consumption of traditional foods, particularly, since sun exposure at this time of the year is limited.[113] Vitamin D intake and, subsequently, vitamin D status will likely be improved when traditional foods are consumed; for instance, among Inuit women (19–44 years) living in Nunavut and the Northwest Territories, consumers of traditional foods had a significantly higher intake of vitamin D (5.1 ± 5.3 μg/d) compared with those not consuming traditional foods (3.5 ± 3.2 μg/d, $P < 0.01$).[115] This speculation has been confirmed among Inuit residing in Nuuk, Greenland (64°N).[112] Rejnmark et al.[112] reported that Inuit adults consuming a diet of market foods and recruited by announcements and notices in public institutions and private companies were more likely to have lower vitamin D status (plasma 25(OH)D, <40 nmol/L) during winter and summer than those consuming a diet of traditional foods and those living at a lower latitude (55°N) consuming a diet of market foods[112] (Table 5). This observation was in concordance with results reported from a large representative sample (n = 2168) of Inuit men and women recruited in the Inuvialuit Settlement Region, Nunavut, and Nunatsiavut[38] (Figure 1). Higher intakes of traditional foods among older adults (≥51 years) were accompanied by higher 25(OH)D concentrations. Most likely, the intake of traditional foods, known as excellent sources of vitamin D,[5,6] could explain the higher 25(OH)D concentrations in older adults. For instance, Inuit adults 51 years and older consumed up to 308.0 ± 2.6 g of traditional foods per day, while adults aged 19 to 30 years consumed only 195.0 ± 3.6 g.[38] In addition, older Inuit adults were consuming at least double the amount of fatty fish as younger adults (18–50 years) and, consequently, double the amount of vitamin D derived from fish. Fatty fish is an excellent source of vitamin D; for example, 100 g of raw Arctic char, including meat and skin, contains 13.3 μg of vitamin D, while a similar amount of dried Arctic char, including meat and skin, contains 44.8 μg.[32]

Age was the most important predictor of 25(OH)D concentrations ≥50 or 75 nmol/L. It is likely that older age is associated with a more traditional lifestyle, including higher intakes of traditional foods.[38] Similarly, older age and intake of fish were predictors of better vitamin D status in Cree populations.[116] Older Cree adults (>40 years) had a better vitamin D status compared with their younger counterparts (15–39 years).[116] For instance, 20.0% of Cree girls (15–19 years) and 8.5% of Cree boys (15–19 years) had 25 (OH)D concentrations <30 nmol/L, while no cases of deficiency were observed in men 40 years and older or in women 60 years and older.[116] Whether higher 25(OH)D concentrations will also be observed in older Yukon First Nations and Métis adults still requires investigation. In addition, among the Inuit Health Survey participants, those who did not consume traditional food in the past day had lower 25(OH)D concentrations by 15 nmol/L compared with those who did.[117] This difference is of a magnitude similar to that observed with the typical seasonal variation (winter vs summer) in other Canadian populations.[101,117] When compared with data from the 2007–2009 Canadian Health Measures Survey, the mean 25(OH)D concentration among Inuit adults 18 years and older (58.8 nmol/L) was lower than that observed in the vitamin D synthesizing period (April–October, 70.0 nmol/L).[101] However, the mean 25(OH)D concentration of individuals 51 years and older was 77.6 nmol and 79.4 nmol for Inuit men and women, respectively.[38] It is important to note that, with only 25% of energy derived from traditional foods in individuals 51 years and older, the mean 25(OH)D concentration in older Inuit adults was higher than that in Canadians living at lower latitudes.[38,101] Accordingly, even low to moderate intakes of traditional foods can confer important protection against vitamin D deficiency.

CONCLUSION

After reviewing the literature, it is clear that several areas of nutritional status in Arctic populations need further investigation. Even though vitamin D intakes were not optimal among many sex and age categories in Arctic communities, assessment of vitamin D status has not been conducted on a large or national scale across Canadian Aboriginal groups, except for Inuit. Low vitamin D status was highly prevalent in Inuit adults and preschoolers living in the Arctic in summer and early fall, when 25(OH)D concentrations should be at their highest, yet the vitamin D status of older adults is satisfactory and even better than that of the general Canadian population. Other Canadian Aboriginal children and adults might be at higher risk of vitamin D deficiency because of lower intakes of traditional foods, milk, and vitamin D supplements. Thus, population studies of other Aboriginal groups with similar geographic issues and sociological transitions are warranted to establish the prevalence of vitamin D deficiency.

Furthermore, given the low rates of milk consumption and the high vitamin D content and cultural acceptability of traditional foods, the consumption of traditional foods should be promoted among the young and the elderly to improve vitamin D intakes and status. In addition to nutritional interventions and health promotion measures, a longitudinal assessment of vitamin D status among children and adults is needed.

Community participation is crucial to the success of interventions among the Inuit population. Accordingly, focus group sessions with community members and health representatives on how to improve vitamin D status of preschoolers and young adults in the population are required. Education about the importance of consuming traditional foods rich in vitamin D as well as small quantities of milk throughout the day is also necessary. A vitamin D supplement intervention is less likely to work among Inuit adults because of lack of compliance. In preschoolers, however, a supplement intervention is more likely to succeed if vitamin D supplements such as fish liver oil are given along with milk and fatty fish on a regular basis at daycare facilities. An increase in vitamin D intake from traditional foods, milk, or supplements is likely to improve vitamin D status, since improved status was observed following higher milk consumption in children and greater consumption of traditional foods in adults. Furthermore, orange juice fortified with vitamin D and calcium could be an appropriate alternative for Inuit, particularly because of the high consumption of juices in this population. In addition, since lactose intolerance has not been assessed recently in this population, further research to evaluate its prevalence and the age of onset in Canadian Aboriginal Peoples is required to help guide public health policies.

As vitamin D has been recently associated with many chronic diseases, recurrent assessment of vitamin D status should be performed in different segments of the Canadian Aboriginal population, particularly in children and young adults, and across different seasons. The finding of very high vitamin D status in those consuming traditional foods provides, for the first time, evidence that Canadian Inuit did not necessarily adapt to low vitamin D status but rather depended on traditional foods as a rich source of vitamin D. It is unclear if declining consumption of traditional foods will mirror the rising incidence of chronic diseases that were previously uncommon among Inuit.[65,117]

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