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Published in:
Public Health Nutrition

DOI:
10.1017/S1368980019002799

Publication date:
2020

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Courraud, J., Quist, J. S., Kontopodi, E., Blomberg Jensen, M., Bjerrum, P. J., Helge, J. W., & Sørensen, K. (2020). Dietary habits, metabolic health and vitamin D status in Greenlandic children. *Public Health Nutrition*, *23*(5), 904-913. https://doi.org/10.1017/S1368980019002799

Public Health Nutrition: 23(5), 904–913 doi:10.1017/S1368980019002799

Dietary habits, metabolic health and vitamin D status in Greenlandic children

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Submitted 21 January 2019: Final revision received 14 June 2019: Accepted 19 June 2019: First published online 1 October 2019

Abstract

Objective: To compare the dietary habits of children living in northern villages and in the capital of Greenland, given the reported transition from traditional to westernised diet in adults over recent decades, and to explore the association between consumption of marine mammals and fish (MMF) and the children's metabolic profile and vitamin D status.

Design: Children answered an FFQ encompassing sixty-four individual food types pooled into six food categories. Their pubertal stage, body fat, fitness level, metabolic profile (non-HDL-cholesterol, glycated Hb, insulin, glucose, high-sensitivity C-reactive protein) as well as serum 25-hydroxyvitamin D (25(OH)D) concentration were evaluated.

Setting: Siorapaluk and Qaanaaq (north of Greenland) and Nuuk (west).

Participants: Children aged 6–18 years (n 177).

Results: MMF were most frequently eaten by children from Siorapaluk (mean (SD): 73·4 (14·1) times/month), followed by children from Qaanaaq (37·0 (25·0) times/month), and least often eaten by children from Nuuk (23·7 (24·6) times/month; $P < 0·001$). Children from Qaanaaq consumed 'junk food' more frequently ($P < 0·001$) and fruits and vegetables less frequently ($P < 0·01$) than children from Nuuk. MMF consumption was positively associated with serum 25(OH)D concentration ($P < 0·05$), but the overall prevalence of vitamin D deficiency was high (18 %). No association was found between MMF consumption and metabolic parameters.

Conclusions: The dietary transition and influence of western diets have spread to the north of Greenland and only the most remote place consumed a traditional diet highly based on MMF. We found no strong associations of MMF consumption with metabolic health, but a positive association with vitamin D status.

Keywords
Marine mammals
Fish
Dietary transition
Glycated Hb
Non-HDL-cholesterol
High-sensitivity C-reactive protein
PUFA

The incidence of metabolic disorders is increasing dramatically worldwide, and metabolic risk is closely related to lifestyle and diet[1]. In Greenland, the hunting-based traditional lifestyle and diet have changed progressively under the influence of sedentary behaviours and 'fast-food-like' western diets[2]. Indeed, the benefits of eating traditional foods, for example marine mammals and fish (MMF), have been stressed for several decades, especially in relation to their content of vitamin D and long-chain PUFA, including n-3 fatty acids[3–6]. Long-chain n-3 fatty acids are recognised for their protective role in CHD[7] and inflammation[8]. A high intake results in decreased non-HDL-cholesterol (non-HDL-C) levels[9], which is predictive for an attenuation of CVD[10]. However, their presumable impact on glycaemic control remains unclarified. Fish oil supplementation has been shown to increase insulin sensitivity in people with metabolic disorders[11], while α-linolenic acid supplementation failed to improve glycaemic control in diabetic patients with overweight or obesity[12].

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Albeit there are positive health effects, MMF also contain contaminants. Persistent organic pollutants and heavy metals have been reported in these traditional foods, forcing the authorities to adjust the nutritional guidelines[13,14]. In 2006, it was recommended not to increase 'the consumption of local products beyond the present level, until the level of contaminants is reduced to a safer level'[13] and it is now recommended to alternate 'between marine and terrestrial animals'[14]. In the 1970s–1990s, Arctic populations were characterised by having healthy lipid profiles and low risk of developing CVD due to their consumption of MMF[3,15,16]. Yet, they now suffer from a dramatic increase in obesity and impaired glucose tolerance[17]. Even though symptoms usually occur in adult life, some alterations can be detected already during childhood[18]. We have previously shown that Greenlandic Inuit children living in northern villages have a more favourable metabolic profile and higher aerobic fitness than those living in the capital Nuuk[19]. The dietary habits of Greenlandic children may partly explain the differences in metabolic profiles. There are, however, very few studies of the diet of Greenlandic children, and none that encompasses all dietary categories. Another specificity of the traditional diet based on MMF is its reported high content of vitamin D that Greenlanders rely on[20]. Indeed, vitamin D status also depends on non-dietary aspects of lifestyle, i.e. exposure to sunlight[5], which is limited at these latitudes[21]. Consumption of marine mammals has been shown to be positively associated with serum 25-hydroxyvitamin D (25(OH)D) concentration in 50–69-year-old Inuit[20], and negatively associated with inflammatory markers in the same cohort[22], but this has not been studied in children.

