Changes in iodine excretion in 50–69-y-old denizens of an Arctic society in transition and iodine excretion as a biomarker of the frequency of consumption of traditional Inuit foods

Stig Andersen, Bodil Hvingel, Kent Kleinschmidt, Torben Jørgensen, and Peter Laurberg

ABSTRACT

Background: Iodine intake in Greenland has been hypothesized to exceed 10 times the recommended amount. The transition from a traditional Arctic society may change the iodine intake, but no field studies have been performed.

Objective: We aimed to ascertain iodine intakes, factors affecting iodine intake in circumpolar populations, and the usefulness of urinary iodine excretion as a biomarker for validation of Inuit food-frequency questionnaires.

Design: Data were collected in a cohort study of 4 Greenland populations: Inuit living in the capital city, the major town, and settlements in East Greenland and non-Inuit. Supplement use and lifestyle factors were evaluated with questionnaires, and dietary habits were ascertained with a food-frequency questionnaire. Iodine was measured in spot urine samples.

Results: One percent of the population of Greenland was invited, and the participation rate was 95%. Less than 5% of Inuit but 55% of non-Inuit had urinary iodine excretion < 50 μg/24 h. Median urinary iodine excretion declined with the degree of decrease in the traditional lifestyle: it was 198, 195, 147, and 58 μg/24 h among Inuit in settlements, town, and city and in non-Inuit, respectively (P < 0.001). Participants were divided into diet groups calculated from Inuit food frequency. Iodine excretion decreased with increasing intake of imported foods (P < 0.001). In regression models, type of diet and the subject’s lifestyle, sex, weight, ethnicity, and intake of iodine-containing supplements affected urinary iodine excretion.

Conclusions: Circumpolar non-Inuit are at risk of iodine deficiency. Departure from the traditional Inuit diet lowers iodine intake, which should be monitored in Arctic societies. Urinary iodine excretion may be a useful biomarker of traditional Inuit food frequency. Am J Clin Nutr 2005;81:656–63.

KEY WORDS Diet, food-frequency questionnaire, biomarker, iodine, Inuit, lifestyle changes, Westernization, Arctic, Greenland, cohort study

INTRODUCTION

Iodine intake from the natural diet is low in most populations studied, and iodine deficiency disorders have been reported on all continents. Iodine deficiency may cause a wide spectrum of diseases (1, 2), but it can be prevented by iodine supplementation (3). A high iodine intake, however, also may cause disease (4, 5). Accordingly, the World Health Organization, the United Nations Children’s Fund, and the International Council for Control of Iodine Deficiency Disorders have recommended daily iodine intakes of 150 μg for adults and 200 μg for pregnant and lactating women and monitoring of the iodine intake of all populations (6).

The circumpolar Inuit make up one of the few populations considered to have a high iodine intake (7, 8), which is due to a high content of marine food items in the traditional Inuit diet (9–11). The suggestion of excessive iodine intake among Inuit (8) was, however, based on assumptions because no field study was conducted.

We previously measured the iodine content of traditional Inuit food items (12) and found it not to be excessive but clearly higher than that of terrestrial and imported food items. Thus, it may be hypothesized that urinary iodine excretion would be a useful biomarker of Inuit dietary habits. This may prove valuable because of limitations of previously used biomarkers (13).

Danish authorities kept Greenland inaccessible until around 1960. The subsequent transition of Greenlandic society has occurred at different paces in different parts of the country (14), and settlements and towns present today at different degrees of Westernization. In parallel, the Inuit diet has decreased in importance, and the intake of imported food items with a low iodine content (15) has increased (14, 16, 17).

We studied dietary habits and the intakes of both imported foods and Inuit foods as evaluated by a questionnaire and by measuring urinary iodine excretion in subjects living in the city of Nuuk, which is in West Greenland, and in the rural Ammassalik district, which is in East Greenland. We evaluated the effect of a number of factors on iodine intake as estimated by urinary iodine excretion and studied iodine excretion as a possible biomarker of the frequency of consumption of traditional Inuit foods.

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Tasiilaq is the main town of the Ammassalik district, which contains settlements with
limited selection and 5 small shops. Each of the settlements has
one store with a limited selection that depends on access by sea
and air. The capital city, town, and settlements are all situated on
fjords, which provide access to the sea.

