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ORIGINAL ARTICLE

Obesity and type 2 diabetes in Northern Canada's remote First Nations communities: the dietary dilemma

F Haman[1], B Fontaine-Bisson[2,4], M Batal[2,3,5], P Imbeault[1], JM Blais[2] and MA Robidoux[1,3]

[1]*School of Human Kinetics, University of Ottawa, Ottawa, Ontario, Canada;* [2]*Nutrition Program, University of Ottawa, Ottawa, Ontario, Canada;* [3]*Indigenous Health Group, Faculty of Health Sciences, University of Ottawa, Ottawa, Ontario, Canada;* [4]*Department of Biology, University of Ottawa, Ottawa, Ontario, Canada and* [5]*Nutrition and Metabolism Research Unit, Institut de Recherche de l'Hôpital Montfort, Ottawa, Ontario, Canada*

First Nations populations in Northwestern Ontario have undergone profound dietary and lifestyle transformations in less than 50 years, which have contributed to the alarming rise in obesity and obesity-related diseases, in particular type 2 diabetes mellitus. Even though the genetic background of First Nations peoples differs from that of the Caucasians, genetics alone cannot explain such a high prevalence in obesity and type 2 diabetes. Modifications in lifestyle and diet are major contributors for the high prevalence of chronic diseases. What remains constant in the literature is the persistent view that locally harvested and prepared foods are of tremendous value to First Nations peoples providing important health and cultural benefits that are increasingly being undermined by western-based food habits. However, the complexities of maintaining a traditional diet require a multifaceted approach, which acknowledges the relationship between benefits, risks and viability that cannot be achieved using purely conventional medical and biological approaches. This brief review explores the biological predispositions and potential environmental factors that contribute to the development of the high incidence of obesity and obesity-related diseases in First Nations communities in Northern Canada. It also highlights some of the complexities of establishing exact physiological causes and providing effective solutions.
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Introduction

According to Indian and Northern Affairs Canada, First Nations Peoples of Canada represent the country's largest aboriginal group (64% registered and non-status First Nations vs 30% Métis and 4% Inuit). In 1997, the First Nations and Inuit Regional Health Survey of Canada recorded rates of chronic conditions such as hypertension, heart disease and diabetes in First Nations populations, far above the national averages.[1] Even more disconcerting is that the prevalence of these diseases in this population is on the rise with symptoms occurring at ages as low as 18 to 30 years.[2] In response to this crisis, the issue of First Nations Health has recently been identified by the Government of Canada as a critical national concern. This brief review explores the biological predispositions and potential environmental factors that could explain these high rates of obesity and obesity-related diseases in First Nations communities in Canada. This paper also highlights some of the complexities of establishing exact physiological causes contributing to the development of these diseases and providing effective solutions. As numerous regional differences exist between First Nations communities across Canada, this review will focus more specifically on First Nations peoples of Northern Ontario living in isolated and remote communities. In some of these communities, individuals have undergone profound dietary and lifestyle transformations in less than 50 years, which have contributed to the alarming rise in obesity and obesity-related diseases, in particular type 2 diabetes mellitus (T2DM).[2–4] In these communities, the prevalence of obesity and T2DM exceeds the highest values currently reported in Canadians of European ancestry. For example, Katzmarzyk and Malina[5] showed that adults of First Nations in Northern Ontario display significantly higher obesity prevalence (50–60%) when compared with individuals of European ancestry (33–38%). Although increased sedentariness and lower levels of physical activity are important

Correspondence: Dr F Haman, Faculty of Health Sciences, University of Ottawa, 125 University St, Ottawa, Ontario, Canada K1N 6N5 and Institut de recherche de l'hôpital Montfort, 713, chemin Montréal, Ottawa, Ontario, Canada K1K 0T2.
E-mail: fhaman@uottawa.ca

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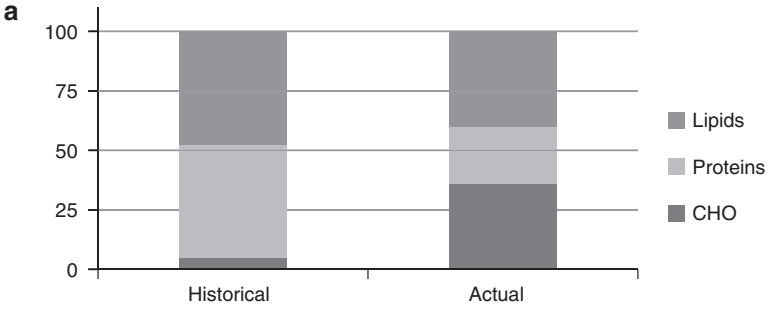

