ABSTRACT

Objectives. Previous studies suggest that dietary patterns and the extent of reliance upon traditional food vary among Inuit communities. Inuit traditional foods are an important source of nutrients such as highly unsaturated \( n-3 \) fatty acids (HUFA \( n-3 \)), whose beneficial effects include protection against ischemic heart disease. Dietary transition is occurring with younger generations consuming less traditional foods and more market foods with low nutrient density. Utilizing erythrocyte membrane fatty acid composition as an indicator of body HUFA \( n-3 \) status, which reflects dietary intake levels of traditional Inuit foods, we explored the regional and age variability of highly unsaturated \( n-3 \) fatty acids (HUFA \( n-3 \)) in the International Polar Year Inuit Health Survey.

Study design. Cross-sectional health survey.

Methods. Participants were recruited through random sampling of households. Fatty acid data were available among 2,200 adults (≥18 yr).

Results. HUFA \( n-3 \) levels in the Eastern Arctic were significantly higher than in the Western Arctic, with Nunatsiavut (northern Labrador) and Baffin showing the highest HUFA \( n-3 \) status compared to Kivalliq, Kitikmeot and Inuvialuit Settlement Region (ISR) (\( p<0.0001 \)). Fatty acid proportion in erythrocyte membranes showed pronounced differences between coastal communities and inland communities, including a higher HUFA \( n-3 \) status among the coastal communities (\( p<0.0001 \)). Additionally, the HUFA \( n-3 \) status showed a strong positive association with age, particularly in Baffin and Kivalliq. HUFA \( n-3 \) were inversely associated with saturated (\( \beta=-0.98 \) [SE=0.03], \( R^2=0.36 \), \( p<0.0001 \)) and trans fatty acids (\( \beta=-0.06 \) [SE=0.004], \( R^2=0.07 \), \( p<0.0001 \)).

Conclusions. The present study results provided biochemical support for varying dietary patterns and dietary transition among Inuit across the Canadian Arctic. The analyses also suggested multifactorial determinants of HUFA \( n-3 \) status among Canadian Arctic Inuit. A nutritional intervention strategy with multiple approaches may be needed to improve and maintain their HUFA \( n-3 \) status.

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Keywords: HUFA \( n-3 \) status, Canada, International Polar Year, Inuit Health Survey
INTRODUCTION

Canadian Inuit, who are a group of Indigenous people residing in Canadian arctic regions, have been experiencing rapid social, cultural and economic changes in recent decades. The nutritional and health data that are available for these populations represent fragmented assessments over time and diverse geographic areas. The lifestyle transition being observed has become a public health concern with epidemiologic transitions being noted in obesity and chronic disease risk (1), which were rare in the past (2–4). Dietary transition away from traditional foods, which are rich in various nutrients (5), is one critical factor linking the lifestyle changes with the shifting pattern in health and disease. In that regard, alterations in dietary fat intake are of interest given their importance in the development of chronic disease risk (6,7).

Most evidence regarding dietary transition among Arctic Inuit has been obtained from dietary studies (8–11) as well as food component analysis (12), while analyses of biomarkers of nutritional exposures have been under-represented. The measurement of fatty acid composition of erythrocyte membranes used in the current study has been commonly used to assess highly unsaturated fatty acids (HUFA) and trans fatty acids (TFA) intake in epidemiologic studies (13). HUFA are fatty acids with more than 3 carbon-carbon double bonds in the carbon chain of the fatty acids, and a HUFA n-3 fatty acid refers to a HUFA with its first carbon-carbon double bond in the third bond from the methyl end of the fatty acid. For HUFA and other unsaturated fatty acids, their chains of carbon atoms are on the same side of the double bond(s), which is called the cis arrangement. Although TFA have carbon-carbon double bonds in their carbon chain, they have the trans arrangement in which the chains are on opposite sides of the double bond(s). In an earlier study in a Baffin community, a strong positive association between age and plasma C20:5 n-3 and C22:6 n-3 was noted (14). Similarly, n-3 fatty acids of erythrocyte membrane phospholipids increased with age in the 2004 Nunavik Health Survey, as well as in Greenland (15). Furthermore, in the 2004 Nunavik Health Survey, TFA levels were especially high among the Inuit youth (15). In a small Baffin community health survey, plasma n-3 fatty acids were inversely related to TFA, indicating that traditional food is replaced by market food of poorer quality (16). A previous health survey measuring plasma phospholipid fatty acids was done in Keewatin (now Kivalliq) whereby an increase of C20:5 n-3 was reported among older Inuit (17).

For Indigenous people, food choice is influenced by multiple factors (18,19). Age is a strong determinant of traditional food consumption, with younger Indigenous people in the arctic consuming less traditional food than older individuals within the same communities (8,14,15,20). Other factors including road access, latitude and population size were also proposed as being determinants of dietary habits (21). Dietary assessment data collected in 16 communities in Canada’s Northwest Territories showed that communities with higher intakes of traditional food were more likely to be located at higher latitudes (22).

It is important to monitor HUFA n-3 status among Arctic Inuit given that HUFA n-3 is an indicator of dietary patterns (23), and has beneficial health effects. The protective effects of HUFA n-3 are attributed to their various physiological functions, including their maintenance of normal biomembrane structure (3) and function and precursors of eicosanoids (24); their key regu-
lation of genes involved in lipid homeostasis (3); and their anti-arrhythmic action (5,6). The current analyses are based upon data from the International Polar Year (IPY) Inuit Health Survey 2007–2008 in 3 Canadian jurisdictions (latitudes: 54° to 76° N; longitudes: 58° to 135° W). Such a vast landscape offers the opportunity to evaluate the extent to which HUFA n-3 status varies across the Canadian Arctic and the extent of dietary transition by region.