Therefore, we first compared the dietary habits of Greenlandic children living in two northern villages and in the capital, Nuuk. We then explored the associations between the children's MMF consumption and their metabolic health and vitamin D status. We hypothesised that children living in northern rural Greenland would have a diet richer in MMF compared with children from the capital, Nuuk, who would have a more westernised diet with higher intake of 'junk food'. Based on results from studies in adults, we also hypothesised that higher consumption of MMF would be associated with more favourable glycaemic control, lipid profile, inflammation, fitness level and serum 25(OH)D concentration in these children.

Methods

Study population

This work is an ancillary study of a cross-sectional study that has already been published (published data included cardiovascular fitness and metabolic risk factors of the children)[19,23]. While the original publications focused on differences between children from the northern villages of Greenland (pooled together) and Nuuk, and compared them with an aged-matched Danish cohort (analyses performed independently for boys and girls), the present study's primary aim was to compare the dietary habits of the children living in Greenland (no comparison with Denmark), distinguishing the two northern villages. Our secondary aim was to study the potential associations between diet and metabolic profile and vitamin D status. As our primary aim resulted in a slightly different cohort than the original study previously published (dietary data available in a subset of children, two distinct northern villages and no gender distinction), we also compared the actual characteristics of our cohort across areas of residence. One hundred and ninety-seven Inuit children (aged 5·7–18·2 years) were recruited in two remote places in the north of Greenland called Siorapaluk (latitude about 77·8°N, approximately eighty inhabitants, all the children present were recruited) and Qaanaaq (latitude about 77·5°N, approximately 650 inhabitants), and in the capital, Nuuk (latitude about 64·2°N, approximately 15 000 inhabitants), in the west of Greenland (see online supplementary material, Supplemental Fig. S1)[24]. Twenty children were excluded due to missing data, leaving 177 children for final analyses: eighty girls (mean age 11·3 (SD 2·3) years) and ninety-seven boys (mean age 11·8 (SD 3·0) years). All tests were conducted in August, in the north in 2007 and in Nuuk in 2008. Informed, written consent was obtained from all children and their parents and the study was conducted according to the Declaration of Helsinki. The study protocols were approved by the ethics committee of the Capital Region of Denmark (J.no. KF 01 282214, KF 11 2006-2033) and the Commission for Scientific Research in Greenland (J.no. 505-117).

Diet assessment

Food habits were assessed using an FFQ[25,26] with modifications to obtain the consumption frequencies of sixty-four individual food types (see online supplementary material, Supplemental Table S1) in times per month (maximum 1 time/d for each food type). The questionnaire was available in Danish and Greenlandic languages (validated translation[26]) and printed copies were filled in with parental help. Invited replies included a number of times per day, week or month, with a maximum of 1 time/d and 28 d/month for homogeneity and comparability purposes. A value of 4 times/month is therefore equivalent to once per week, while a value of 28 times/month is equivalent to once per day. Food portion sizes were to be recorded, but because of too many missing values, the data could not be used to calculate food amounts reliably. Therefore, the results were limited to frequencies of consumption. The food types were pooled into six mutually exclusive categories: marine mammals and fish (MMF: seal, whale, various fish and seafood, etc.); meat and eggs (MEg: reindeer, beef, pork, poultry, eggs, etc.); dairy products (DaP, excluding ice cream); non-starchy vegetables and fruits (VegFr: carrot, cabbage, apple, orange, etc.); complex carbohydrates (CCarb: potatoes, bread, cereals, etc.); and 'junk food' (JunkF: ice cream, sweets, pizza, fries, soda, etc.). Each category containing from four to fifteen food types, their consumption frequency can sum up to more than 28 times/month. To study the effect of MMF consumption on metabolic variables and vitamin D status, MMF consumption was divided in four consumption profiles: <4, 4–<28, 28–<56 and >56 times/month.

Anthropometric and biochemical measurements

Pubertal stage was assessed by medical doctors according to the Tanner classification[27]. Body fat (%) was assessed using skinfold thickness and calculated based on a formula based on Danish children[28]. For logistical reasons, VO_{2max} could not be directly measured for all participants as previously described[28]. Therefore, after linear regression analysis from the maximal power output (using a cycle ergometer) from participants with valid VO_{2max} measurements[28], estimated VO_{2max} was calculated using the following formulas:

$$VO_{2max}\text{ boys} = (\text{maximal power output} \times 12{\cdot}2) + 368{\cdot}9$$
$$VO_{2max}\text{ girls} = (\text{maximal power output} \times 12{\cdot}4) + 303{\cdot}9$$

Blood samples were collected between 08.00 and 09.00 hours after an overnight fast. Plasma glucose, insulin, lipid profile and high-sensitivity C-reactive protein (hs-CRP) were measured using conventional assays on automated Roche Modular Analytics Serum Work Area modules (Roche Diagnostics, Mannheim Germany) as previously described[28]. Lipid profile included total cholesterol, HDL-C, LDL-cholesterol, TAG, apoA1 and apoB, and non-HDL-C (total cholesterol minus HDL-C[10]). High non-HDL-C level was defined as non-HDL-C > 145 mg/dl (>3·75 mmol/l)[29]. Glycated Hb (HbA1c) was analysed in fingertip capillary blood using a Bayer DCA 2000+ analyser (Bayer Healthcare, Elkart, IN, USA). Leptin and adiponectin were determined using high-sensitivity human ELISA kits (leptin: Human Leptin Immunoassay, R&D Systems, Minneapolis, MN, USA; adiponectin: Human ADIPONECTIN RIA-kit, Millipore, St. Charles, MI, USA) as previously described[23].