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Historical	Contemporary Wild	Contemporary Store-bought*
Animals* *Mammals*: moose, caribou, beaver, rabbit, muskrat Birds: geese, duck, partridge *All fish captured*	Animals* *Mammals*: moose, caribou, beaver, rabbit, muskrat Birds: geese, duck, partridge *Preferred fish*: walleye, northern pike, sturgeon, sucker, whitefish	Fruits and Vegetables: Infrequent access and limited choices fresh but more abundant frozen
		Bread and cereals products: Limited access to whole wheat bread and cereals
		Meats and substitutes: Frozen or canned beef, pork and chicken, bologna, sausages, beans
		Milk products: some access to milk, cheese (mostly processed sliced cheese) and yogurt
Plants Wild berries, roots, wild rice, intestinal content?	Plants Wild berries, roots, wild rice	Junk food: large variety of soft drinks, chocolate bars, chips, cookies, low quality prepared meats
*all parts of the animals were generally consumed	*few consume all parts of the animals	* Healthy food choices are 3 to 5 times more available and less expensive in urban areas of Canada whereas junk food is comparable in price and availability.

Figure 1 (**a**) Average macronutrient relative composition and (**b**) primary food staples consumed historically and currently in Oji-Cree communities of Northwestern Ontario, Canada.

contributors to this high incidence of obesity and T2DM,[4,6–8] the sudden shift from off-the-land foods (or traditional foods, as they are referred to in the communities) to more energy/less nutrient-dense processed foods containing large amounts of simple sugars and saturated fats have been associated with this increase in the prevalence of chronic diseases,[9] as depicted in Figure 1. At first glance, the nutritional composition of locally harvested foods strongly suggests that a greater reliance on off-the-land food sources would be greatly beneficial for reducing health concerns. However, the implementation of strategies to promote such a return to traditional food habits is far from simple and may even involve important health risks.

Dietary transition and genetic predispositions of Northern First Nations Peoples

The genetic make-up of humans has evolved and adapted to its environment with most favorable genotypes being transmitted through generations to ensure survival of the species.[10] In this context, the human genome has likely adapted to the quantity and quality of foods available for consumption, assuming that survival was at stake. For thousands of years before the westernization of food habits (for example, better food transport, access to processed foods), First Nations populations of Canada consumed plants and animals obtained from the land. Dietary practices would have been regionally and historically diverse, with some First Nations groups almost entirely drawing from animal food sources, whereas others benefited more significantly from agriculturally produced food items.[11,12] In Northern Canada, historical diets would have involved eating all food sources available on the land at any particular time, and almost all parts of the animals were consumed (that is, liver, gonads, gut, brain and bone marrow).[13] Figure 1 illustrates the theoretical macronutrient composition of local diets based on historical accounts as well as the effects of contemporary food availability and dietary behavior on food consumption

patterns in this region. The traditional diet would be considered mostly carnivorous, providing low amounts of carbohydrates (CHO) and large amounts of animal fat and protein. CHO would have been derived only seasonally from wild plants and berries. In contrast to the more contemporary diet, it would have contained no refined sugars and would have been lower in saturated fats but rich in vital nutrients[14–19] and essential Ω3 and Ω6 fatty acids.[20–22] Even though the types of local food consumed recently have been well studied in various regions of Canada,[11,14–16,19,21,23–30] the exact proportions of macronutrients and micronutrients traditionally consumed in an exclusively off-the-land diet remain difficult to assess. Unfortunately, historical accounts seldom specify proportions of various parts and species consumed. Variations in total local food intake were and remain greatly linked to seasonal availability of foods and preparation practices. Nonetheless, it is clear that fats were particularly valued as an energy-dense metabolic substrate ($40\,kJ\,g^{-1}$ vs 16 for CHO and $19\,kJ\,g^{-1}$ for proteins) essential to sustain the high energy demands of hunting, fishing, gathering and domestic activities.[13] They would typically be separated from tissues by way of boiling and mixing with meat protein and berries. As permanent settlements were established in the latter half of the 20th century as a result of Treaties being signed in this region, a progressive reliance on store-bought foods and a decrease in traditional activities were initiated.[31,32] In some communities, wide access to store-bought processed foods occurred in less than 50 years (one to two generations); a snapshot in evolutionary time. In some cases, these lifestyle changes led to an excess in energy intake and included the consumption of processed fats and refined CHO in the form of snack foods and soft drinks. It is widely believed that this lifestyle transition is mainly responsible for the significant rise in the rates of obesity and obesity-related diseases in the First Nations of Canada (that is, T2DM,[2,33,34] hypertension,[35] dyslipidemia[36] and cardiovascular diseases).[37] However, could there also be a genetic incapacity in Northern First Nations to deal with such rapid changes in food quantity and quality leading to increased prevalence of obesity-related chronic diseases?