MATERIAL AND METHODS

Location and participants
IPY Inuit Health Survey was conducted in Nunavut, Nunatsiavut and Inuvialuit Settlement Region (ISR) in August and September 2007–2008 (Fig. 1). A total of 36 communities were included, 3 of which were inland communities. Adult Inuit (≥18 years, excluding pregnant women) who self-identified as Inuk were recruited through a random selection of households stratified by community. Overall, 2,796 households were approached and 1,901 (68%) agreed to participate with a total of 2,595 participants, representing approximately 11% of the Inuit population in the geographic areas surveyed. Among them, fasting red blood cell samples were available from 2,200 individuals (84.8%) for the measurement of erythrocyte membrane fatty acids. The project was reviewed and approved by McGill Institutional Review Board and by all 3 jurisdictions.

Figure 1. Map of IPY Inuit health survey regions.
**Anthropometric measures**

Weight and body fat percentage were measured using a 4-point bioelectrical impedance scale (Tanita, Tokyo, Japan). Height was measured without shoes to the nearest millimetre using a stadiometer with the patient standing on a hard surface. BMI was calculated (kg/m²). Waist circumference was measured at the end of a normal expiration with the tape placed horizontally between the last floating rib and the top of the hip, and the measurement was taken to the nearest millimetre. Obesity was defined by BMI ≥30 kg/m² and abdominal obesity was defined by the waist circumference (waist ≥102 cm in men and ≥88 cm in women) (25).

**Interview**

Detailed methodology has been described previously (26). Briefly speaking, trained interviewers who were bilingual in English and Inuit language administered questionnaires to collect demographic data including alcohol consumption, smoking, education and primary language spoken in the home. Alcohol consumption information included whether the participant had drunk in the past 12 months; what type of alcohol they drank (such as beer, wine, liquor, etc.); and how much alcohol they had consumed in 1 day the last time they drank. A drink was defined as 1.5 ounces of liquor, 5 ounces of wine or 12 ounces of beer.

**Fatty acid analysis**

Blood concentrations of fatty acids were determined in erythrocyte membrane by gas-liquid chromatograph (Lipid Analytical Laboratories Inc, Guelph, Canada). Fatty acid composition of erythrocytes was determined based on methodology previously reported (6,27–29). The fatty acid methyl esters were analysed on a Varian 2400 gas-liquid chromatograph (Palo Alto, CA) with a 60-m DB-23 capillary column (0.32-mm internal diameter).

**Statistical analysis**

Fatty acid concentrations as a percentage of total fatty acids were evaluated by demographic characteristics, including geographic regions, and by coastal versus non-coastal communities. Mann-Whitney U-test was applied to compare the compositions of fatty acid classes by demographic characteristics. Due to the pronounced differences in the fatty acid composition of their erythrocyte membranes, coastal and inland Inuit were analysed separately. General linear models (GLM) were used to compare fatty acid profiles of erythrocyte membranes among Inuit from coastal regions. If the overall difference was significant, pairwise comparisons were conducted with Bonferroni correction. Highly skewed variables were log-transformed before being entered into the GLM. Chi-square tests were used for categorical variables, and if the overall difference was significant, a multiple comparison procedure was conducted by the methods established by Zar and COMPPROP macro in SAS, which was applied for the test (30). Mann-Whitney U-test was also used to compare 1 inland community, Baker Lake, with the other 2 inland communities, Inuvik and Aklavik. As gender and obesity measures did not significantly interact with the fatty acid–related associations, data on men and women were combined for analyses. Age-adjusted multivariable linear regression was used to separately evaluate the associations of \( n-3 \) fatty acids (independent variables) with total SFA and TFA (dependent variables). All P values were obtained from 2-sided tests. Data were analysed with the SAS software (version 9.2; SAS Institute, Cary, NC).
RESULTS

Subject characteristics of each survey region

The mean age of survey participants ranged from 41.0 years (SD=15.0) in Kitikmeot to 44.5 years (SD=14.0) in Nunatsiavut (Table I). The significant difference in age among regions (p=0.012) was largely due to the large survey sample size, rather than biologically meaningful age differences. Female participants were more prevalent than male participants in each region, from 58.0% in coastal communities (in Kivalliq) to 69.7% in Aklavik and Inuvik (in ISR). However, the gender distribution did not significantly vary by region (Table I). Obesity is prevalent among all regions, with abdominal obesity showing particularly high rates, ranging from 35.7% in Baffin to 74.3% among the inland communities of ISR (Table I). In general, over 50% of Inuit participants reported current smoking and alcohol consumption with a median (interquartile) of 6.00 drinks (3.00–10.00) consumed the last time they drank. In the current survey, 88.0% of Baffin Inuit and 82.4% of Kivalliq Inuit reported speaking Inuktutat at home. Only 19.8% of Kitikmeot Inuit, 12.1% of Inuvialuit Inuit and 1.3% of Nunatsiavut Inuit reported speaking their Inuit language at home.

Fatty acid composition of erythrocyte membranes by demographic characteristics

Speaking an Inuit language in the home was associated with significantly higher HUFA n-3 levels when compared to those residing in non-Inuit-speaking homes (p<0.05) (Table II). On the other hand, males had slightly higher SFA than females; smokers had slightly higher MUFA and HUFA n-6 than non-smokers; and obese Inuit showed higher SFA than non-obese Inuit (Table II). However, these differences were largely due to the large survey sample size rather than biologically meaningful differences in fatty acid compositions.