Serum 25(OH)D (including both ergocalciferol (vitamin D_2) and cholecalciferol (vitamin D_3)) was measured in blood samples (analysed as single determinations in random order) using isotope dilution–liquid chromatography–tandem mass spectrometry (LC-MS/MS) as described before[30]. The standard reference material vitamin D in human serum (SRM 972) from the National Institute of Standards and Technology[31] was used as the primary calibrator. The analytical quality of the 25(OH)D assay was measured by Vitamin D External Quality Assessment Scheme certification. Interassay CV for our methods were 2·2 and 2·8 % at 30 and 180 nmol/l, respectively, for $25(OH)D_3$ and 7·6 and 4·6 % at 43 and 150 nmol/l, respectively, for $25(OH)D_2$. Serum 25(OH)D insufficiency and deficiency were defined as serum 25(OH)D concentration below 50·0 and 25·0 nmol/l, respectively[32]. No information regarding vitamin D supplementation was obtained.

Statistical methods

Metabolic variables of children from the three locations (Siorapaluk, Qaanaaq and Nuuk) were compared using ANCOVA after ln(x) transformation to obtain approximate normal distribution when necessary. ANCOVA were adjusted for BMI (except when BMI was the dependent variable), age and pubertal stage, and gender. When comparing plasma hs-CRP (ln), the model was additionally adjusted for serum 25(OH)D. Food consumption and age of the children living in the three locations were compared using one-way ANOVA. Four food categories were transformed using ln(x + 1) as there were zero values (MMF, MEg, VegFr, JunkF). Pearson's χ^2 tests were used to compare prevalence of high non-HDL-C and vitamin D insufficiency and deficiency between groups or genders. Associations between MMF consumption profiles and HbA1c, fasting glucose, fasting insulin (ln), non-HDL-C (ln), skinfold thickness (ln), hs-CRP (ln), VO_{2max} and serum 25(OH)D (ln) were assessed using ANCOVA adjusted for age, pubertal stage, the five other food categories, gender and VO_{2max} (no adjustment for VO_{2max} in the test with serum 25(OH)D). The association between MMF consumption profiles and hs-CRP (ln) was additionally adjusted for serum 25(OH)D. When the ANCOVA and ANOVA showed a significant difference between the groups, *post hoc* pairwise comparisons were run to tease out differences between groups. After ANCOVA, pairwise group comparisons were conducted using Bonferroni correction (assuming homogeneity of variances). No *post hoc* test assuming non-homogeneity of variance was available, so variables of which the homogeneity of variance could not be verified (Levene's test) have been flagged in Table 1. After ANOVA, pairwise group comparisons were conducted using two different *post hoc* tests: Hochberg's GT2 test when the homogeneity of variances could be verified and the Games–Howell test when it could not be verified. Since age and pubertal stage are positively correlated, we made a variable reduction using principal component analysis (regression method with fixed number of factors = 1, the component scores were used as a new variable representing age and pubertal stage together). In the ANCOVA comparing plasma hs-CRP concentrations between locations and in the ANCOVA comparing plasma hs-CRP concentrations between MMF consumption profiles, children with hs-CRP > 2·00 mg/l were excluded (considered as outliers because of probable infection). $P < 0{\cdot}05$ was considered significant except for pairwise *post hoc* tests comparing

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Table 1 Characteristics and metabolic profiles of the Inuit children aged 6–18 years from Siorapaluk (n 15) and Qaanaaq (n 70) in the north of Greenland and the capital, Nuuk (n 92), in the west, August 2007 and 2008