The genetic determinants of obesity, T2DM and biomarkers of cardiovascular disease, in northern aboriginal communities have been extensively studied, particularly by Hegele *et al*.[38–41] Although a number of polymorphisms have been associated with these diseases or their related traits, the magnitude of the effect of each genetic variant is relatively small.[38] One rare mutation (G319S) in the *hepatic nuclear factor (HNF)-1α* gene, however, has been strongly associated with T2DM in the Oji-Cree (Sandy Lake, First Nations reserve in northern Ontario).[39] Almost 40% of diabetic Oji-Cree in Sandy Lake are carriers of this variant allele, which confers more than 95% risk of developing T2DM by the age of 50 years.[39,40] This mutation, however, was not found in other Canadian ethnic groups (that is, Ojibwa, Inuit, Africans, Caucasians, South Asians and Chinese), suggesting that it is a private mutation for Oji-Cree.[39] The frequency of certain rare mutations associated with hereditary disorders may be higher in isolated communities owing to lower genetic diversity, as observed with the Founder effect in Northeastern Québec communities.[42] Nevertheless, the genetic influence of complex diseases in Northern First Nations is probably attributable to a set of small effect size variants, which collectively confer a global genetic predisposition to disease development.

The physical manifestation of the genome, where an allele may confer risk, protection or have no effect, is dependent upon signaling molecules influenced by environmental factors capable of triggering or silencing gene expression.[10] Diet is among the most important environmental factors capable of interacting with the human genome.[43] For example, a polymorphism (Pro12Ala) in the *peroxisome proliferator-activated receptor-γ2* (*PPAR-γ2*) gene was found to be strongly associated with T2DM among Oji-Cree women,[44] but conferred a protective effect among Caucasians.[45] Interestingly, this polymorphism has been shown to interact with dietary fat (that is, polyunsaturated, saturated or their ratio) in two different Caucasian populations to affect indices of obesity or insulin concentrations,[46,47] which are themselves risk factors for T2DM. Similarly, a polymorphism (Ala54Thr) in the *fatty acid-binding protein-2* (*FABP2*) gene has been associated with higher triglyceride concentrations and indices of obesity among the Oji-Cree,[35,48] but not among an Italian population comprising Black and Caucasian individuals.[49] Again, this *FABP2* Ala54Thr polymorphism was shown to modify the association between dietary saturated fat intake and lipid cholesterol concentrations as well as markers of insulin resistance in the Italian population.[49] Published reviews of gene–diet interactions clearly show that dietary factors modify the predisposing or protective effect of gene loci[50] and that the effect varies between populations.[43,50] To our knowledge, gene–environment interactions have never been studied in Northern First Nations populations. This may provide better insight into the relationship between their genetic make-up and current environment/lifestyle exposure (for example, diet, pollutants, physical activity and smoking habits) and disease development.

As expected, the genetic background of First Nations varies compared with other Canadian ethnic groups.[38] Indeed, both Oji-Cree from Sandy Lake and Inuit from the Keewatin region have a higher prevalence of complex disease-predisposing alleles (that is, T2DM and atherosclerosis) compared with Caucasians.[38] This would suggest that both aboriginal groups are at greater risk of developing these diseases compared with Caucasians. However, the prevalence of diabetes and coronary heart disease is much lower in the Inuit compared with the Caucasians (about 1:3 and 1:2, respectively), but much higher in the Oji-Cree peoples compared with the Caucasians (about 5:1 and 2:1, respectively).[38] These genetic differences between the Inuit and Oji-Cree peoples cannot explain the discrepancy in the prevalence of diabetes and the rate of coronary heart disease between the two populations as they are overshadowed by striking differences in diet and lifestyle,

with the Inuit maintaining a more traditional diet and food procurement-related activities (hunting and fishing). Even though these findings suggest that a return to more locally harvested foods may be greatly beneficial for reducing health concerns, the implementation of traditional food habits in a contemporary context is far from simple and may even involve important health risks.