Table I. Population characters of survey regions (mean±SD).

| Variable          | Nunatsiavut | Baffin | Kitikmeot | Kivalliq | Inuvialuit | Baker Lake (Kivalliq) | Aklavik, Inuvik (Inuvialuit) | p     |
|-------------------|-------------|--------|-----------|----------|------------|-----------------------|-----------------------------|-------|
| Age (yr)          | 44.5±14.0, n=265 | 41.8±14.9, n=778 | 41.0±15.0, n=360 | 41.1±15.9, n=407 | 44.2±17.2, n=163 | 44.5±16.2, n=107 | 44.2±17.9, n=129 | 0.0012 |
| BMI               | 29.2±5.7, n=259 | 26.8±6.0, n=751 | 29.4±6.8, n=335 | 28.6±6.9, n=392 | 29.8±6.3, n=145 | 28.2±5.9, n=106 | 29.4±6.5, n=112 | <0.0001 |
| Waist (cm)        | 96.5±14.2, n=260 | 88.5±14.3, n=750 | 95.7±17.1, n=334 | 92.5±16.4, n=385 | 100.0±16.6, n=147 | 93.4±14.5, n=99 | 98.4±17.2, n=114 | <0.0001 |
| Body fat (%)      | 33.1±10.1, n=257 | 28.0±10.9, n=750 | 31.0±11.3, n=332 | 30.0±11.0, n=392 | 33.4±10.6, n=145 | 30.3±10.6, n=105 | 32.0±10.7, n=112 | <0.0001 |
| Female%           | 62.6 | 61.5 | 60.0 | 58.0 | 63.6 | 58.9 | 69.7 | ns |
| Obesity%          | 39.6 | 26.8 | 38.1 | 35.1 | 40.3 | 29.9 | 49.3 | <0.0001 |
| Obesity%α         | 58.1 | 35.7 | 48.3 | 42.0 | 55.8 | 45.8 | 74.3 | <0.0001 |
| Smoking%          | 54.8 | 73.0 | 73.5 | 72.0 | 70.9 | 71.0 | 62.2 | <0.0001 |
| Drinking%         | 70   | 62   | 67   | 51   | 70   | 40   | 63   | <0.0001 |
| Speaking Inuit language at home(%) | 1.3 | 88.0 | 19.8 | 82.4 | 12.1 | 39.5 | 3.6 | <0.0001 |

α Baker Lake is an inland community in Kivalliq; Aklavik and Inuvik are inland communities in Inuvialuit Settlement Region.

β Obesity: BMI≥30.

γ Obesity: waist >88cm for women and waist >102 for men.

δ Reported consuming any alcohol in the past year.
HUFA n-3 status and Canadian Inuit

Table II. Median (interquartile ranges) of selected fatty acid classes as a percent of total fatty acids of erythrocyte membranes by characteristics of study population.

| SFA | MUFA | TFA | HUFA n-6 | HUFA n-3 |
|-----|------|-----|---------|---------|
| Gender |
| Male (n=849) | 41.9 (39.7–45.5) | 24.6 (22.9–26.7) | 1.3 (0.9–1.7) | 8.7 (6.7–10.7) | 5.1 (3.1–7.4) |
| Female (n=1,351) | 42.4 (40.0–45.6) | 24.6 (22.7–26.9) | 1.2 (0.9–1.7) | 8.7 (6.5–10.9) | 5.1 (3.0–7.5) |

| Education (completed secondary school) |
| No (n=1,812) | 42.1 (40.0–45.6) | 24.6 (22.7–26.8) | 1.3 (0.9–1.7) | 8.7 (6.7–10.9) | 5.1 (3.1–7.6) |
| Yes (n=387) | 42.6 (39.7–46.8) | 24.8 (23.0–27.0) | 1.0 (0.9–1.7) | 8.4 (6.1–10.4) | 4.8 (3.0–6.9) |

| Obesity |
| No (BMI<30, n=1,440) | 41.8 (39.7–45.2) | 24.6 (22.8–26.8) | 1.3 (0.9–1.7) | 8.7 (6.7–10.8) | 5.1 (3.1–7.4) |
| Yes (BMI≥30, n=760) | 42.9 (40.3–46.4) | 24.7 (22.6–26.9) | 1.0 (0.9–1.7) | 8.6 (6.3–10.9) | 5.3 (3.0–7.7) |

| Smoking |
| No (n=643) | 42.2 (39.8–45.6) | 24.3 (22.3–26.6) | 1.2 (0.9–1.7) | 9.0 (6.9–11.1) | 5.1 (3.0–7.6) |
| Yes (n=1,481) | 42.2 (39.7–45.6) | 24.7 (22.9–26.8) | 1.3 (0.9–1.7) | 8.6 (6.5–10.6) | 5.1 (3.1–7.4) |

| Alcohol consumption |
| No (n=933) | 42.3 (40.1–45.4) | 24.7 (22.6–26.8) | 1.2 (0.9–1.7) | 8.9 (6.7–11.3) | 4.6 (2.9–6.7) |
| Yes (n=1,200) | 42.1 (39.7–45.7) | 24.6 (22.6–26.8) | 1.2 (0.9–1.7) | 8.6 (6.6–10.6) | 5.8 (3.5–8.7) |

Comparison of the fatty acid class by characteristics of study population by Mann-Whitney (p<0.05).