Subjects
Participants were 50–69-y-old men and women, Greenlanders (all Inuit) and non-Greenlanders (all white). Subjects in this age range were selected to obtain a valid representation of the different steps in the transition of Greenlandic society because that group is more homogeneous with respective to changes in lifestyle (13) and tends to have a higher participation rate than younger subjects. We included persons who were selected and confirmed to be living at the address registered with the National Civil Registration System. The places selected for investigation were the city of Nuuk, the town of Tasiilaq, and the settlements of Tiniteqilaaq, Sermiligaaq, Kulusuk, and Kuummiut in the Ammassalik district (Table 1). For practical reasons, settlements with ≤15 inhabitants in the selected age group were not included. In Nuuk, names and addresses were obtained from the hospital registration system. A random sample of 480 (25% of the total population aged 50–69 y) was selected. The hospital registration system had not been regularly updated, and, for the investigation in the Ammassalik district, names and addresses were obtained from the National Civil Registration System in which every person living in Denmark, the Faroe Islands, and Greenland is registered.

Ethical approval by the Commission for Scientific Research in Greenland was obtained before the beginning of this study. All subjects gave informed written consent in Danish or Greenlandic by participant choice.

Investigational procedures
A letter of invitation was delivered to each subject by the local hospital porter or the nursing station attendant. Nonresponders were invited 3 times. The investigation took place at the local hospital or nursing station or, by request, at home visits. A physical examination performed by one of the investigating doctors (SA, PL, or BH) included height without shoes, weight in indoor clothing, and any major disabilities. Participants were interviewed by an interpreter or by one of the investigational physicians, who completed the questionnaire in either Danish or Greenlandic, as appropriate for the subject. Information on age and sex was obtained from the National Civil Registration System. Information on lifestyle patterns and dietary habits was obtained by using questionnaires. Questions were asked as written in the questionnaires. The same interpreter was used in Nuuk, Tasiilaq, and all settlements.

Dietary habits
An interview-based food-frequency questionnaire (FFQ) was used to assess the dietary habits. It included 14 food items, of which 7 were traditional Inuit items (ie, seal, whale, wild fowl, fish, reindeer, musk ox, and hare), and 7 were imported items (ie, cooked meals, potatoes, vegetables, butter, cheese, eggs, and fresh fruit). For each food item, 6 frequency categories were given, ranging from never to daily. Each item was given a frequency score calculated as the average number of days per month it was ingested (13): daily intake = 30.4, 4–6 times/wk = 21.7, 1–3 times/wk = 8.7, 2–3 times/mo = 2.5, 1 time/mo = 1, and...

TABLE 1
Participant selection and inclusion

<table>
<thead>
<tr>
<th>Cohort selected</th>
<th>No contact at the address provided</th>
<th>Invited</th>
<th>Nonattenders</th>
<th>Investigated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuuk</td>
<td>12 909</td>
<td>920</td>
<td>255</td>
<td>225</td>
</tr>
<tr>
<td>Tasiilaq</td>
<td>1724</td>
<td>197</td>
<td>13</td>
<td>184</td>
</tr>
<tr>
<td>Settlements</td>
<td>1093</td>
<td>161</td>
<td>9</td>
<td>152</td>
</tr>
<tr>
<td>Total</td>
<td>838</td>
<td></td>
<td>561</td>
<td></td>
</tr>
</tbody>
</table>

1 Nuuk is the capital of Greenland and is situated on the relatively more populated west coast of Greenland.
2 Selected at random from the hospital register.
3 The hospital register was not updated for years, and some persons had died or moved.
4 Tasiilaq is the main town of the Ammassalik district, in sparsely populated East Greenland.
5 Names and addresses were obtained from the National Civil Registration System in which every person living in Denmark, the Faroe Islands, and Greenland is registered.
6 Some persons had moved or died, but were still in the National Civil Registration System because of late reporting.
7 Only settlements in the Ammassalik district with >15 inhabitants in the selected age group (50–69 y) were included in the study: Tiniteqilaaq, n = 19; Sermiligaaq, n = 28; Kulusuk, n = 52; and Kuummiut; n = 53.

The Ammassalik district (65.35N 38.00W) of East Greenland was isolated until 1884 and is now a modern city with access to a wide variety of food items, including fast food, Italian and Thai food, and carry-out food, that are supplementary to the traditional Greenlandic food items. In addition, a wide variety of food items imported from Denmark are available in stores.