Challenges: the dietary dilemma

Throughout the world, researchers agree that improving the quality of the diet and increasing levels of physical activity are essential to reduce the prevalence of obesity and obesity-related diseases. Urban centers in Canada have a broad range of food and physical activity amenities and food prices are extremely competitive between distributors. Conversely, remote First Nations communities must rely on one primary food distributor and prices are exorbitant owing to the cost of transport (for example, $9.00 CND for six apples in 2007). In this context, local food harvesting seems like one strategy to improve the quality of the diet. However, a number of important challenges exist that prevent regular access to off-the-land foods. In this context, understanding the complexities of maintaining a traditional diet would require a multifaceted and multidisciplinary approach, which acknowledges the relationship between benefits, risks and viability. Our model for effectively documenting the complexities around land-based food practices in remote First Nations of Northern Canada is exemplified in Figure 2. Using such an approach could provide a more comprehensive analysis of not only the food sources, but also what is involved in procuring them.

Benefits

What remains constant in the literature is the persistent view that locally harvested and prepared foods are of tremendous value to First Nations peoples providing important health and cultural benefits that are increasingly being undermined by western-based food habits. However, scientific evidence clearly identifying these benefits is virtually non-existent in First Nations communities of Northwestern Ontario. From a metabolic standpoint, consumption of large amounts of refined CHO, sugar-sweetened drinks, soft drinks and processed meat has been linked to an increase in chronic inflammation, insulin resistance and T2DM.[51] In contrast, consumption of foods low in refined CHO and high in long-chain polyunsaturated fatty acids found in wild foods has been associated with reduced inflammatory markers, insulin resistance and T2DM.[22,52] Researchers have made important first steps in responding to the current health crisis facing these northern communities by attempting to involve Euro-Canadian education initiatives, informing residents of harmful dietary patterns and inactive lifestyles.[53] Unfortunately, advocating Canada's Food Guide standards[54] for Northern Communities accessible only by air for 9 months of the year (ice roads are constructed in the coldest months of the winter), where grocery produce is exorbitantly priced and not an affordable option for many residents, is proving economically impractical and inconsistent with the historical dietary patterns in this region.[55–57] It is also important to note that most of the information available on the effects of dietary behavior in Northern First Nations communities is based on clinical parameters as they relate to the metabolic syndrome. Consequently, more mechanistic information on the effects of specific dietary habits is virtually non-existent. Such data may help better understand the mechanisms involved in the development of chronic diseases in First Nations peoples and should be included in future research.

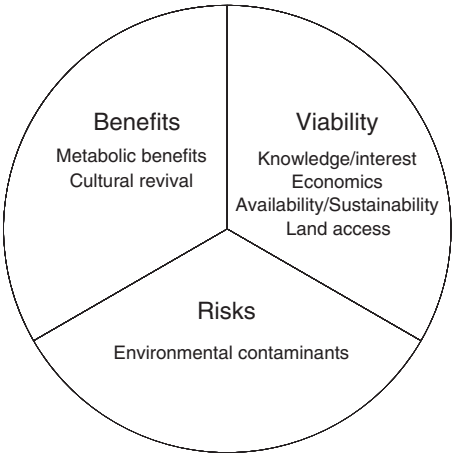

Figure 2 Schematic representation of a model to study off-the-land food practices.

In addition to ensuring proper nutrition, the lifestyle associated with hunting/gathering activities is generally associated with increased fitness due to an increase in daily energy expenditure. Hayes *et al*.[58] estimated that the highly active lifestyle of the ancient hunter-gatherers tripled daily energy expenditure when compared with sedentary adult humans living in industrialized countries. Yet, today, hunting/gathering techniques have greatly improved owing to the increased access to engine-driven transportation and modern cooking methods. Even though the energy costs associated with tracking a moose through the boreal forest in the winter remains high, energy demands for reaching hunting/gathering areas have been substantially decreased. The exact extent of this reduction in daily energy expenditure is far from being quantified. Clearly, use of gasoline-powered engines has reduced energy demands of off-the-land sustenance, but not without substantially increasing the financial costs for maintaining such activities.

In addition to the metabolic benefits of off-the-land consumption, there is greater recognition of the cultural benefits of traditional diets. For First Nations peoples, the importance of traditional foods has always been understood, but more recently, academics are finally sharing in this

knowledge as evidenced in the latest Arctic Monitoring and Assessment Program assessment of Human Health in the Arctic,[59] where authors summarize key points which northern indigenous populations identified as health benefits of traditional food. Of the six points identified, three of the six pertain to the cultural importance of traditional foods:

- Traditional food is a cultural anchor and its use is often important to the identity of aboriginal peoples.
- The sharing of traditional foods has a role in the maintenance of social norms and expectations.
- There are important spiritual aspects associated with traditional food use.