	Siorapaluk		Qaanaaq		Nuuk		Missing values (S/Q/N)	P value*
Gender (girls/boys)	2/13		39/31		39/53		–	–
Pubertal stage (I–V) (%)	67/0/27/7/0		37/20/13/14/16		33/18/14/21/14		–	–
	Mean	SD	Mean	SD	Mean	SD		
Metabolic variables								
Age (years)	10·0	2·3	11·3	2·9	12·0	2·6	–	0·014
BMI (kg/m^2)	17·7	2·3	18·5	2·9	19·8	3·0	–	0·018
Body fat (%)	20·0	3·5	20·2	4·7	21·5	5·7	–/1/–	0·031
Skinfold thickness (mm)†	24·5[a,b]	1·1	33·4[a]	1·5	44·6[b]	2·4	–/–/–	<0·001
VO_{2max} (ml/kg per min)	48·7	6·4	44·9	6·4	44·6	7·7	4/11/1	0·92
Fasting glucose (mmol/l)	5·4	0·4	5·0	0·4	5·2	0·5	1/1/9	0·012
Fasting insulin (pmol/l)	45·9	25·8	47·8	28·0	60·7	34·8	1/1/9	0·18
HbA1c (mmol/l)	5·4[a]	0·1	5·1[b]	0·2	5·4[a]	0·2	–/1/–	<0·001
Total cholesterol (mmol/l)	4·53	0·66	4·07	0·54	4·09	0·67	1/1/9	0·29
HDL-cholesterol (mmol/l)	1·65	0·28	1·35	0·32	1·40	0·27	1/1/9	0·035
LDL-cholesterol (mmol/l)	2·37	0·55	2·12	0·46	2·37	0·64	1/1/9	0·034
Non-HDL-cholesterol (mmol/l)	2·88	0·52	2·72	0·52	2·69	0·64	1/1/9	0·62
TAG (mmol/l)†	0·78	0·21	0·89	0·37	0·83	0·31	1/1/9	0·38
ApoA1 (μmol/l)†	67·1[a,b]	11·9	63·7[b]	11·3	57·1[a]	8·7	1/1/9	<0·001
ApoB (μmol/l)†	2·5	0·5	2·5	0·5	2·4	0·6	1/1/9	0·43
Leptin (ng/l)	2195	1434	5153	4892	5686	7432	–	0·09
Adiponectin (μg/l)	23 236	9153	28 872	15 069	21 361	12 773	–/1/–	0·018
hs-CRP (mg/l)‡	0·35	0·23	0·46	0·41	0·45	0·42	1/1/9	0·53
25(OH)D (nmol/l)§	50·9	16·1	44·1	20·6	41·1	18·2	–/–/1	0·84

HbA1c, glycated Hb; hs-CRP, high-sensitivity C-reactive protein; 25(OH)D, 25-hydroxyvitamin D.
The raw data used to build this table (except for 25(OH)D) have been used in two previous publications that adopted a different approach to group the children, i.e. girls *v.* boys, and pooled northern villages[19,23]. Moreover, the data presented here are only from the children for whom quality dietary data were available. More details are provided in the online supplementary material, Supplemental Tables S4A and S4B.
[a,b]Mean values within each characteristic with unlike superscript letters were significantly different ($P < 0·005$) in the pairwise *post hoc* tests.
**P* value from the ANOVA and ANCOVA (difference between the three groups). With the exception of the analysis comparing age between locations, all models were adjusted for age and pubertal stage, BMI, gender and – for hs-CRP only – for serum 25(OH)D.
†The homogeneity of variance could not be verified for these variables (Levene's test $P < 0·05$).
‡In addition to missing values, children with hs-CRP > 2·00 mg/l were excluded (n 0, n 3 and n 13 in Siorapaluk, Qaanaaq and Nuuk, respectively).
§No 25-hydroxyergocalciferol (25-hydroxyvitamin D_2) could be detected in the samples.

the three locations, where $P < 0·005$ was considered significant.

Results

The characteristics and metabolic profiles of the children by area of residence are presented in Table 1, with gender-specific details provided in the online supplementary material, Supplemental Table S2. Children in Qaanaaq had lower HbA1c ($P < 0·001$) and higher apoA1 ($P < 0·005$) levels than children in Nuuk. Children in Siorapaluk had a higher HbA1c than the other northerners from Qaanaaq ($P < 0·005$). Also, none of the children from Siorapaluk had high non-HDL-C, which affected two children in Qaanaaq (3 %) and six in Nuuk (7 %; $P = 0·31$). There was no difference between genders in the prevalence of high non-HDL-C (all areas of residence pooled, $P = 0·86$).

The prevalence of vitamin D insufficiency and deficiency was high, with eight children in Siorapaluk (53 %), forty-seven in Qaanaaq (67 %) and sixty-six in Nuuk (73 %) having serum 25(OH)D below 50·0 nmol/l ($P = 0·31$), of whom one (7 %), twelve (17 %) and eighteen (20 %) had serum 25(OH)D below 25·0 nmol/l in the three groups, respectively ($P = 0·46$). There was a trend towards more boys being vitamin D deficient (13 % of girls *v.* 22 % of boys, $P = 0·10$), but no significant difference between genders regarding insufficiency (74 % of girls *v.* 65 % of boys, $P = 0·19$).

The dietary habits of the children differed with area of residence in all food categories except for dairy products and complex carbohydrates (Fig. 1 and online supplementary material, Supplemental Table S3). Consumption of MMF was most frequent in Siorapaluk, less so in Qaanaaq and least frequent in Nuuk ($P < 0·001$). Children in Siorapaluk ate meat and eggs more frequently than children in Qaanaaq and Nuuk ($P < 0·001$). Children in Qaanaaq ate vegetables and fruits less frequently ($P < 0·005$) and 'junk food' more frequently ($P < 0·001$) than the children in Nuuk. These differences were not observed between Siorapaluk and Nuuk ($P > 0·99$ and $P = 0·83$, respectively).