The Ammassalik district (65.35N 38.00W) of East Greenland was isolated until 1884 and is now a modern city with access to a wide variety of food items, including fast food, Italian and Thai food, and carry-out food, that are supplementary to the traditional Greenlandic food items. In addition, a wide variety of food items imported from Denmark are available in stores.
never = 0 d/mo. Inuit food items were scored positively, and imported food items were scored negatively. Frequency scores for all food items consumed by each participant were added, and the participants were placed into 1 of 5 diet groups according to a scale on which a score of 100% represented a totally Inuit diet and a score of 0% represented a diet completely made up of imported food. Diet group 1 had Inuit food item scores of >80%, diet group 2 had scores of 60–80%, diet group 3 had scores of 40–60%, diet group 4 had scores of 20–40%, and diet group 5 had scores of <20%.

Dietary habits were validated from 2 cross-check questions: 1) “How many days per week is your main meal from Greenlandic food items?” and 2) “How often do you eat Greenlandic food items at different times of the year?” The same 6 frequency categories were used for each season.

Dairy intake was calculated by the average number of days per month that milk, butter, or cheese was ingested (13), and scores from the 3 dairy products were summed into dairy unit scores. A score of 100% indicated daily intake of all 3 dairy products, a score of 66% indicated an average intake of 20 times/mo, and a score of 33% indicated an average intake of 10 times/mo. Participants were split into 3 groups on the basis of their scores: dairy group 1 had scores of >66%, dairy group 2 had scores of 33–66%, and dairy group 3 had scores of <33%.

The intake of iodine-containing vitamins or mineral supplements was evaluated by asking the frequency of intake. Supplements were presented to one of the investigational doctors for evaluation of iodine content. If no supplement was presented, the iodine content was evaluated on the basis of the interview. From the combined information, participants were divided into 2 groups by whether they took iodine supplements or not. Salt is used for cooking in Greenland, but salt was not iodized at the time of the study.

Urine collection and analysis

At the visit, a spot urine sample was collected from all 535 participants. A subgroup of 36 participants, representing 25% of the Inuit participating in the investigation in Nuuk, was randomly selected for a subsequent 24-h urine collection. All participants were visited at home between 1200 and 1600 by one of the investigational doctors (SA). First, a spot urine sample was collected, and then a 24-h urine collection was initiated after careful instruction. The final urine collection was performed during a second home visit exactly 24 h later. Samples were stored at −20 °C until they were analyzed. One 24-h urine sample was omitted from the calculations because of incomplete collection. The iodine concentrations in the spot urine samples and the 24-h urine samples did not differ significantly (P > 0.1); the median and interquartile range was 75 and 90 µg/L and 75 and 100 µg/L in the spot and 24-h urine samples, respectively, and the difference was 0 and 70 µg/L.

Iodine was determined by using the Sandell-Kolthoff reaction modified according to Wilson and van Zyl (18) as described previously (19, 20). The principle is evaporation and alkaline ashing of the sample, followed by resuspension and measurement of iodine by using spectrophotometric detection of the catalytic role or iodine in the reduction of ceric ammonium sulfate in the presence of arsenious acid. To measure the iodine content, a 1.5-mL sample was used, which gave an analytical sensitivity of 2.0 µg/L. The intraassay CV was 1.5% (>15 µg/L). Recovery of added iodine was >95%. Urinary creatinine was determined by a kinetic Jaffé method (21). The 24-h urinary creatinine excretion measured in Inuit was used to calculate an age-, sex-, and ethnicity-adjusted 24-h urinary iodine excretion in Inuit according to recommendations (22–24).

Creatinine excretion in 50–59- and 60–69-y-old Inuit men and women was 1230 and 1112 mg/24 h and 747 and 641 mg/24 h, respectively. In non-Inuit, this same estimation was based on creatinine excretion in an age- and sex-matched group of white Danes (1445 and 1252 mg/24 h in men and 989 and 871 mg/24 h in women) (25). Thus, urinary iodine excretion was expressed in µg/L, as a ratio of iodine (µg) to creatinine (g), and as estimated 24-h urinary iodine excretion by adjustment of iodine:creatinine for age, sex, and ethnicity (22–24).