Scientific support for off-the-land foods, however delayed, does assist in valorizing local traditions in the face of western dietary influence, which impact local culinary practices. Research by García[60] in rural India and by Wilken[61] in rural Mexico describes how local agricultural dietary customs have been disparaged and equated with poverty and backwardness, yet recent scientific evidence documenting the important health benefits of locally produced foods has assisted in increasing local pride around harvesting traditions, which has led to an eventual increase in their consumption. It is believed that local and scientific support for traditional food consumption in Northern Canada will raise awareness of the importance of local food resources to develop strategies, in turn ensuring that they are maintained as part of local dietary practices within a contemporary framework.

Viability

An important component of the proposed model is to comprehensively analyze the viability of traditional dietary practices, which varies from community to community. On the basis of research in four First Nations communities in Northwestern Ontario,[13] four factors that hinder or enhance the viability of regularly consuming off-the-land foods have been identified: (1) knowledge; (2) economics; (3) availability/sustainability; and (4) land access.

Knowledge around food harvesting, food preparation and consumption has been traditionally passed down from generation to generation, typically by younger people participating in daily harvesting/preparation practices. For certain communities where harvesting/preparation practices are being replaced by market food acquisition, opportunities to harvest/prepare foods are dwindling, preventing people from developing the required skills to harvest/prepare foods safely and efficiently.

Economic analysis[59] points to traditional foods as being a cheaper alternative to market foods. Although the costs of harvesting foods vary across regions in the north, for the First Nations in Northern Ontario, it is expensive to get on the land to hunt and fish. Harvesting food requires traveling significant distances and having the proper materials and supplies (clothing, motor boat/snowmobile, tools, ammunition, food and fuel) to get on the land for lengthy periods of time in what are often extreme conditions. Despite the relatively remote location and abundance of fish/wildlife, prime fishing and hunting grounds are at a considerable distance from the community and people have become dependent on modern technologies to access them. Technology has increased hunting capacity, to the extent that harvesting without these technologies is impractical and wasteful in terms of one's time and energy. Therefore, only those with substantial economic resources can afford to get on the land and harvest enough food to feed themselves and their families.

The potential for First Nations communities to rely extensively on off-the-land foods is contingent on the availability and sustainability of local food resources. The First Nations in this region traditionally lived semi-nomadic lives, traveling seasonally in large hunting groups, hunting large game and returning to traditional territories in less active hunting periods. With the signing of Treaties and the gradual establishment of permanent settlements, traveling was more restricted, which led to drawing more extensively from wild food resources in smaller territories. Interviews with local hunters in this northern region still point to a relative abundance of a variety of local food resources, but the availability and sustainability of local food resources vary across regions in Canada.

In conjunction with wild food availability and sustainability, there exists the issue of land access and the repeated contestations of traditional hunting territories between aboriginal peoples and various public and private interest groups in Canada. For example, provincial and federal park development can infringe on traditional hunting areas, restricting access to important food resources. In Northwestern Ontario specifically, the First Nations communities are embroiled in a dispute with the Ontario government claiming that provincial park boundaries are restricting access to critical hunting and fishing grounds. An even greater concern, however, is the increased interest in forestry, mining, gas and oil development in Canada. Private and public pressure is mounting to secure land access deals with aboriginal groups to pave the way for mineral and natural resource exploration and development. The ability to protect traditional lands will be critical for the viability and sustainability of off-the-land dietary practices. Support for traditional dietary practices must be understood alongside the challenges each community faces in accessing local food resources. Any of these factors alone or in combination seriously reduce the viability or regular access to off-the-land foods.