Only two children from Qaanaaq and four children from Nuuk reported never eating fish (excluding shellfish), and five children from Nuuk reported never eating marine mammals (only two children would never eat both). Ten (67 %), forty-three (61 %) and forty-nine (53 %) children reported eating fish (excluding shellfish) 8 times/month (or 2 times/week) or more in Siorapaluk, Qaanaaq and

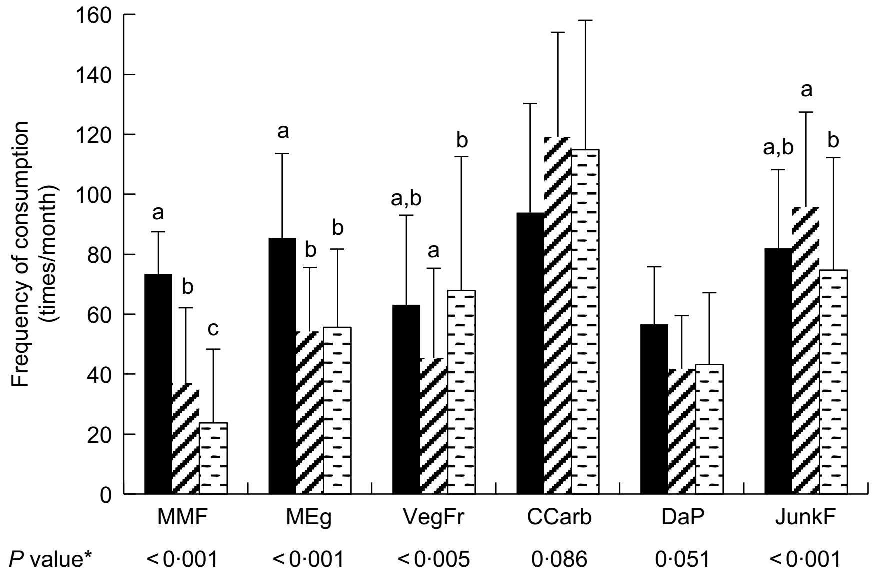

Fig. 1 Dietary habits of the Inuit children aged 6–18 years from Siorapaluk (■, *n* 15) and Qaanaaq (▨, *n* 70) in the north of Greenland and the capital, Nuuk (⊟, *n* 92), in the west, August 2007 and 2008. Data are presented as means, with their SD represented by vertical bars, for the frequencies of consumption expressed in times per month (maximum 1 time/d for each food type) and are a sum of sixty-four individual food types divided into six food categories (see details in the online supplementary material, Supplemental Tables S1 and S3). **P* values from ANOVA (difference between the three groups). [a,b,c]Mean values within each food category with unlike superscript letters were significantly different ($P < 0.005$) in pairwise *post hoc* tests (MMF, marine mammals and fish; MEg, meat and eggs; VegFr, non-starchy vegetables and fruits; CCarb, complex carbohydrates; DaP, dairy products; JunkF, 'junk food')

Nuuk, respectively. If we consider the entire MMF category, fifteen (100 %), sixty-four (91 %) and sixty-nine (75 %) children reported eating MMF 8 times/month (or 2 times/week) or more in Siorapaluk, Qaanaaq and Nuuk, respectively. For better characterisation of MMF consumption, see the online supplementary material, Supplemental Tables S4A and S4B.

The mean levels of HbA1c, fasting insulin and glucose, non-HDL-C, hs-CRP, VO_{2max} and serum 25(OH)D of the children across the four MMF consumption profiles are presented in Table 2. The weak associations between MMF consumption and HbA1c and VO_{2max} were not significant in the pairwise comparisons. There was no significant association between MMF consumption and fasting insulin, glucose, non-HDL-C or hs-CRP. Serum 25(OH)D concentration was positively associated with MMF consumption, with a pairwise comparison statistically significant between extreme consumption profiles only (<4 *v.* >56 times/month). Furthermore, we observed a significant difference in the frequency of vitamin D deficiency across the four MMF consumption profiles with fewer children being deficient in higher consumption profiles (Table 3, $P < 0.05$).

Discussion

In the present study, we compared the dietary habits of children living in the north of Greenland (Siorapaluk and Qaanaaq) and in the capital (Nuuk) in the west of Greenland in the context of the current dietary transition from a traditional to a more westernised diet[2]. The children from the most remote place (Siorapaluk) had maintained the most traditional diet which was primarily comprised of MMF. It appears that the western lifestyle had spread even to Qaanaaq (about 650 inhabitants); although the children still ate MMF more frequently than those from Nuuk, they also consumed 'junk food' more often and vegetables and fruits less often. To our knowledge, no other studies have compared the diet of children in these areas, encompassing all food categories.