Table III. Median (interquartile ranges) of selected fatty acids as a percent of total fatty acids of erythrocyte membranes in different regions: International Polar Year Inuit Health Survey, 2007–2008.

| Fatty acids | Nunatsiavut | Baffin | Coastal communities | Inuvialuit | Inland communities |
|-------------|------------|--------|---------------------|-----------|------------------|
|             | n=230      | n=749  | Kivalliq            | n=163     | Baker Lake (Kivalliq) |
|             | n=358      | n=438  |                     | n=110     | Aklavik, Inuvik (Inuvialuit) |
| SFA/PUFA    | 1.1 (1.0–1.2) | 1.2 (1.1–1.4) | 1.0 (1.0–1.2) | 1.3 (1.0–1.9) | 1.4 (1.3–1.5) | 1.5 (1.2–2.1) | 4.9 (2.4–6.9) | 3.5 (2.9–4.2) |

Table IV. Age-adjusted linear regression coefficients predicting erythrocyte membranes saturated fatty acids (SFA) and trans fatty acids (TFA) by RBC HUFA n-3 fatty acids.*

| Fatty acids | SFA/B | TFA/SE | R²a | p  | B  | SE | R² | p  |
|-------------|-------|--------|-----|----|-----|----|----|----|
| C20:5 n-3  | -1.00 | 0.08   | 0.07 | <0.001 | -0.10 | 0.01 | 0.03 | <0.001 |
| C22:5 n-3  | -3.78 | 0.10   | 0.38 | <0.001 | -0.19 | 0.02 | 0.05 | <0.001 |
| C22:6 n-3  | -2.24 | 0.05   | 0.44 | <0.001 | -0.12 | 0.01 | 0.07 | <0.001 |
| HUFA n-3   | -0.98 | 0.03   | 0.36 | <0.001 | -0.06 | <0.01 | 0.07 | <0.001 |

*a Adjusted for age, n=2,197. 
R² referred to the fatty acid predictors.

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**Fatty acid composition of erythrocyte membranes by region**

Regional differences in the fatty acid composition of erythrocyte membranes were observed, particularly between inland and coastal communities (Table III) (Fig. 2). The $n$-3 status of inland communities was pronouncedly lower than that of coastal regions. Within inland communities, HUFA $n$-3 status was lower in the Aklavik and Inuvik regions of ISR than in Baker Lake ($p<0.05$). Among coastal communities, Kitikmeot (Nunavut) and Kivalliq (ISR) had the lowest HUFA $n$-3 status of all the Arctic regions ($p<0.05$ for all). A much lower $n$-6 fatty acid status was also noted in inland communities. At the same time, SFA levels for the inland communities were considerably higher than that of coastal regions. Moreover, higher TFA was observed among inland Inuit than coastal Inuit. Among coastal communities, TFA were lowest in Baffin ($p<0.05$).

Similarly, fatty acids–derived ratios showed significant regional discrepancies: the $n$-6/$n$-3 ratio was higher in inland communities, particularly in Aklavik and Inuvik where the ratio was more than 2 times higher than that observed in other survey regions. Among coastal regions, the $n$-6/$n$-3 ratio was higher in Kivalliq than in other coastal communities ($p<0.05$). The other ratio, C22:5 $n$-3/C20:5 $n$-3, was lower in the inland compared to that in the coastal communities. Among coastal regions, C22:5 $n$-3/C20:5 $n$-3 seemed to be higher in Kivalliq and Nunatsiavut ($p<0.05$). SFA/PUFA of inland communities was noticeably higher than that of coastal regions. Among the coastal regions, the highest SFA/PUFA was observed in Kitikmeot and coastal Inuvialuit ($p<0.05$).

**Associations of primary HUFA $n$-3 fatty acids with SFA and TFA**

In the age-adjusted linear regression models, HUFA $n$-3 fatty acids were inversely related to SFA and TFA (Table IV). In particular, C22:5 $n$-3, C22:6 $n$-3 and total HUFA $n$-3 fatty acids were strongly related to SFA (in the linear regression models, $R^2$ attributed to SFA >0.3).

![Figure 2. Median level of fatty acid classes of erythrocyte membranes of Inuit from coastal regions and inland communities.](image_url)
HUFA $n$-3 status and Canadian Inuit

**Fatty acid composition across age groups**

HUFA $n$-3 fatty acids correlated strongly with age ($r=0.622$ in Baffin and Kivalliq, $r=0.256$ in other regions, both $p<0.0001$, data not shown). The regional factor showed a significant interaction regarding the association between age and HUFA $n$-3, as the trend of an increasing HUFA $n$-3 status with age was more evident in Baffin and Kivalliq than in the other regions (Fig. 3).

**DISCUSSION**

The fatty acid profiles of erythrocyte membranes shifted across the Canadian Arctic area. Generally speaking, HUFA $n$-3 status was highest in Nunatsiavut to the east and in Baffin in the northeast, and lowest in the western regions. In contrast, TFA, $n$-6 to $n$-3 ratio and SFA to PUFA ratio demonstrated an opposite trend regarding the above regional differences. Overall, coastal Inuit and inland Inuit appear to have dietary fat intake patterns that are very distinct from each other, with the latter more dependent on market foods containing high SFA and TFA but low HUFA $n$-3. Further, HUFA $n$-3 fatty acids showed a strong positive association with age among survey participants from Baffin and Kivalliq, indicating that dietary transition is occurring in these communities. Conversely, the age-associated differences in fatty acids in other regions were relatively minor, suggesting a more uniform dietary pattern in the population.

