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Balancing the benefits and costs of traditional food substitution by indigenous Arctic women of childbearing age: Impacts on persistent organic pollutant, mercury, and nutrient intakes

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ABSTRACT

For indigenous Arctic Canadians, traditional food consumption represents a key source of nutrients and environmental contaminants. Particularly, ingestion of marine mammal blubber and meat may lead to persistent organic pollutant levels and mercury intakes that exceed regulatory thresholds for sensitive populations. We investigated whether temporary adjustments to the consumption of traditional food derived from marine mammals appreciably impacted contaminant exposure and nutrient intakes among indigenous women of childbearing age. Such adjustments can be motivated by the desire to lower contaminant exposure or to increase nutrition, or by the diminishing availability of other traditional food sources. We combined the contaminant fate and transport model GloboPOP with the food chain bioaccumulation model ACC-Human Arctic to simulate polychlorinated biphenyl exposures in female 2007–08 Inuit Health Survey participants. We also calculated daily mercury and nutrient intake rates. Our results suggest that a temporary decrease in marine mammal consumption is largely ineffective at reducing exposure to polychlorinated biphenyls, because of their long elimination half-lives. In contrast, substitution of marine mammals was highly efficient at reducing mercury intake, but also appreciably lowered intakes of iron, manganese, selenium, and ω-3 polyunsaturated fatty acids. The impact of increasing intake of traditional food derived from marine mammals during childbearing age greatly depended on baseline consumption rates; replacement is ill-advised for those who already consume a lot of traditional food due to greater polychlorinated biphenyl and mercury exposures, while replacement was potentially beneficial for those with very limited marine mammal consumption due to increased nutrient intakes. Our calculations primarily suggest that considering baseline traditional food intake rates is critical to devising reproductive dietary adjustment strategies that maximize nutrient intake while minimizing environmental contaminant exposure.

1. Introduction

The importance of traditional food (TF) consumption to the cultural, spiritual, physical, financial, and relational well-being of indigenous communities from the Canadian Arctic is well documented (AMAP, 2009). For example, TF harvesting affords several physical health benefits and also fosters community food-sharing (Kuhnlein and Chan, 2000; Van Oostdam et al., 2005), while TFs themselves serve as excellent sources of many nutrients including vitamins A, D, and E, minerals iron (Fe), selenium (Se), and Zinc (Zn), and several ω-3 polyunsaturated fatty acids (PUFAs) (Belinsky and Kuhnlein, 2000; Kuhnlein et al., 1991, 2002, 2006; Kuhnlein and Receveur, 2007; Sharma et al., 2009). Days on which indigenous Arctic individuals consumed TFs were therefore characterized by significantly higher intakes of these as well as other compounds [manganese (Mn), sodium (Na), vitamin B-6, etc.] (Kuhnlein et al., 2004). Due to the wealth of benefits associated with TF intake, governmental regulators at the municipal, territorial/provincial, and federal levels encourage continued consumption (HC, 2007a).

However, TF consumption also represents the main route of indigenous Arctic exposure to environmental contaminants such as persistent organic pollutants (POPs) and mercury (Hg) (AMAP, 2009; Donaldson et al., 2010; Kuhnlein and Chan, 2000; Van Oostdam et al., 2005). Particularly, Arctic marine mammal (MM) TFs often exhibit appreciable POP and Hg levels based on the trophic levels and lipid contents of relevant

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Abbreviations: AI, adequate intake; ANSES, Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement, et du travail; CA, childbearing age; CNF, Canadian Nutrient File; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; FFQ, food frequency questionnaire; HC, Health Canada; IF, imported food; IHS, Inuit Health Survey; MM, marine mammal; POP, persistent organic pollutant; PUFA, polyunsaturated fatty acid; PCB, polychlorinated biphenyl; RDA, recommended daily allowance; TF, traditional food; UBA, Umweltbundesamt; UL, tolerable upper intake levels; WCBA, women of childbearing age; WHO, World Health Organization.

