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Original Research

Features of lipid metabolism in Arctic residents depending on ethnicity and lifestyle

AUTHORS

Olga Vlasova[1] PhD, Senior Researcher * [https://orcid.org/0000-0002-6956-6905]

Fatima Bichkaeva[1] ScD Biology, Chief Research Scientist and Head of Laboratory [https://orcid.org/0000-0003-0727-3071]

Boris Shengof[1] Researcher [https://orcid.org/0000-0002-3776-1474]

Ekaterina Nesterova[1] Researcher [https://orcid.org/0000-0001-8467-2514]

Alexandra Strelkova[1] PhD, Senior Researcher [https://orcid.org/0000-0002-9077-889X]

Nina Baranova[1] Junior Researcher [https://orcid.org/0000-0002-7527-8088]

CORRESPONDENCE

*Ms Olga Vlasova

AFFILIATIONS

[1] Laboratory of Biological and Inorganic Chemistry, N. Laverov Federal Center for Integrated Arctic Research, Russian Academy of Sciences (FCIAR UrB RAS), Ural Branch, Arkhangelsk, Russia

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Abstract

Introduction: Metabolic adaptations can differ significantly among Arctic residents with different ethnicities, lifestyles and adherences to traditional diets. The objective of this study was to examine the status of saturated fatty acids (SFAs) and triglycerides and the variability of BMI among Russian Arctic residents according to ethnicity and lifestyle.

Methods: The study involved adult females and males living in the territories of the Russian Arctic. The participants were divided into three groups: Indigenous reindeer herders leading a nomadic lifestyle (NIP), Indigenous people leading a sedentary lifestyle (SIP) and the Caucasian population (CP). The content of SFAs (C6–C24) and metabolic characteristics was determined using gas chromatographic and spectrophotometric methods. The study also included a quantitative comparison of the consumption of certain categories of food products. To analyze data, we used the descriptive analyses by non-parametric methods, as well as multiple linear regression analysis.

Results: The study found that the Caucasian females had higher triglyceride levels ($p<0.001$), higher total content of long-chain SFAs (LCSFAs) (C13–C18) ($p=0.002$) and that the SIP females had reduced content of very-long-chain fatty acids (C20–C24) ($p=0.039$). These changes were not statistically significant for the males, partly due to the almost identical levels of triglycerides C16:0 and C18:0 in the NIP and the CP. The content of medium-chain SFAs (MCSFAs) (C6–C12) was higher in the SIP ($p<0.001$ for females; $p=0.002$ for males). The Indigenous males tended to have a lower BMI compared to the Caucasian males, resulting in a lower prevalence of overweight or obesity: 49.3% in the NIP ($p=0.006$) and 57.4% in the SIP versus 69.3% in the CP. In female participants, these frequencies did not differ, being 64%, 65.4% and 66% respectively. The NIP and SIP groups had higher consumption of traditional foods, carbohydrate-rich foods, meat products and vegetable oils, the latter of which was positively associated with SFA content.

Conclusion: The study revealed the dependence of the studied parameters of lipid metabolism on ethnicity (Indigenous v Caucasian) and lifestyle (nomadic v sedentary). The population metabolic variability was expressed as the increase in the levels of LCSFAs and triglycerides in the CP, reflecting, most likely, an imbalance in the processes of their accumulation and consumption with a predominantly western type of nutrition. Indigenous populations, despite changes in diet towards an increased consumption of carbohydrate-rich products, have preserved an adaptive metabolism with the predominant use of lipids as energy resources. Higher levels of MCSFAs in the SIP, who are less adherent to a traditional diet compared to the NIP, may be compensatory, with a growing role of such fatty acids in energy consumption and thermogenesis.

Keywords

Arctic residents, BMI, Nenets, nomadic lifestyle, reindeer herders, saturated fatty acids, traditional diet, triglycerides.