Statistical analysis

Results are given as medians, with 25th and 75th percentiles. Urinary iodine excretion in groups was compared by using non-parametric statistics: Mann-Whitney U test for comparison of 2 groups, Kruskal-Wallis test for comparing several groups, and Kendall’s tau for the relation between groups. Wilcoxon’s signed rank test was used to test for difference between iodine in spot urine and 24-h urine samples. For multiple linear regression analysis, urinary iodine excretion data were transformed [ln(x)] because the distribution was positively skewed. Transformation also gave homogeneity of variances [Bartlett’s test: P = 0.8 (diet group), P = 0.6 (participant group)]. Linear regression models were used with transformed estimated 24-h iodine excretion entered as the dependent variable. Independent variables entered were: diet group, participant group, sex, weight, ethnicity, and iodine from supplements. The independent variables included in the model explain 37% of the variation in iodine excretion (R² = 0.37). Random selection of participants in Nuuk was performed by using MEDSTAT software (version 2.12; Astra, Albertslund, Denmark). Data were processed and analyzed using Corel Quattro Pro 8 (version 8.0; Corel Corp, Ottawa, Canada) and SPSS (version 10.0; SPSS Inc, Chicago) software. A P value of <0.05 was considered significant.

RESULTS

Study cohorts

One percent of the population of Greenland was invited. The participation rate was 95%, and there were minor regional differences (Table 1). The characteristics of the study cohorts are given in Table 2. Seven non-Inuit subjects had one parent born in Greenland, and 94 had neither parent born in Greenland. The non-Inuit subjects were skilled laborers from Denmark, and the group included significantly more men than women (P < 0.001, chi-square test). In addition, there were fewer non-Inuit than Inuit in the 60–69-y-old group, and the mean age of the non-Inuit was significantly (men, P = 0.001; women, P = 0.005) lower than that of the Inuit (Table 2) because some non-Inuit leave Greenland when they retire.

The study cohorts represented different stages of Westernization as illustrated by hunting habits: 54% of Inuit men living in settlements, 24% of Inuit men living in the town, 8% of Inuit men living in the city, and 0% of non-Inuit men made their living by hunting.
Intake of iodine-containing supplements

Non-Inuit were more frequent users of iodine-containing vitamin or mineral preparations than were Inuit living in settlements (Table 2). The intake of iodine-containing supplements in Inuit increased with increasing urban residence ($P < 0.001$, Kruskal-Wallis test) in parallel with the decrease in traditional lifestyle.

Urinary iodine excretion

Urinary iodine excretion differed significantly ($P < 0.001$, Kruskal-Wallis test) between participant groups and decreased significantly in parallel with the decrease in the traditional lifestyle ($P < 0.001$; Kendall’s $\tau$ 0.3) (Table 2).

The use of iodine-containing supplements was an important contributor to iodine excretion among populations in Nuuk, where urinary iodine excretion differed significantly between supplement users and nonusers (non-Inuit: $P < 0.001$; Inuit: $P = 0.001$; Mann-Whitney $U$ test). Supplement use did not, however, significantly affect iodine excretion among the population in Nuuk ($P = 0.27$). Accordingly, the use of iodine-containing supplements may compensate for some of the difference in iodine excretion between participant groups (a shift in Kendall’s $\tau$ from 0.33 to 0.30) (Table 2).

Urinary iodine excretion was $< 50 \mu g/24$ h in 55% of samples [43% were $< 50 \mu g/L$, which indicated moderate iodine deficiency (6)] and $< 25 \mu g/24$ h in 20% of samples [9% were $< 20 \mu g/L$, which indicated severe iodine deficiency (6)] from non-Inuit participants not taking iodine-containing supplements (Figure 1), and only 10% of samples were $> 100 \mu g/24$ h [23% were $> 100 \mu g/L$, which indicated no iodine deficiency (6)]. No significant difference was seen between non-Inuit from East and West Greenland ($P = 0.26$).

Inuit had a higher urinary iodine excretion: < 5% of the samples were $< 50 \mu g/24$ h (Figure 1). There were 4% samples with excretion $< 20 \mu g/L$, 25% with excretion $< 50 \mu g/L$, and 50% with excretion $> 100 \mu g/L$, which suggest severe, moderate, and no iodine deficiency, respectively (6). The large dispersion of urinary iodine excretion in Inuit, irrespective of supplement use (Figure 1), was partly due to a difference in urinary iodine excretion between Inuit in Nuuk, Tasiilaq, and the settlements ($P = 0.001$, Kruskal-Wallis test) (Table 2).