Regional differences of fatty acid composition of erythrocyte membranes among Inuit populations reflect the relative extent of their reliance upon traditional and market foods. The ratio of $n$-
HUFA \( n-3 \) status and Canadian Inuit

6/\( n-3 \) in Indigenous people’s diets has been used as an indicator of dietary Westernization, with higher ratios indicating lower consumption of traditional foods (31). Similarly, TFA and SFA also indicate a greater reliance upon market food. Interpretation of the \( n-6/n-3 \) ratios without other dietary indicators, however, should be viewed with caution. Although marine mammals, such as seals and whales, as well as marine and freshwater fish are all part of the Inuit traditional food system, wild land animals such as game animals and birds are also consumed (16). Analyses of Arctic food items showed that the fatty acid composition differs in the meat from marine mammals and from land animals (32). A high consumption of land animals relative to marine mammals or fish would also result in a high \( n-6/n-3 \) ratio. Compared to land animals, marine mammals and marine fish are the good sources of HUFA \( n-3 \), particularly of C20:5 \( n-3 \) and C22:6 \( n-3 \), and are low in SFA and \( n-6 \) fatty acids. Compared to C22:6 \( n-3 \), C20:5 \( n-3 \) was suggested to be a better indicator of fish intake (36). Land animals, on the other hand, were found to be high in C22:5 \( n-3 \) (33,34) and C18:2 \( n-6 \) (32,33). Similarly, a study of repeated 24-h recalls showed that C22:5 \( n-3 \) was the dominant HUFA \( n-3 \) in meat (35). Given the suggested discrepancy regarding the main dietary sources of HUFA \( n-3 \), a high C22:5 \( n-3/C20:5 \) \( n-3 \) might be a novel indicator of a diet containing a larger proportion of land animals than that of both fish and marine mammals, which has not been examined in the literature. However, when land animal meat was compared to market meat, the former would still be a better choice for health in terms of its fatty acid profile. For example, the National Nutrient Database of United States and Canada showed that even lean beef has a pronouncedly higher proportion of SFA, which would account for about half of the beef fat (37,38). In contrast, beef only contains negligible PUFA, which mostly are \( n-6 \) (37,38). Interestingly, beef from grass-fed cows had higher HUFA \( n-3 \) fatty acids than that from grain-fed cows (37). Also, wild Atlantic salmon was reported to be “leaner” but had proportionally higher HUFA \( n-3 \) compared to farmed Atlantic salmon (38). The above findings suggest that when evaluating the intake level of traditional foods vs. market foods in a given Inuit region, a variety of different overall indicators need to be considered, rather than using 1 specific biomarker. When dietary patterns shift, the fatty acid composition of erythrocyte membranes will change accordingly.

In the current study, the fatty acid profile of erythrocyte membranes between inland Inuit and coastal Inuit demonstrated strikingly pronounced differences. Technically, the Baker Lake community of Kivalliq is the only inland Arctic community in Canada (39); it is located on the shore of Baker Lake, a freshwater lake. Aklavik and Inuvik of Inuvialuit are situated along the Mackenzie Delta, which is Canada’s largest freshwater delta (40), and so these communities were also categorized as inland communities in the analysis. Inland Inuit would have less access to marine mammals and marine fish than coastal Inuit. The low PUFA status – including both HUFA \( n-3 \) and \( n-6 \) – that was observed among inland Inuit along with their relatively high TFA, SFA and SFA/PUFA levels indicate that they have a more Westernized dietary pattern than Inuit residing along the coast. At the same time, the much higher \( n-6/n-3 \) ratio of Aklavik and Inuvik along with their lower C22:5 \( n-3/C20:5 \) \( n-3 \) ratio suggests that these Inuit communities have a higher consumption of market foods than Baker Lake Inuit.

Ranging from the Eastern Arctic to the Central and Western Arctic regions, a decreasing HUFA \( n-3 \) status was observed in the coastal communities. On the western side of Canadian Arctic, popula-
tions in ISR had the lowest HUFA \( n-3 \) status. ISR is a rather modernized region with mining and oil production being an important industry (40,41). Wage-earning employment provide current Inuvialuit Inuit with more reliable livelihood than traditional hunting (41), but could also consequently set restraints on time and/or energy for community members to engage in hunting or fishing for obtaining traditional foods, resulting in a greater dependence upon store-bought foods.

The fatty acid profile of the erythrocyte membranes of survey participants showed a shifting pattern in the north-to-south dimension, from Baffin to Kitikmeot to Kivalliq. Among the 3 regions, Baffin Inuit showed the highest HUFA \( n-3 \) status and the lowest ratios of C22:5 \( n-3 \)/C20:5 \( n-6 \)/\( n-3 \), suggesting higher consumption of marine mammals and marine fish among Baffin Inuit relative to their consumption of wild land animals.

Among Inuit across the Canadian Arctic, the fatty acid profile clearly demonstrated generational differences. Young Indigenous people are consuming less traditional food than older individuals, indicating that a dietary transition is occurring consistent with previous reports in Nunavik (10), Baffin Island (9), Belcher Islands (42) and more recently among the Cree of James Bay, Quebec (20). Age-related dietary transition is driven by the interplay among multiple factors, such as age differences in food preference (43); greater representation of younger adults in the workforce, leaving them less time for hunting and harvesting activities (43); and customs of providing traditional food to an elder as an expression of respect (42).