Over the past 20 years, Nordic countries have published dietary guidelines with various recommendations regarding fish[33]. The ten dietary recommendations of Greenland[34] invite consumers to 'eat traditional foods, and fish and fish products often', with an additional advice to pregnant women and smaller children to 'avoid or limit the intake of polar bear, toothed whales, elderly seals and sea birds'[33], without being more specific. Dietary guidelines from Canada[35], Norway[36], Iceland[37], the UK[38] and Denmark[39] suggest that fish or fish spreads should be consumed 2–3 times weekly as main dish (with varying serving size), with sometimes special instructions for babies and/or pregnant women. Among the guidelines cited above, only the Canadians suggest that 2 servings/week should be the upper limit, while the others invite consumers to eat fish at least 2 times or servings/week. In our study, 58 % of the children (*n* 102) reported consuming fish at least twice weekly on average (8 times/month). However, it was not possible to distinguish when fish was

Table 2 Association of the consumption of marine mammals and fish (MMF) with glycated Hb (HbA1c), fasting insulin and glucose, non-HDL-cholesterol (non-HDL-C) and high-sensitivity C-reactive protein (hs-CRP) blood levels, fitness level and serum 25-hydroxyvitamin D (25(OH)D) concentration of the Greenlandic children aged 6–18 years (*n* 177), August 2007 and 2008

		HbA1c (mmol/l)		Insulin (pmol/l)		Glucose (mmol/l)		Non-HDL-C (mmol/l)		hs-CRP† (mg/l)		VO_{2max} (ml/kg per min)		Serum 25(OH)D (nmol/l)	
		$P=0.045$		$P=0.36$		$P=0.97$		$P=0.73$		$P=0.08$		$P=0.047$		$P=0.019$	
MMF consumption profile*	*n*†	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<4	13	5·3[a]	0·2	32·0	32·0	5·2	0·4	2·8	0·8	0·62	0·58	41·9[a]	5·4	32·0[a]	17·0
4–<28	87	5·3[a]	0·3	42·7	42·7	5·1	0·4	2·8	0·6	0·45	0·41	43·1[a]	7·1	42·7[a,b]	20·1
28–<56	37	5·2[a]	0·3	42·0	42·0	5·1	0·5	2·6	0·5	0·51	0·41	47·1[a]	5·9	42·0[a,b]	16·3
>56	39	5·3[a]	0·2	48·9	48·9	5·2	0·4	2·7	0·5	0·28	0·19	47·9[a]	5·1	48·9[b]	18·7
Total	176	5·3	0·3	43·1	43·1	5·1	0·4	2·7	0·6	0·44	0·40	44·8	6·7	43·1	19·1

The associations between biological variables and MMF consumption profiles were studied using ANCOVA. The models were adjusted for age and pubertal stage, VO_{2max} (not for serum 25(OH)D), gender, serum 25(OH)D (for hs-CRP only), and the consumption of the other five food categories (MEg (meat and eggs), VegFr (non-starchy vegetables and fruits), CCarb (complex carbohydrates), DaP (dairy products) and JunkF ('junk food')).

[a,b]Mean values within each biological variable with unlike superscript letters were significantly different ($P<0.05$) in the pairwise *post hoc* tests. Serum 25(OH)D was significantly different between the two extreme consumption profiles (i.e. <4 *v.* >56 times/month, $P=0.028$).

*The MMF consumption is expressed in times per month with a maximum of 1 time/d for each of the fifteen individual food types.

†Data were missing for eleven children regarding insulin, glucose, non-HDL-C and hs-CRP (*n* 166), and one child regarding the other variables. In addition to missing values, children with hs-CRP > 2·00 mg/l were excluded (*n* 1, *n* 14, *n* 3 and *n* 8 in the consumption profiles from <4 to >56 times/month, respectively).

Table 3 Prevalence of vitamin D insufficiency and deficiency across marine mammals and fish (MMF) consumption profiles in the Greenlandic children aged 6–18 years (*n* 177), August 2007 and 2008

		Vitamin D insufficiency (<50·0 nmol/l)		Vitamin D deficiency (<25·0 nmol/l)	
		$P=0.34$		$P=0.050$	
MMF consumption profile*	*n*†	*n*	%	*n*	%
<4	13	11	85	5	38
4–<28	87	61	70	14	16
28–<56	37	26	70	9	24
>56	39	23	59	3	8
Total	176	121	69	31	18

The associations between MMF consumption profiles and vitamin D insufficiency and deficiency prevalence were studied using Pearson's χ^2 test.

*The MMF consumption is expressed in times per month with a maximum of 1 time/d for each of the fifteen individual food types.

†Missing data for one child living in Nuuk in the 4–<28 times/month consumption profile.

consumed as a main dish or not, and the lack of portion size and wide age range make it impossible to conclude whether our cohort was meeting guidelines or not, and to compare with studies reporting quantitative intake. Furthermore, although several Nordic countries consume marine mammals[40], and may even publish guidelines targeted towards indigenous populations including Inuits[35], we could not find quantitative instructions regarding the consumption of marine mammals for children[14]. As mentioned earlier, the conflicting health benefits (long-chain PUFA *v.* contaminants) obviously make it difficult for health authorities to publish quantitative dietary guidelines. Two Swedish studies on 8-year-old children (*n* 1970[41] and *n* 888[42]) reported that children ate fish 1·70 and 1·75 times/week (median values), respectively, which is slightly below our median value of 2·3 times/week (9·4 times/month), all ages together (online supplementary material, Supplemental Table S4A). Findings from a study assessing dietary patterns of 3850 Spanish individuals aged 2–24 years, based on 24 h recalls and FFQ, indicated that 84·4 % were consuming fish regularly, at least 2–3 times/week[43].