Dietary habits

Inuit food frequency as ascertained from cross-check questions correlated well with the FFQ (Kendall’s $\tau$ 0.8, $P < 0.001$). A distinct difference in dietary habits was seen between the population cohorts (Figure 2). Among Inuit in settlements, 93% lived on mainly traditional Greenlandic food items (diet groups 1 and 2). Among Inuit in Tasiilaq and in Nuuk and among non-Inuit, these proportions were 87%, 58%, and 3%, respectively. These findings corresponded to the general difference in lifestyle (14), to the availability of imported food items, and to the frequency at which the main daily meal was made up of items from a person’s own fishing or hunting; the frequency was reported to be 24%, 20%, and 6% among Inuit in settlements, Tasiilaq, and Nuuk and 1% among non-Inuit. No seasonal difference in the frequency of consumption of Inuit foods was reported.

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**TABLE 2**

Characteristics of the 4 participant groups representing different steps in the westernization of Greenlandic society

<table>
<thead>
<tr>
<th></th>
<th>Non-Inuit</th>
<th>Inuit in Nuuk</th>
<th>Inuit in Tasiilaq</th>
<th>Inuit in settlements</th>
<th>$P$ for difference</th>
<th>$P$ for trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of participants ($n$)</td>
<td>101</td>
<td>150</td>
<td>141</td>
<td>143</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taking iodine-containing supplements</td>
<td>24</td>
<td>18</td>
<td>8</td>
<td>3</td>
<td>$&lt;0.001^a$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All ($n$)</td>
<td>80/21</td>
<td>70/80</td>
<td>80/61</td>
<td>79/64</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taking iodine-containing supplements ($n$)</td>
<td>177</td>
<td>7/11</td>
<td>6/2</td>
<td>1/2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age ($y$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>56.0$^a$</td>
<td>58.8</td>
<td>58.6</td>
<td>58.8</td>
<td>$&lt;0.001^a$</td>
<td></td>
</tr>
<tr>
<td>Iodine concentration in urine ((\mu g/L))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>75 (35; 133)$^b$</td>
<td>70 (40; 135)</td>
<td>108 (50; 205)</td>
<td>115 (59; 226)</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Taking iodine-containing supplements</td>
<td>165 (79; 350)</td>
<td>110 (65; 290)</td>
<td>205 (21; 240)</td>
<td>270 (80; 725)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Not taking iodine-containing supplements</td>
<td>60 (30; 95)</td>
<td>70 (40; 130)</td>
<td>105 (50; 205)</td>
<td>115 (55; 215)</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Iodine in urine ((\mu g/g) creatinine)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>73 (49; 128)</td>
<td>120 (81; 187)</td>
<td>175 (110; 278)</td>
<td>172 (110; 330)</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Taking iodine-containing supplements</td>
<td>218 (124; 345)</td>
<td>267 (148; 379)</td>
<td>136 (94; 239)</td>
<td>362 (161; 400)</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>Not taking iodine-containing supplements</td>
<td>66 (41; 89)</td>
<td>111 (79; 168)</td>
<td>176 (110; 279)</td>
<td>171 (107; 319)</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Estimated 24-h iodine excretion ((\mu g/24) h)$^c$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>58 (37; 98)</td>
<td>147 (84; 231)</td>
<td>195 (106; 312)</td>
<td>198 (114; 379)</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Taking iodine-containing supplements</td>
<td>182 (86; 249)</td>
<td>267 (195; 417)</td>
<td>158 (90; 239)</td>
<td>516 (130; 623)</td>
<td>0.041</td>
<td>0.085</td>
</tr>
<tr>
<td>Not taking iodine-containing supplements</td>
<td>49 (29; 70)</td>
<td>134 (82; 219)</td>
<td>196 (106; 333)</td>
<td>195 (114; 373)</td>
<td>$&lt;0.001$</td>
<td>$&lt;0.001$</td>
</tr>
</tbody>
</table>

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1 Test for difference between groups: Kruskal-Wallis test.
2 Test for trend (all increasing): Kendall’s $\tau$.
3 In Inuit: the intake of iodine-containing supplements increased with increasing urban residence.
4 $\tau$ (all such values).
5 Non-Inuit had a lower mean age than did Inuit because some non-Inuit leave Greenland when retiring.
6 Median; 25th and 75th percentiles in parentheses (all such values).
7 Estimated from age-, sex-, and origin-adjusted 24-h creatinine excretion.
Diet and iodine excretion

Estimated 24-h urinary iodine excretion decreased with a decreasing intake of traditional Inuit foods ($P < 0.001$, Kendall’s $\tau = -0.32$) to the point of indicating iodine deficiency in diet groups 4 and 5 (Figure 3). The use of iodine-containing supplements increased urinary iodine excretion in the population by 1, 6, 5, 17, and 15 $\mu$g/24 h in diet groups 1 through 5 to totals of 204, 148, 104, 86, and 58 $\mu$g/24 h, respectively.