Introduction

Research by Russian scientists, dating back to the 1970s, established that living in the harsh and extreme conditions of the North and the Arctic created the so-called 'northern' type of metabolism, characterized by increased protein–lipid metabolism and minimization of carbohydrate metabolism[1-3]. They suggested this was associated with a different energy supply for which lipid energy carriers become more important. In addition, an economical and optimal tissue homeostasis, as well as adaptability at the level of the whole organism, created an optimal lipid profile in the Indigenous population living in the North for thousands of years[3,4]. The typical lipid spectrum in this case featured a low triglycerides level, while the values of free fatty acids could exceed the upper boundaries of the norm[5,6]. The Indigenous population tended to have increased fatty acid blood levels, primarily the levels of omega-3 polyunsaturated fatty acids[7,8].

The diet of Arctic residents has been of great importance. The northern type of metabolism, combined with a specific endocrine background, predetermines the protein–lipid type of diet, characterized by an increased proportion of proteins and lipids and a decreased proportion of carbohydrates[9]. The Indigenous Peoples achieve this by including many traditional foods in their diet: sea and river fish, meat and fat of terrestrial and marine mammals, berries and plants[10,11].

In the Caucasian population (CP) of the North, metabolic manifestations of adaptation may differ. Numerous studies of lipid metabolism indicate an increase in the content of total cholesterol and atherogenic lipid fractions in migrant populations compared with Indigenous Peoples[12-14]. However, few studies have compared the range of fatty acids in these populations on the territory of the Russian Federation.

The Indigenous Peoples of the Arctic have traditionally been nomadic hunter-gatherers, well adapted to a traditional diet rich in animal products and traditional methods of cooking and consuming food. At the same time, hunting, fishing, nomadic herding, and methods of gathering and processing food have provided the necessary physical activity[15]. These populations are now experiencing acculturation to the values and practices of western communities and the wage economy. As a result of commercialization and urbanization, purchased food has become much more affordable. Also, access to traditional products is decreasing due to climate change (e.g. changes in the habitats of local fauna and flora, migration routes of animals, and reduction of their populations) and environmental pollution[15,16]. Food availability is also affected by the low socioeconomic status of the population and the high cost of transportation to hard-to-reach areas. Physical activity levels among Indigenous Peoples are also declining due to reduced participation in traditional activities and the use of motorized vehicles[15,17]. As a result, there is a shift from traditional diets and lifestyles to energy-intensive and less nutritious purchased foods and sedentary and mechanized lifestyles, which are associated with increases in obesity and non-communicable diseases (e.g. cardiovascular disease and type 2 diabetes)[18]. Thus, most Arctic communities have experienced varying degrees of dietary and lifestyle changes in recent decades. To some extent, this also applies to members of the CP, since they sometimes use local food sources and follow the dietary traditions of the Indigenous Peoples.

Therefore, the objective of this study was to investigate the status of lipid metabolism (serum triglycerides and SFAs), and the variability of BMI in Russian Arctic residents depending on their ethnicity and lifestyle.

Methods

Design and participants

An observational, cross-sectional, uncontrolled study was conducted on females and males aged 22 to 60 years living in the Arctic zone of the Russian Federation during expeditions carried out from 2009 to 2018. The total number of the participants was 1086 (773 females and 313 males). The median age of the participants was 44 years (25th and 75th percentiles 35 and 52 years, respectively). The subjects were randomly selected after a medical examination and a survey. The exclusion criteria were a history of diabetes mellitus and/or acute somatic diseases, and exacerbations of chronic diseases at the time of the study. All the participants signed an informed consent.

The medical examination included anthropometric measurements and taking venous blood. The blood was centrifuged to separate the serum, which was frozen until laboratory tests were conducted.

Residence

The study participants lived in the territories included in the Arctic zone of the Russian Federation by the Decree of the President of the Russian Federation dated 2 May 2014: Mezensky Municipal District of Arkhangelsk Oblast, the Nenets Autonomous Okrug and the Yamalo-Nenets Autonomous Okrug. The participants were divided into three groups depending on their ethnicity and lifestyle. The first group was nomadic Indigenous people (NIP) engaged in a traditional activity, nomadic reindeer herding. The second group included the so-called 'settled' Indigenous people (SIP), who permanently resided in settlements. The third group was the CP, primarily ethnically Russian (over 90% of those surveyed). The nomadic lifestyle of reindeer herders implies higher physical activity compared to people residing in settlements. In terms of their ethnicity, the Indigenous populations were predominantly Nenets, as well as Komi. The Nenets are a Samoyed people of the Russian Federation inhabiting the Eurasian coast of the Arctic Ocean from the Kola Peninsula to the Taimyr Peninsula. Of the Indigenous Peoples of the North, Siberia and Far East (a population less than 50,000 people) the Nenets population is the largest[19]. We used the survey data to define the ethnicity. For all three groups, the results of the study are given separately for females and males.