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species, as well as their inclusion of organ tissues (liver, kidney, etc.) (Belinsky and Kuhnlein, 2000; Borgå et al., 2004; Braune et al., 2005; Kuhnlein et al., 1991, 2002, 2006; Kuhnlein and Receveur, 2007; Muir et al., 1999; Sharma et al., 2009; Tian et al., 2011). Indigenous Arctic Canadians regularly possess POP and Hg levels that surpass those of Southern comparator populations (AMAP, 1998, 2003; Curren et al., 2014; Kuhnlein et al., 2004), and some even exhibit concentrations that exceed regulatory guidelines for contaminant intakes (Donaldson et al., 2010; Laird et al., 2013a). While current TF intakes are generally deemed safe for the broad indigenous Arctic community (Hoekstra et al., 2005), members of population subgroups sensitive to the deleterious effects of POPs and Hg may be at risk. For example, POP and Hg exposure among women of childbearing age (WCBA) remains a concern due to these chemicals' impacts on the developing fetus and nursing infant (Grandjean et al., 1997; Jacobson et al., 1990; Walkowiak et al., 2001). In fact, prenatal Hg exposure is the basis for the majority of current Canadian territorial government TF advisories. For example, advisories recommend that WCBA reduce consumption of fish residing in particular Arctic lakes (GNWT, 2012), ringed seal liver (NTI, 2012), and beluga whale meat (NRBHSS, 2011).

The issue of TF intake among indigenous Arctic populations is further complicated by their ongoing dietary transition away from TFs and toward more imported foods (IFs) (Blanchet and Rochette, 2008; Kuhnlein et al., 2004; Sharma et al., 2009). This is reflected in the decreasing proportion of dietary energy intake derived from TFs through time among these populations, with recent estimates reaching as low as 16% of total daily calories (Blanchet and Rochette, 2008), predicated mainly by lower TF intakes in younger generations (Bersamin et al., 2007; Blanchet and Rochette, 2008; Kuhnlein et al., 2004; Receveur et al., 1997; Sheikh et al., 2011). This phenomenon, particularly reductions in MM intake, has likely contributed in part to the trend of declining POP levels in some indigenous Arctic communities (Armstrong et al., 2007; Donaldson et al., 2010; Potyrala et al., 2008). However it has also led to decreasing intakes of key nutrients from TFs due to their replacement with non-nutrient dense IF alternatives (Kuhnlein et al., 2008; Sharma et al., 2010).

Notably, this population-wide dietary transition may also coexist with more transient adaptive dietary behaviours. For example, while complying with the ringed seal liver or beluga whale meat advisories cited above, Inuit WCBA might temporarily reduce their MM intake to avoid exposure to Hg. Alternatively, indigenous Arctic mothers sometimes increase their MM TF consumption during pregnancy based on the nutritional and cultural value of these items, and/or changes in food preference and appetite (Muckle et al., 2001). Additionally, certain Canadian Arctic communities have been forced to temporarily transition away from certain types of TFs based on availability issues. A particular example is the region of Nunatsiavut, Labrador where a dramatic decline in local caribou herd size has led to a hunting ban by the local indigenous government (NG, 2014a, 2014b).