Effect on iodine intake

The factors found to have a major effect on estimated 24-h urinary iodine excretion in the multivariate analysis were diet, intake of iodine-containing supplements, lifestyle, sex, and weight (Table 3). These factors explain 37% of the variation in iodine excretion ($R^2 = 0.37$), a proportion that is high, considering the large spontaneous variation in iodine excretion (24, 26).

Milk had no effect on urinary iodine excretion ($P = 0.6$, univariate analysis), but dairy products as a group contributed to the iodine intake ($R^2 = 0.016$, $P = 0.003$; univariate analysis), although the effect was limited (1.6%) and not significant in the multivariate analysis ($P = 0.36$). Nevertheless, the intake was associated with urinary iodine excretion ($P = 0.002$, Kendall’s $\tau = 0.103$) (Figure 4). Seal, whale, and fish intakes were likely to contribute to the iodine intake individually, but they were not considered individually because they were included as part of the overall diet group. Weight was preferred over BMI because weight was a better predictor of urinary iodine excretion (univariate $\beta_{\text{weight}} = -0.31$, $P < 0.001$). Ethnicity could be an important influence on iodine intake ($P < 0.001$, univariate analysis; $P = 0.047$, multivariate analysis), but it was not included because of a high collinearity with lifestyle.

If estimated 24-h urinary iodine excretion was replaced by iodine concentration in spot urine samples as a dependent variable, the degree of explanation of the variation in iodine excretion was only 12% ($R^2 = 0.12$), and the contribution by weight disappeared ($\beta = 0.07$, $P = 0.15$).

DISCUSSION

This is the first field study of iodine nutrition among an Inuit population. Rather than the exceedingly high iodine intake that was anticipated (7, 8), we found that urinary iodine excretion among Inuit living in Greenland indicated mere iodine sufficiency (1–3). The intake of traditional Inuit food items had decreased with increasing Westernization, which lowered the iodine intake among Inuit. In addition, the iodine intake differed significantly between population groups, and 77% of urine samples from non-Inuit living in Greenland had iodine concentrations in the range corresponding to iodine deficiency—ie, $<100 \mu$g/L (6). The intake of iodine-containing supplements was higher among this low iodine intake group. Finally, urinary iodine excretion may serve as a biomarker for validation of Inuit food-frequency questionnaires in Arctic societies.

Iodine intake is determined principally by the diet (27). Marine food items had a major influence on the iodine intake in some populations (28, 29), and Inuit had a very high intake of fish and marine mammals (9–11). Accordingly, the iodine intake among Inuit was hypothesized to be $>10$ times that recommended (8). However, the current study showed that the intake of traditional Inuit food items did not lead to the exceedingly high iodine intake expected but rather caused an iodine excretion of $\approx 200 \mu$g/24 h, which reflected a high-normal iodine intake (6).

Inuit communities undergo profound changes in transitioning from their traditional hunting lifestyle to a modern, Westernized lifestyle (14, 17). We included 4 population groups at 4 different stages of this transition: rural Inuit in remote settlements in East Greenland, small-town Inuit in the main town on the east coast of Greenland, urban Inuit in the capital city, Nuuk, and non-Inuit,
who had the most Westernized lifestyle. The changing lifestyle was associated with decreasing iodine intake, and it may reduce iodine intake in Inuit even to the point of iodine deficiency (6).

Traditional Inuit food items have high contents of contaminants (30–32). Dietary recommendations of a reduced intake of traditional Inuit food items in vulnerable subjects such as pregnant and lactating women (31, 32) are constrained by the socio-cultural and nutritional benefits of these food items (30, 32). Nevertheless, the focus on contaminants in Inuit food items is likely to reduce the intake of traditional Inuit foods and thereby further lower iodine intake in groups that are particularly vulnerable to a low iodine intake.