Dietary pattern scoring

Dietary analysis was conducted for the preceding 12-month period using a frequency and questionnaire-based method[20]. The frequency of consumption was understood as a number of daily intakes. Portion size questions were asked separately for fish and meat dishes. For the rest of the products, standard serving sizes were determined according to the *Food portion and dish album*[21]. Daily food intake (g/day) was calculated by multiplying the frequency of consumption by the corresponding serving size.

Fatty dairy products included butter, margarine, *tvorog* (similar to cottage cheese), cheeses and sour cream. Meat products were meat (e.g. beef, venison, pork, chicken), canned meat and other processed meat. Carbohydrate-rich products referred to products including simple carbohydrates (e.g. sugar, flour and confectionery), grain products (bread, cereals and pasta), fruits and potato. Traditional foods comprised meat (reindeer meat) and fish products, as well as forest berries growing in the North, which have always been part of a traditional diet for the Nenets and the Komi. Traditional fish products included northern river fish belonging to the whitefish subfamily of the salmon family (e.g. muksun, broad whitefish and humpback whitefish).

The number of participants who underwent a dietary questionnaire (N=824) was smaller than the total number of study participants.

Clinical laboratory measurements

Serum metabolic characteristics (triglycerides as well as total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol and glucose) were measured using spectrophotometry and the following equipment and kits: CA-270 Furuno Clinical Chemistry Analyzer, Japan; Biolab-100 Lumex Analyzers, Russia; Cary 50 Bio UV-Visible Spectrophotometer, Varian, Australia; Chronolab kits, Switzerland. Frequencies of hypertriglyceridemia (hypertriglycerides) in the populations were calculated at serum triglyceride levels at or above 1.7 mmol/L.

The content of fatty acids was determined by gas–liquid chromatography with preliminary extraction of lipids from blood serum and subsequent formation of fatty acid methyl esters[22]. Methyl fatty acid derivatives were analyzed on a 7890A Gas Chromatograph (Agilent, USA) with a flame ionization detector on Analytical Science BPX90 GC Capillary Columns (60 m, 0.25 mm, 0.25 µm; SGE, UK) and Agilent DB-23 GC Columns (60 m, 0.25 mm, 0.15 µm; Agilent, USA). Fatty acids were identified using standard mixtures of 37 FAME C4–C24 fatty acid methyl esters (Supelco Inc., USA) and GLC-569 B (Nu-Chek Prep. Inc., USA), and the quantitative calculation was performed using the internal standard method, where nonadecanoic acid (C19:0) was the internal standard. The concentrations of the following SFAs were determined: caproic (C6:0), caprylic (C8:0), decanoic (C10:0), undecylic (C11:0), lauric (C12:0), tridecanoic (C13:0), myristic (C14:0), pentadecanoic (C15:0), palmitic (C16:0), margaric (C17:0), stearic (C18:0), arachidic (C20:0), heneicosanoic (C21:0), behenic (C22:0), tricosanoic (C23:0) and lignoceric (C24:0).

SFAs are usually short-chain (SC), medium-chain (MC), long-chain (LC) or very-long-chain (VLC) SFAs. According to the classifications provided in the works of Huang et al[23] and Lemaitre and King[24], SFAs are distributed into families: MCSFAs include C6–C12, LCSFAs include C13–C18 and VLCSFAs include C20–C24. The corresponding total values ∑MC, ∑LC, ∑VLC and ∑SFA were calculated.