We have previously assessed the influence of transient dietary changes on POP exposure for temperate populations (Binnington et al., 2014), wherein we found that short-term reductions in fish intake exerted little effect on the maternal body burdens of long-lived POPs such as polychlorinated biphenyls (PCBs). However, we also expected that compliance with such advisories could be highly effective for contaminants with relatively short human elimination half-lives, such as Hg (Smith and Farris, 1996; Yaginuma-Sakurai et al., 2012). The purpose of this study was to extend our investigation of transient dietary change impacts on maternal POP exposure to indigenous Arctic mothers consuming TFs. Specifically, we utilized data from the Inuit Health Survey (IHS) (Egeland et al., 2011a; Huet et al., 2012; Saudny et al., 2012) to generate TF intake and substitution scenarios for indigenous Arctic mothers. We chose this dataset based on its size (2072 TF consumers) and recruitment of participants from across the Canadian Arctic, as our goal was to generate TF substitution findings that were generally applicable to Inuit living throughout Northern Canada. Our main aims were to employ IHS TF intake data in i) simulating POP exposure changes among indigenous Arctic mothers varying in their degree and duration of hypothetical MM TF substitution, ii) estimating differences in POP exposure among indigenous Arctic mothers realistically substituting TFs based on traditional knowledge, TF availability, and/or TF advisories, and iii) supplementing mechanistic POP calculations with estimated changes to Hg and nutrient intakes.

2. Methods

2.1. A brief conceptual overview of the modeling approach

As in previous studies (Quinn et al., 2012; Binnington et al., 2016), we utilized an approach combining a POP fate and transport model with a bioaccumulation model. Estimates of global PCB emissions were input into the global fate and transport model GloboPOP, which estimated historical contaminant concentrations in Arctic air, seawater, and soil. These levels were then input into the food chain bioaccumulation model ACC-Human Arctic, which estimated time-variant PCB concentrations in important TF species. PCB levels in IF items were obtained using the food chain bioaccumulation model ACC-Human Temperate. Human exposure to PCBs was then calculated using the human bioaccumulation module within ACC-Human Arctic, assuming mothers consumed TFs and IFs in one of three baseline diet composition scenarios: i) 100% of mean IHS TF consumption rates - deemed the “high” TF scenario, ii) 33% of mean IHS TF consumption rates - “moderate”, or iii) 33% of the mean IHS TF consumption rates, except that no MM TFs were consumed - “low”. The impact of plausible TF substitution was then estimated via three dietary substitution approaches: a) replacement of MM TFs, b) replacement of caribou, or c) modest increases to MM TF intake.

PCB exposure was calculated mechanistically and formulated as lipid-adjusted ΣPCB blood concentrations, while Hg and nutrient intake rates were calculated empirically using published data on TF Hg, fatty acid, mineral, and vitamin concentrations. Calculated maternal PCB levels and Hg and nutrient ingestion rates were then compared between baseline and TF replacement diets to discern TF substitution impact. We also assessed these PCB concentrations and Hg and nutrient intake rates using guidelines on contaminant exposure and nutritional adequacy from Health Canada (HC), France's Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement, et du travail (ANSES), Germany's Federal Environment Agency (Umweltbundesamt - UBA), and the World Health Organization (WHO).

2.2. Details of the mechanistic POP fate/bioaccumulation model approach

For specifics on our model framework, including details on the parameterization of several TF organism sub-models that were recently added to the ACC-Human Arctic food chain (caribou, Canada goose, narwhal, etc.), see Binnington et al. (2016). Briefly, estimated emissions for the PCB congeners 138 and 153 served as primary input parameters to the GloboPOP model (Armitage et al., 2013), which calculates the transport and distribution of POPs among 10 zonally averaged latitudinal bands. The calculated PCB concentrations in air, seawater, fresh water, and soil of the North Temperate (38–54° N), North Boreal (54–64° N), and Arctic (64–90° N) zones then served as inputs to one of two food chain bioaccumulation models: ACC-Human Temperate for migratory TF species (Canada goose) and IFs (beef, dairy) (Binnington et al., 2014; Czub and McLachlan, 2004), or ACC-Human Arctic for Arctic TF species (caribou, Arctic char, beluga whale, narwhal, ringed seal) (Binnington and Wania, 2014; Binnington et al., 2016; Czub and McLachlan, 2007; Quinn et al., 2012). Simulations of PCB bioaccumulation in temperate and Arctic food webs were performed just once to minimize calculation time, and the resulting TF and IF concentrations were stored as an input file for human exposure simulations (Binnington et al., 2016).