This study included subjects aged 50–59 y to achieve a valid representation of the different steps in Westernization. The decreasing iodine intake seen with Westernization is of concern, particularly with respect to young women, who are likely to be more Westernized than are the older subjects included here. It is pertinent to include younger women in future studies because the iodine requirements increase during pregnancy and lactation (6), and iodine deficiency may have an effect on fetal brain development (1–3).

Dairy products are major sources of iodine intake in other populations (29, 33). It could be speculated that the decrease in iodine intake among Inuit caused by decreased intake of marine food items may be compensated for by an increased intake of iodine-containing dairy products from an imported diet. We found a trend suggesting an effect of dairy products on iodine excretion, but the contribution was limited and clearly not sufficient to obscure the decrease resulting from the reduced intake of Inuit food items.

**TABLE 3**

Factors affecting the estimated 24-h urinary iodine excretion in regression models

<table>
<thead>
<tr>
<th></th>
<th>Univariate model</th>
<th>Multivariate model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diet</td>
<td>$\beta$</td>
<td>$P$</td>
</tr>
<tr>
<td>Diet group 1</td>
<td>$-0.38$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Diet group 2</td>
<td>$-0.08$</td>
<td>0.06</td>
</tr>
<tr>
<td>Diet group 3</td>
<td>$-0.41$</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Diet group 4</td>
<td>0.41</td>
<td>$&lt;0.001$</td>
</tr>
<tr>
<td>Diet group 5</td>
<td>$-0.31$</td>
<td>$&lt;0.001$</td>
</tr>
</tbody>
</table>

1. $\beta$ (regression coefficients) were decreasing Inuit diet group; iodine supplements, yes or no; increasingly westernized participant group; men/ women; and decreasing weight (kg).
2. The dependent variable entered was estimated 24-h iodine excretion. The independent variables included in the model explain 37% of the variation in iodine excretion ($R^2 = 0.37$).
3. Diet groups were calculated from the frequency of intake of 7 Inuit and 7 imported food items. Diet group 1: 0–20%; diet group 2: 20–40%; diet group 3: 40–60%; diet group 4: 60–80%; diet group 5: >80%.
4. Intake of iodine-containing supplements (yes or no).
5. Represented by participant groups at different levels of westernization: Inuit in settlements, Inuit in town, Inuit in city, and non-Inuit (whites) (as in Table 2).
6. Median estimated 24-h iodine excretion (M/F): Inuit, 120/235 μg; non-Inuit, 48/106 μg.
7. Weight in kg was superior to BMI in predicting iodine excretion (univariate $\beta_{\text{weight}} = -0.31$, $P < 0.001$ compared with $\beta_{\text{BMI}} = -0.07$, $P = 0.15$).
respectively). Iodine excretion showed an increasing trend with increasing group 3 had scores of group 1 had scores of and dairy group 3 had scores of >66% for dairy \( n = 224, 159, \) and \( 114 \) in groups 1–3, respectively. Iodine excretion showed an increasing trend with increasing intake of dairy products \( P = 0.002, \) Kendall’s \( \tau = 0.1)\), but the effect on iodine excretion was limited \( R^2 = 0.016, P = 0.003 \) (univariate analysis); \( P = 0.36 \) (multivariate analysis after correction for dietary habits, lifestyle, sex, and weight).

In other populations, the use of iodine-containing supplements was found to be related more to self-perceived health than to actual iodine intake \( 29,34 \), and it was high even in groups that were not iodine deficient before taking supplements \( 29,34 \). With a relatively high iodine intake among Inuit in Greenland, such a pattern could be of some concern. However, we found that the use of iodine-containing supplements significantly influenced iodine intake only in low-iodine-intake groups.

In multivariate regression models, diet, lifestyle, and iodine intake from supplements were significant determinants of iodine excretion. Together with body weight and sex, these factors may explain 37% of the variation in urinary iodine excretion in the current study, which is a large percentage, considering the high spontaneous variation in urinary iodine excretion \( 24,26 \). Body weight had an effect on 24-h urinary iodine excretion calculated from the concentrations of iodine and creatinine in urine samples. This effect could result from the creatinine correction, because that was not stratified by body weight. When unadjusted urinary iodine concentration was used, the effect of body weight was no longer significant, although the trend was the same. The lack of significance could be due to the greater variance in crude urinary iodine concentration compared with that in the age- and sex-adjusted, creatinine-corrected 24-h iodine excretion \( 24 \). The effect of diet, lifestyle, and supplementation suggests that the groups at risk of iodine deficiency include persons who have a low intake of traditional Inuit food items, persons who do not take iodine-containing supplements, and persons who have a Westernized lifestyle. It remains necessary, however, to identify groups at risk of low iodine intake, and a dietary questionnaire is a compelling short-cut.