The higher consumption of MMF in northern Greenland was reported in a study from 2006 in adults[2]. In contrast, another study in Greenlandic pregnant women from 2010 to 2011 showed no significant difference in the consumption of MMF between the geographic locations (median of 19·3 and 24·5 times/month for west and north, respectively)[44]. However, fish spreads, herring and canned fish seemed absent in that study, and citizens from remote places such as Siorapaluk were not included. Another study from 1993 to 1994 reported similar frequency of consumption of MMF in adults living in western Greenland: 25·0 times/month (seal, whale and fish)[45], which is close to our findings for Nuuk (mean 23·7 (SD 24·6) times/month, including fish spreads). The study in Greenlandic pregnant women[44] also showed that northerners tended to eat vegetables and fruits less often (median of 27·4 times/month) than westerners (median of 46·8 times/month), which was also found in a study from 2006[2]. However, northerners and westerners had a similar consumption of 'junk food' (fast-food, snacks and candy)[44]. Consumption of 'junk food' as well as fruits and vegetables may be more affected by urbanisation[46]. Fresh fruits and vegetables are accessible throughout the year in most urban places in Greenland, but the supply, variety and prices vary. Qaanaaq, with its 650 inhabitants, remains a village, and we can assume that this had an impact on the availability and prices of fruit and vegetables. 'Junk food' could therefore represent a cheaper alternative accessible throughout the year as these products have longer shelf-life. Yet, following this explanation, we would have expected children from Siorapaluk to have the least easy access to fruits and vegetables. Part of the explanation may lie in the socio-economic parameters (not addressed in our study) which also play a role in the dietary habits, especially with regard to healthy eating[25] and adherence to nutritional guidelines[47].

In our study, the prevalence of high non-HDL-C was very low in the north, while in Nuuk, it was similar to (if not lower than) the prevalence reported in children of similar age in the USA (about 10 %)[48]. The consumption of MMF was associated with higher serum 25(OH)D concentration (resulting in less deficiency), which has also been observed in adults[20], and was expected when considering the high content of vitamin D in MMF. However, vitamin D insufficiency and deficiency remained highly prevalent, also considering that the analyses were performed in August. In August, at the latitudes tested (77·8°N, 77·5°N and 64·2°N for Siorapaluk, Qaanaaq and Nuuk, respectively) and according to Webb[21], an exposure time of 1–3 h of 0·25 of skin surface area to 0·25 of the personal minimum erythema dose would be needed to synthesise 25 μg (1000 IU) of vitamin D. At this time of year, it is difficult to see whether the difference in latitude between northern villages and Nuuk has a significant impact on vitamin D synthesis[21]. We could not obtain information on potential vitamin D supplementation in our cohort unfortunately. According to the Nordic Nutrition Recommendations[32], the recommended dietary vitamin D intake is 10 μg/d (400 IU/d) and the average vitamin D requirement is 7·5 μg/d (300 IU/d) for people aged 2–60 years, regardless of sun exposure, which might actually be limiting in our population. In a study in adults living in Nuuk, vitamin D insufficiency (defined as serum 25(OH)D < 40 nmol/l) ranged from 23 % in Inuit eating seal or whale at least once weekly to 76 % in Inuit eating seal or whale three times per month or less[49]. In Danish adolescent girls (about 12 years old), the prevalence of vitamin D insufficiency (<50 nmol/l) and deficiency (<25 nmol/l) was 93 and 52 %, respectively, in winter and went down to 19 and 0 % in summer[50]. Their dietary intake was about 2·3 μg/d while an additional 1·6 μg vitamin D/d came from supplementation (total dietary intake: 1·9–7·0 μg/d, 25th–75th percentiles). The higher prevalence of vitamin D insufficiency (74 %) and deficiency (13 %) in our Greenlandic girls in summer than in Danish teenagers[50] may be due to a combination of less sun exposure and lower dietary intake (we had no way to accurately calculate the vitamin D intake of the children). Several studies[5] report a mean dietary vitamin D intake for adults in Arctic regions in Canada ranging from 2·1 to 13·9 μg/d, i.e. similar to or higher than the dietary intake of Danish teenagers[50]. However, in addition to the differences in age and region, the different thresholds that these studies[5] apply to define deficiency and insufficiency make a direct comparison speculative at best.