Between-regional differences of HUFA \( n-3 \) status among Canadian Arctic Inuit are more difficult to interpret. When comparing regions, it is important to recognize that market food choices – but not market food, per se – influence fatty acid profiles (5). Moreover, traditional foods are harvested locally and nutrient concentration of traditional foods from the same species could vary by geographic locations. Additionally, household economy varies between regions, which could also influence market food choices.

Interestingly, the association between HUFA \( n-3 \) and age in the Central Arctic regions of Baffin and Kivalliq was much stronger than that in other Arctic regions. The reasons for the latter observation are not clear. Among the Ganasan of Siberia, Russia, there was no age-related association with \( n-3 \) and \( n-6 \) levels. The Ganasan population was suggested to have adapted to a stable dietary pattern, as their “acculturation” process had already been completed (14). Coincidentally or not, according to the 2006 Canada census, Baffin and Kivalliq are the 2 regions that reported the highest proportion of people speaking non-official languages (presumably Inuit traditional languages) at home rather than English: 65% and 60%, respectively (44). The proportion of homes that spoke a non-official language was only 24% in Baker Lake, 14% in Kitikmeot and as low as 2–3% in Inuvik and Aklavik (44). Similarly, in our survey, a large proportion of Baffin Inuit and Kivalliq Inuit reported to speak Inuit languages only at home, in contrast to only a minority of Inuit in Kitikmeot, ISR and Nunatsiavut. Language is the core of a culture. The predominant and primary language spoken at home likely reflects the degree of western influence and could also be related to traditional food-harvesting activities, consumption and fatty acid status. The above conclusion was supported by the observation from the current study, in that higher levels of HUFA \( n-3 \) were found among Inuit who only spoke Inuit language at home than among Inuit who spoke English or French at home.

Data from the IPY Inuit Health Survey strongly
suggests that Inuit foods that are rich in HUFA n-3 are being replaced by low-quality market foods or other local foods with inferior HUFA n-3 levels. These trends are particularly evident in inter-generational differences and the difference between inland and coastal communities. Consequently, a deteriorating fatty acid profile, characterized as a reduced protective factor (HUFA n-3) and elevated detrimental factors (SFA and TFA), is occurring among Inuit, particularly the young and those living in inland communities.

Our data confirms that obesity is prevalent among Canadian Arctic Inuit. In line with a recently published study conducted among the Cree of James Bay (20), and other human observational studies (45–47) and animal experiments (48,49), an inverse relationship was observed between adiposity and Δ5 (waist: r = -0.162, p<0.0001, adjust for age, data not shown), a critical enzyme in the biosynthesis of HUFA. Obesity is also related to insulin resistance, whose inhibition on Δ5 has been well-documented in the literature (50). Thus, obesity among Inuit could reduce biosynthesis of long-chain fatty acids and thereby exacerbate the effects of reduced n-3 intake associated with dietary transition. In the current study, no significant difference was observed between obese and non-obese participants, but non-obese Inuit were younger than obese Inuit. (For non-obese and obese Inuit, their ages were 41.13 yr ±15.43 and 44.40 yr ±14.81 yr respectively, p<0.05; after age adjustment, their HUFA n-3 levels were 5.54 ±0.09 % and 5.48 yr ±0.12 % respectively, though the above difference was not statistically significant [data not shown]). Furthermore, a hypothesized genetic impairment in Δ5 activity was proposed by Gibson and Sinclair (51). A few studies among Canadian Central Arctic Inuit, Canadian west-coastal Inuit and Greenland Inuit also reported similar observations, which were not explained by these populations’ diets (17,52,53). While further research is warranted, it can be hypothesized that dietary transition compounded by a high prevalence of obesity among Inuit could eventually increase disease burden in this population.

There are a few limitations of the current study. As a cross-sectional survey, no causality can be established from the observed associations. Moreover, there were no data available at the time of data analysis and manuscript drafting about the absolute calorie intake of food items consumed – nor about insulin, which is an important regulator of Δ5. Also, compositional analysis of meal samples is recommended in future studies, which could provide a more accurate assessment of regional differences than dietary studies alone. Furthermore, comparison of the composition of meals collected over time could help in the evaluation of temporal changes in diet. Additionally, the fatty acids in the erythrocyte membranes are under the control of both genetic and environmental factors: consumption, assimilation and absorption in the gastrointestinal tract; β-oxidation, synthesis, elongation and desaturation in tissues; redistribution in tissues; and incorporation into the bio-membrane, though red blood cell HUFA respond to differences in dietary intake more so than saturated fatty acids do (23).