Risks

Northern communities are fearful of the risks caused by contaminants.[62] There is evidence that people consuming contaminated fish in some parts of Canada and the United States experience reduced fertility,[63] develop neurological and neurobehavioral deficits,[64] and possibly cancer.[65] In

many cases, the fear of contaminated foods is unwarranted, but is propagated by frequent media reports on contaminants in traditional foods. Clearly, these concerns must be weighed against the nutritive benefits of traditional food sources and the actual risks posed by contaminants. To date, no information pertaining to the risks of dietary persistent organic pollutant (POP; that is, polychlorinated biphenyls, organochlorine insecticides, polychlorinated dioxins and furans, perfluorinated acids, and brominated flame retardants) exposure to energy metabolism has ever been reported to the populations in Northwestern Ontario. The Northern Contaminants Program, supported by Canada's Department of Indian and Northern Affairs, has overseen most of the contaminant research done in Canada's north, but its research was restricted to Nunavut, the Northwest Territories, Yukon, Nunavik and the north coast of Labrador (CACAR II 2003), thus, only limited information is available for this sub-arctic region of Northwestern Ontario. An understanding of contaminant concentrations in wild food resources is therefore critical for community members to fully embrace integrating traditional food sources into daily dietary practices.

Safe levels of dietary consumption for humans is evaluated by the tolerable daily intake, which quantifies the amount of a chemical that can be safely consumed over a lifetime without causing adverse health effects.[66] Tolerable daily intake is calculated based on clinical tests on animals to determine a no-adverse-effect level or a lowest adverse effect level.[67] A safety factor is applied to account for the uncertainties in the tolerable daily intake calculation, which arise from differences in susceptibilities by contaminants between humans and the species tested, and toxicokinetic variation among humans and test animals.[67]

In addition to the toxicological effects of contaminants, environmental pollutants are also associated with obesity and T2DM. Because of their lipophilic nature and chemical stability, POP levels reach several parts per million in fatty tissues (brain, liver and adipose tissue) in some aboriginal communities.[68] It has been reported that plasma organochlorine levels are positively associated with fat mass in humans.[69–71] In addition, POPs are also proinflammatory in nature and the effects of POPs have been demonstrated in various cell types (reviewed in Hennig *et al*.[72] and Matsumura[73]). Consequently, it is not unlikely that POPs, which mainly accumulate in fat tissues, contribute to the production and release of inflammation-related adipose tissue proteins known to be involved in the development of chronic metabolic disorders such as T2DM. A number of studies have found associations between T2DM and POPs, such as polychlorinated biphenyls,[74–78] polychlorinated dibenzo-*p*-dioxins[75–77,79] and organochlorine pesticides,[74–75,77,80–82] which are usually detectable at low levels in humans. The previous observations arise from cross-sectional studies, making it difficult to establish a cause–effect relationship. Recent case–control studies strengthen the possible causal role of POPs in diabetes.[81–83] Among women from the general Swedish population, Rignell-Hydbom *et al*.[83] showed that women with the highest exposed quartile for *p,p′*-dichlorodiphenyldichloroethane had a fivefold increased risk of developing T2DM compared with their controls, 6 years after the baseline examination. Furthermore, using the cohort of the Great Lakes sport fish consumers, Turyk *et al*.[81,82] showed that plasma concentrations of *p,p′*-dichlorodiphenyldichloroethane and the sum of polychlorinated biphenyls were higher in participants who subsequently developed diabetes. Even though direct experimental evidence linking POPs with the prevalence of obesity and T2DM has not yet been demonstrated, this association raises public health concerns, particularly in northern aboriginal communities that are likely more exposed to these substances owing to their geographical location and traditional dietary habits.

Conclusions

Finding adequate and effective dietary strategies for dealing with obesity and obesity-related diseases remains a challenge. In Oji-Cree communities of Northwestern Ontario, little is known as yet of the relationship between the Oji-Cree genetic make-up and environment/lifestyle exposure (for example, diet, pollutants, physical activity and smoking habits) on one hand and disease development on the other. Although it is clear that for most individuals, the current diet may lead to the development of obesity and T2DM, access to alternative healthier food options is highly limited. Low-quality, store-bought foods generally become the most affordable and highly available selection. Reintroducing off-the-land food strategies in a community context must be weighed against the variations in land use/access, health of the people, local knowledge competencies and environmental conditions (that is, contamination levels). Although there are certainly obstacles to reintroducing the dietary strategies of the past, these are not insurmountable. Formal food-sharing initiatives may have a crucial role in reversing the negative perceptions of traditional diets, subsequently increasing the likelihood that community members would engage in, adhere to and benefit from their health advantages. In so doing, the Oji-Cree communities may become better equipped to respond to the decline in health status and to assess the practicality of reintroducing off-the-land food sources as one avenue to health. This review identifies the scale of the problem of obesity and T2DM. It also calls for further research into the potential benefits of wild food consumption while seeking ways to promote increased physical activity levels and improved health.

Conflict of interest

The authors declare no conflict of interest.

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