In our study, the hypothesised positive associations of MMF consumption with non-HDL-C and hs-CRP could not be confirmed, and the association with markers of glycaemic control was not clear. *n*-3 Fatty acids have inconsistent effects on glycaemic control and insulin sensitivity[11,12]. Inuit are known to be particularly sensitive to carbohydrate intake and prone to insulin resistance[51]. Indeed, it is important to note that the 'healthiest' children in our study regarding fasting glucose, insulin and HbA1c displayed similar values as average Danish children[19]. In a study from 1993 to 1994 in Greenlandic adults[16], the consumption of marine mammals was associated with higher HDL-C, lower VDLC-cholesterol, lower TAG, but higher fasting blood glucose. In another study in adults living in west Greenland, the frequent (4 times/week) consumption of seal was associated with a decreased risk of glucose intolerance[17]. Furthermore, in a recent meta-analysis, the effect of long-chain *n*-3 fatty acids on insulin resistance has been shown to be gender-dependent, with no effect in men while women showed an increased insulin sensitivity after interventions lasting 6 weeks or longer[52]. In our study, the association between MMF consumption and fitness levels, although not significant when comparing extreme profiles, is probably an indirect effect, reflecting a more active lifestyle in the remote places.

Aside from the healthy aspects of MMF consumption, many studies have also reported that MMF are a source of toxic contaminants[2,13,14]. These conflicting pieces of evidence are known as the 'Arctic dilemma'[13] and could partly explain why the health effects of MMF observed some decades ago are not widely observed in more recent studies. Indeed, several contaminant classes have been associated with adverse health outcomes, including type 2 diabetes[53]. However, we did not analyse the exposure of the children to these contaminants.

The main finding of our study is the observation of great variation in dietary habits between the studied places which enabled us to compare children eating a more westernised diet with children adhering to the traditional Inuit diet. In addition, the cohort is meticulously described with puberty staging, body fat, aerobic fitness levels and metabolic profiles. However, our study has limitations. Even though only few products are seasonal, and many households have freezers to store foods throughout the year[25], dietary intake very likely varies with the season. Thus, the study is limited in that it was conducted in August and the findings may not accurately reflect potential seasonal variations.

The serum 25(OH)D concentrations would be different during the winter when there is no sunlight[5] and less marine mammals available. The questionnaire was not filled in by the children themselves, but by their parents. The amount of food intake could not be assessed, as portion sizes were not sufficiently reported. When considering the age of the children (5–17 years), it was not realistic to reliably assume portion sizes. The small sample size limited our statistical power. One consequence is that we could not distinguish between girls and boys as previously published[19,23]. Finally, the study was conducted in 2007 and 2008. Although no similar study has been conducted in the past decade, results might not adequately reflect the current dietary habits of the children. A follow-up study would indeed shed light on how diet has evolved in the last 10 years in children. A study from 2016 in Greenland reported a decrease in frequency of consumption of marine mammals between 2005 and 2014 among adults from several locations in Greenland; however, the evolution of the vitamin D status of the participants was not assessed[54].

Conclusion

In conclusion, children from the most remote place (Siorapaluk) consumed a traditional diet highly based on MMF. Children from Qaanaaq ate MMF more frequently than children from the capital, Nuuk, but also ate 'junk food' more often and vegetables and fruits less often. This means that the dietary transition and influence of a western lifestyle have spread to the north, and also reflects differences between villages and the capital. While the positive association between MMF consumption and serum 25(OH)D concentration was significant, the association with glycaemic control was unclear. The previously reported positive association between MMF consumption in adults and lipid profile and inflammation could not be confirmed in children. Finally, there remains a high prevalence of vitamin D deficiency among Greenlandic children, probably due to lack of sun exposure and maybe changing food habits.

Acknowledgements

Acknowledgements: The authors are grateful to the participating children, their families, schools and the teachers in Nuuk, Qaanaaq and Siorapaluk. They also thank the medical centre in Qaanaaq for housing and the use of its equipment. They are grateful to Mogens Morgen for helping out with the planning of the project and Associate Professor Jim Cotter for assisting with the experiments in Nuuk. The authors thank Christine Søholm Hansen for her good advice on the statistical analyses, and Nicolai Paulsen for the editorial assistance. Finally, this study could not have been conducted without the qualitative work of Thor Munch-Andersen who designed it and collected data in the field. *Financial support:* The authors would like to thank the Danish Pharmacy Fund (Apotekerfonden af 1991) for funding. The Danish Pharmacy Fund had no role in the design, analysis or writing of this article. *Conflict of interest*: The authors declare no conflicts of interest. *Authorship:* J.C. gathered and curated the data, performed the statistical analyses, and drafted the manuscript. J.S.Q. and E.K. collected additional data on diet composition. M.B.J. and P.J.B. performed various biological analyses. J.W.H. and K.S. designed the study. J.W.H. and K.S. collected the data and samples in the field and performed most of the measurements. All authors critically revised the manuscript for important intellectual content and approved the final version of this manuscript. J.C. and K.S. had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. *Ethics of human subject participation:* This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving human subjects were approved by the ethics committee of the Capital Region of Denmark (J.no. KF 01 282214, KF 11 2006-2033) and the Commission for Scientific Research in Greenland (J.no 505-117). Written informed consent was obtained from all subjects (parents or legal representative).

Supplementary material

To view supplementary material for this article, please visit https://doi.org/10.1017/S1368980019002799

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