According to the best knowledge of the authors, the present study is the first to describe the fatty acid composition of erythrocyte membranes in Inuit across the Canadian Arctic. In contrast to popular perceptions of a homogeneous population, considerable differences in fatty acid profiles were observed among Canadian Inuit, reflective of the heterogeneous dietary intake patterns between regions and generations. The current study provides additional evidence of dietary transition among Arctic Inuit, which may unfortunately exacerbate their chronic disease risk.
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REFERENCES
1. Gracey M, King M. Indigenous health part 1: determinants and disease patterns. Lancet 2009;374(9683):65–75.
2. Young TK, Szatmary EJE, Evers S, Wheatley B. Geographical distribution of diabetes among the native population of Canada: a national survey. Soc Sci Med 1990;31(2):129–139.
3. Kjaergaard M, Andersen S, Holten M, Mulvad G, Kjaergaard J. Low occurrence of ischemic heart disease among Inuit around 1963 suggested from ECG among 1851 East Greenland Inuit. Atherosclerosis 2009;203(2):599–603.
4. Friborg JT, Melbye M. Cancer patterns in Inuit populations. Lancet Oncol 2009;9(9):892–900.
5. Kuhnlein HV, Receveur O. Unique patterns of dietary adequacy in three cultures of Canadian Arctic Indigenous peoples. Public Health Nutr 2008;11(4):349–360.
6. Dewailly E, Blanchet C, Lemieux S, Sauge L, Gingras S, Ayotte P, et al. n-3 Fatty acids and cardiovascular disease risk factors among the Inuit of Nunavik. Am J Clin Nutr 2001;74(4):464–473.
7. Counil E, Julien P, Lamarche B, Chateau-Degat ML, Ferreyra F. Nutritional food use affects diet quality for adult Dene/Me Pei in 16 communities of the Canadian Northwest Territories. J Nutr 1999;129(1):217–218.
8. Kuhnlein HV, Receveur O, Soueida R, Egeland GM. Arctic Indigenous peoples experience the nutrition transition with changing dietary patterns and obesity. J Nutr 2004;134(6):1447–1453.
9. Kuhnlein HV, Soueida R, Receveur O. Dietary nutrient profiles of Canadian Baffin Island Inuit differ by food source, season, and age. J Am Diet Assoc 1996;96(2):155–162.
10. Blanchet C, Dewailly E, Ayotte P, Bruneau S, Receveur O, Holub BJ. Contribution of selected traditional and market foods to the diet of Nunavik Inuit women. Can J Diet Pract Res 2000;61(2):50–59.
11. Egeland GM, Bert P, Soueida R, Arbour LT, Receveur O, Kuhnlein HV. Age differences in vitamin A intake among Canadian Inuit. Can J Public Health 2004;95(6):465–469.
12. Deucht B, Dyerberg J, Pedersen HS, Aschlund E, Hansen JC. Traditional and modern Greenlandic food – dietary composition, nutrients and contaminants. Sci Total Environ 2007;384(1–3):106–119.
13. Baylin A, Kim MK, Donovan-Palmer A, Siles X, Dougherty L, Tocco R, et al. Fasting whole blood as a biomarker of essential fatty acid intake in epidemiologic studies: comparison with adipose tissue and plasma. Am J Epidemiol 2005;162(4):373–381.
14. Rode A, Shephard RJ, Vloshinsky PE, Kukis A, Plasma fatty acid profiles of Canadian Inuit and Siberian Greenlandic Arctic Med Res 1995;54(1):10–20.
15. Counil E, Dewailly E, Bjerringaard P, Julien P. Trans-polar-fat: all Inuit are not equal. Br J Nutr 2008;101:1–4.
16. Egeland GM, Charbonneau-Roberts G, Kuluguqutj J, Kilabuk J, Okalik L, Soueida R, et al. Chapter 1: Back to the future: using traditional food and knowledge to promote a healthy future among Inuit. In: Kuhnlein HV, Erasmus B, Spigeliski D, editors. Indigenous peoples’ food system: the many dimensions of culture, diversity and environment for nutrition and health. Rome: Food and Agriculture Organization of the United Nations, Centre for Indigenous Peoples’ Nutrition and Environment; 2009. p. 9–22.
17. Young TK, Gerrard JM, O’Neil JD. Plasma phospholipid fatty acids in the central Canadian Arctic: biocultural explanations for ethnic differences. Am J Phys Anthropol 1999;109(1):9–18.
18. Kuhnlein HV, Receveur O. Dietary change and traditional food systems of Indigenous peoples. Annu Rev Nutr 1996;16:417–442.
19. Willows ND. Determinants of healthy eating in Aboriginal peoples in Canada: the current state of knowledge and research gaps. Can J Public Health 2005;96(Suppl 3):S36–S41.
20. Zhou YE, Kubow S, Dewailly E, Julien P, Egeland GM. Decreased activity of desaturase 5 in association with obesity and insulin resistance aggravates declining long-chain n-3 fatty acid status in Cree undergoing dietary transition. Br J Nutr 2009;102(6):888–894.
21. Whiting SJ, Mackenzie ML. Assessing the changing diet of Indigenous peoples. Nutr Rev 1998;56(8):248–250.
22. Receveur O, Boulay M, Kuhnlein HV. Decreasing traditional food use affects diet quality for adult Dene/Metis in 16 communities of the Canadian Northwest Territories. J Nutr 1999;127(1):217–218.
23. Poppitt SD, Kilmartin P, Butler P, Keogh GF. Assessment of erythrocyte phospholipid fatty acid composition as a biomarker for dietary MUFA, PUFA or saturated fatty acid intake in a controlled cross-over intervention trial. Lipids Health Dis 2005;4:30.
24. Harris WS, Miller M, Tighé AP, Davidson MH, Schaefer EJ. Omega-3 fatty acids and coronary heart disease risk: clinical and mechanistic perspective. Atherosclerosis 2008;197(1):12–24.
25. Health Canada. Canadian guidelines for body weight classification in adults. Ottawa: Health Canada; 2003 [cited 2009 Dec 18]. Available from: http://www.hc-sc.gc.ca/fn-an/alt_formats/hpfb-dgpsa/pdf/nutrition/weight_book-livres_des poids-eng.pdf.
26. Egeland GM, Cao Z, Young TK. Hypertriglyceridemic-waist phenotype and glucose intolerance among Canadian Inuit; the International Polar Year Inuit Health Survey for Adults 2007–2008. CMAJ 2011;183(9):E553–558.
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27. Stark KD, Holub BJ. Differential eicosapentaenoic acid elevations and altered cardiovascular disease risk factor responses after supplementation with docosahexaenoic acid in postmenopausal women receiving and not receiving hormone replacement therapy. Am J Clin Nutr 2004;79(5):765–773.