FFQs are widely used to obtain data on the intake of foods and nutrients because they are easy to distribute and collect, easy to understand, fast to fill in, and of low cost. Such features may be particularly appealing in the sparsely populated Arctic, where clinical investigations are expensive and may entail undesirable challenges. However, validation of a questionnaire is as important as those other characteristics, and it can be done in several ways \( 13,35–37 \). We applied 2 cross-check questions and used urinary iodine excretion as a biomarker because we have previously found a relatively high content of iodine in Inuit food items \( 12 \) that, in Greenland, are mostly obtained from the sea. The measurement error for the cross-check questions was not independent of the FFQ, but that for urinary iodine excretion was. Even though questions about portion sizes were not included, the dietary classification in this study seemed valid. Thus, an FFQ may provide a convenient short-cut for identifying groups at risk of iodine deficiency in the Arctics, and urinary iodine excretion proved a useful biomarker of Inuit food frequency.

The validity of the current study was enhanced by 3 factors. First, the same interpreter was used in all areas and among all population groups. This ensured equal understanding and interpretation of the questionnaire between regions and between participant groups. Second, the participation rate was high, and, third, the selection of subjects aged 50–69 y was the basis for a valid representation of the different steps in the transition of Greenlandic society, because this group is more homogeneous with respect to changes in lifestyle than are younger groups \( 13 \). However, this cohort study has limitations in evaluating transition because this study represents the first data collection. Proof that differences between population groups in Greenland represent different steps in modernization will have to be obtained from subsequent data collections. Nevertheless, our data are in keeping with other indicators \( 14 \).

Urinary iodine excretion reflects dietary iodine intake in that \( = 90% \) of ingested iodine is excreted in the urine \( 27 \). The iodine concentration in spot urine samples is the reference for delineating low iodine intake in population surveys \( 6 \). Some have suggested the use of iodine/creatinine \( 22,24 \) because that ratio reduces the variation in urinary iodine caused by dilution \( 22,23 \). Applying this ratio introduces the variation of urinary creatinine excretion \( 38,39 \), but that variation can be reduced by comparing homogeneous populations, ie, by stratification \( 23,24 \). Such a step reduces the individual variation in iodine excretion \( 24 \), improves the ability of a single urinary iodine value to predict the true iodine excretion \( 24 \), and gives a more precise estimate of the actual iodine excretion in a person than does the crude urinary iodine concentration \( 23,26 \). Moreover, it predicts thyroid enlargement and volume more accurately does than urinary iodine concentration \( 40 \), and it has been used in several population studies \( 1,2,26,41 \). Finally, the higher \( R^2 \) obtained when using estimated 24-h urinary iodine excretion in this study supports the use of estimated 24-h urinary iodine excretion. We used that value in figures, calculations, and the evaluation of the FFQ, whereas the crude urinary iodine excretion and iodine/creatinine values were retained in Table 2 for comparison with other studies and with the World Health Organization and International Council for Control of Iodine Deficiency Disorder studies \( 6 \).

A single low urinary iodine value does not necessarily indicate iodine deficiency in a person \( 24 \). Still, the variance among non-Inuit was low, and an iodine excretion rate as low as that found in this study correlates with an increased risk of thyroid disease \( 1–3,6 \).

The transition of Arctic societies to a more Westernized lifestyle alters iodine intake, and we recommend that iodine intake be monitored and that Arctic populations at risk of iodine deficiency be followed. We also suggest that future studies include whites and Westernized Inuit, and that an FFQ may guide future clinical investigations to groups at risk. Finally, monitoring is important as Greenland is included in the Danish salt iodization program \( 42 \).
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SA was responsible for the conception and design of the study, raising funds, data collection, analysis and interpretation of data, and writing of the manuscript. BH was responsible for data collection and writing of the manuscript. KK was responsible for the study design, translations and explanations, and techniques to improve Inuit participation rate. TJ was responsible for the study design and manuscript review. PL was responsible for design of the study, raising funds, data collection, analysis of data, interpretation of data, and writing of the manuscript. None of the authors had any personal or financial conflicts of interest.

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