BMI was calculated as weight (kg) divided by height^2 (m). BMIs of 25–29.99 kg/m^2 were considered as overweight, and BMIs of 30 kg/m^2 or more were considered as obesity.

Statistical analysis

To analyse statistical data and find the boundaries of the normal distribution, we used Statistica v10.0 (StatSoft, statist.exe). The obtained samples were checked for normal distribution using the Shapiro–Wilk test. Due to the partial asymmetry of the distribution series, non-parametric methods of analysis were applied. A descriptive analysis was performed: the median and interquartile range – 25th and 75th percentiles – were calculated. The evaluation of statistically significant differences for two

independent samples when comparing males and females was carried out using the Mann–Whitney *U*-test, the significance of differences in the three groups was determined using the Kruskal–Wallis test, and in the case of obtaining a significant *H*-value, posthoc comparisons were made using Dunn's test. The *z*-test for proportions was used to evaluate the significance of the difference in frequencies when comparing the three groups using the Bonferroni correction. Multiple linear regression analysis was performed using the ethnicity, lifestyle, age, BMI and food intake as predictor variables, and lipid parameters as dependent variables. Lipid parameters, BMI and food intake were log transformed. The critical level of significance (p) when testing statistical hypotheses was set at 0.05.

Ethics approval

The study complied with the World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research (2000) and was approved by the relevant ethics committees (minutes of the meetings of the ethics committees of the Institute of Environmental Physiology, Ural Branch of the Russian Academy of Sciences and N. Laverov Federal Center for Integrated Arctic Research of the Ural Branch of the Russian Academy of Sciences dated 2 February 2009, 4 February 2013 and 9 November 2016). All the participants signed an informed consent.

Results

Metabolic characteristics in blood serum are presented in Table 1. The NIP and SIP groups had lower low-density lipoprotein cholesterol levels and higher high-density lipoprotein cholesterol levels compared to the CP group. NIP and SIP women also had lower glucose levels, while NIP men had the highest total cholesterol levels.

Table 1: Metabolic characteristics in females and males in the Arctic, by ethnicity and lifestyle

Sex	Parameter	Measurement (median (25th percentile; 75th percentile))			*H*-test and *p*-value[†]
		NIP (1) 74 F, 62 M	SIP (2) 408 F, 113 M	CP (3) 291 F, 138 M	
Female	TC, mmol/L	5.3 (4.6; 6.2)	5.2 (4.5; 6.0)	5.4 (4.5; 6.3)	3.5; 0.171
	LDL-C, g/L	3.2 (2.6; 3.9)	3.7 (3.0; 4.8)	4.6 (3.6; 5.6)	73.1; <0.001 (1)–(2)=0.001; (1)–(3), (2)–(3)<0.001
	HDL-C, mmol/L	1.4 (1.2; 1.8)	1.2 (1.0; 1.5)	1.2 (0.9; 1.5)	20.4; <0.001 (1)–(2), (2)–(3)<0.001
	Glucose, mmol/L	4.7 (4.2; 5.3)	4.6 (4.1; 5.3)	5.0 (4.5; 5.6)	25.2; <0.001 (1)–(3)=0.011, (2)–(3)<0.001
Male	TC, mmol/L	5.7 (4.8; 6.4)	5.0 (4.4; 5.8)	5.2 (4.4; 6.1)	12.5; 0.002 (1)–(2)=0.001
	LDL-C, g/L	3.4 (2.7; 4.4)	3.5 (2.8; 4.6)	4.5 (3.6; 6.0)	34.7; <0.001 (1)–(3), (2)–(3)<0.001
	HDL-C, mmol/L	1.6 (1.2; 2.0)	1.1 (0.9; 1.3)*	1.2 (0.89; 1.5)	34.3; <0.001 (1)–(2), (2)–(3)<0.001
	Glucose, mmol/L	4.7 (4.4; 5.5)	4.9 (4.4; 5.3)*	5.0 (4.5; 5.6)	2.9; 0.237

* Statistically significant differences by gender: for HDL-C p=0.026, for glucose p=0.022.

[†] p-values were obtained using Dunn's test; p<0.05 values are shown.