28. Folch J, Lees M, Sloane Stanley GH. A simple method for the isolation and purification of total lipides from animal tissues. J Biol Chem 1957;226(1):497–509.

29. Morrison WR, Smith LM. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride – methanol. J Lipid Res 1964;5(4):600–608.

30. Duncan D, Johnson R, Molnar B, Azrael D. Association between neighborhood safety and overweight status among urban adolescents. BMC Public Health 2009;9(1):289.

31. Simopoulos AP. The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. Exp Biol Med 2008;233(6):674–688.

32. Kuhnlein HV, Chan HM, Leggee D, Barthe V. Macronutrient, mineral and fatty acid composition of Canadian Arctic traditional food. J Food Compos Anal 2002;15(5):545–566.

33. Innis SM, Kuhnlein HV. The fatty acid composition of Northern-Canadian marine and terrestrial mammals. Acta Med Scand 1987;222(2):105–109.

34. Appavoo DM, Kubow S, Kuhnlein HV. Lipid composition of indigenous foods eaten by the Sahtu (Hareskin) Dene-Metis of the Northwest Territories. J Food Compos Anal 1991;4(2):107–119.

35. Astorg P, Arnault N, Czerneckow S, Noisette N, Galan P, Hercberg S. Dietary intakes and food sources of n-6 and n-3 PUFA in French adult men and women. Lipids 2004;39(6):527–535.

36. Brown AJ, Pang E, Roberts DC. Erythrocyte eicosapentaenoic acid versus docosahexaenoic acid in postmenopausal women receiving and not receiving hormone replacement therapy. Am J Clin Nutr 2004;79(5):765–773.

37. United States Department of Agriculture. Search the US National Nutrient Database for Standard Reference. United States Department of Agriculture, Agricultural Research Service. Nutrient Data Laboratory [cited 2009 Dec 13]. Available from: http://www.nal.usda.gov/ fnic/foodcomp/search/.

38. Health Canada. Food and Nutrition, Nutrient Data. Ottawa: Health Canada; 2010 [cited 2011 Sept 6]. Available from: http://www.hc-sc.gc.ca/fn-an/nutrition/fiche-nutri-data/index-eng.php.

39. Government of Nunavut, Nunavut Communities. Iqaluit: Government of Nunavut [cited 2009 August 21]. Available from: http://www.gov.nu.ca/English/about/.

40. Town of Inuvik. Inuvik: Town of Inuvik; 2010 [cited 2011 Sept 6]. Available from: http://www.inuvik.ca.

41. Inuvialuit Regional Corporation. Inuvialuit Regional Corp; 2011 [cited 2011 Sept 6]. Available from: http://www.irc.inuvialuit.com/.

42. Wein EE, Freeman MM, Makus JC. Preliminary assessment of nutrients in daily diets of a sample of Belcher Island Inuit adults. Int J Circumpolar Health 1998;57(Suppl 1):205–210.

43. Wein EE, Milton MR, Freeman MMR, Makus JC. Use of an preference for traditional foods among the Belcher Island (NWT) Inuit. Arctic 1996;49(3):256–264.

44. Statistics Canada. 2006 Community Profiles. Ottawa: Statistics Canada; 2007 [cited 2009 Oct 28]. Available from: http://www12.statcan.gc.ca/census-recensement/index-eng.cfm.

45. Warenjo E, Ohrvall M, Vessby B. Fatty acid composition and estimated desaturase activities are associated with obesity and lifestyle variables in men and women. Nutr Metab Cardiovasc Dis 2006;16(2):128–136.

46. Decsi T, Molnar D, Koletzko B. Long-chain polyunsaturated fatty acids in plasma lipids of obese children. Lipids 1996;31(3):305–311.

47. Pan DA, Lillioja S, Milner MR, Kriketos AD, Baur LA, Bogardus C, et al. Skeletal muscle membrane lipid composition is related to adiposity and insulin action. J Clin Invest 1995;96(6):2802–2808.

48. Blond JP, Henchiri C, Bezard J, Delta 6 and delta 5 desaturase activities in liver from obese Zucker rats at different ages. Lipids 1989;24(5):389–395.

49. Cunnane SC, Manku MS, Horrobin DF. Abnormal essential fatty acid composition of tissue lipids in genetically diabetic mice is partially corrected by dietary linoleic and gamma-linolenic acids. Br J Nutr 1985;53(3):449–458.

50. Vessby B, Gustafsson IB, Tengblad S, Boberg M, Andersson A. Desaturation and elongation of fatty acids and insulin action. Ann NY Acad Sci 2002;967:183–195.

51. Gibson RA, Sinclair AJ. Are Eskimos obligate carnivores? Lancet 1981;1(8229):1100.

52. Stark KD, Mulvad G, Pedersen HS, Park EJ, Dewailly E, Holub BJ. Fatty acid compositions of serum phospholipids of postmenopausal women: a comparison between Greenland Inuit and Canadians before and after supplementation with fish oil. Nutrition 2002;18(7–8):627–630.

53. Bates C, van Dam C, Horrobin DF, Morse N, Huang YS, Manku MS. Plasma essential fatty acids in pure and mixed race American Indians on and off a diet exceptionally rich in salmon. Prostaglandins Leukot Med 1985;17(1):77–84.