CP, Caucasian population. F, female. HDL-C, high-density lipoprotein cholesterol. LDL-C, low-density lipoprotein cholesterol. M, male. NIP, Indigenous reindeer herders leading a nomadic lifestyle. SIP, Indigenous people leading a sedentary lifestyle. TC, total cholesterol.

A descriptive analysis of the obtained data showed that there were few differences by gender. Among the NIP, males had higher concentrations of triglycerides and lower levels of three minor VLCSFAs (C21:0, C22:0 and C23:0). In the SIP, higher BMIs were found in females. In the CP, lower levels of C10:0, C20:0 and C23:0, and higher levels of C22:0, were observed in females compared to males (Tables 2 and 3).

Table 2: BMI, triglycerides and saturated fatty acid levels in Arctic females, by ethnicity and lifestyle

Parameter	Measurement (median (25th percentile; 75th percentile))			*H*-test and *p*-value[†]
	NIP (1) (n=74)	SIP (2) (n=408)	CP (3) (n=291)	
BMI, kg/m^2	26.8 (23.2; 30.4)	27.8 (23.4; 31.6)	27.8 (23.4; 31.6)	2.9; 0.24
TG, mmol/L	0.91 (0.64; 1.16)	0.98 (0.71; 1.32)	1.10 (0.81; 1.49)	23.4; <0.001 (1)–(3)<0.001; (2)–(3)=0.001
C6:0, µg/mL	0.60 (0.39; 1.02)	1.03 (0.44; 2.00)	0.45 (0.26; 0.97)	73.4; <0.001 (1)–(2)=0.038; (1)–(3)=0.034; (2)–(3)<0.001
C8:0, µg/mL	0.66 (0.46; 1.13)	1.15 (0.64; 1.79)	0.52 (0.38; 0.85)	104.4; <0.001 (1)–(2)<0.001; (2)–(3)<0.001
C10:0, µg/mL	0.98 (0.63; 1.53)	1.37 (0.84; 2.25)	0.98 (0.69; 1.41)	38.1; <0.001 (1)–(2)=0.002; (2)–(3)<0.001
C11:0, µg/mL	0.47 (0.32; 0.68)	0.64 (0.39; 1.07)	0.49 (0.35; 0.69)	31.7; <0.001 (1)–(2), (2)–(3)<0.001
C12:0, µg/mL	4.97 (3.53; 8.04)	7.74 (4.16; 13.38)	5.56 (3.73; 9.49)	22.2; <0.001 (1)–(2), (2)–(3)=0.001
∑MC, µg/mL	8.18 (5.85; 12.21)	12.52 (7.30; 19.62)	8.31 (6.04; 12.87)	45.5; <0.001 (1)–(2), (2)–(3)<0.001
C13:0, µg/mL	3.91 (1.81; 6.97)	3.83 (2.14; 9.18)	4.29 (2.84; 8.25)	3.5; 0.172
C14:0, µg/mL	28.49 (20.52; 35.47)	29.32 (22.05; 38.08)	33.08 (24.76; 46.18)	25.4; <0.001 (1)–(3), (2)–(3)<0.001
C15:0, µg/mL	8.95 (5.77; 11.59)	10.00 (6.76; 13.54)	10.39 (7.98; 14.08)	11.2; 0.004 (1)–(3)=0.005
C16:0, µg/mL	554.54 (460.47; 686.25)	558.85 (453.85; 683.92)	606.04 (493.89; 717.69)	11.5; 0.003 (1)–(3)=0.033; (2)–(3)=0.008
C17:0, µg/mL	11.86 (8.98; 16.0)	10.84 (7.61; 13.77)	11.38 (9.08; 13.88)	5.7; 0.043
C18:0, µg/mL	239.79 (192.71; 274.55)	225.59 (182.40; 277.03)	247.59 (203.34; 287.02)	11.9; 0.003 (2)–(3)=0.002
∑LC, µg/mL	843.54 (708.65; 1012.01)	848.09 (693.82; 1034.26)	910.77 (765.29; 1087.55)	12.8; 0.002 (2)–(3)=0.002
C20:0, µg/mL	2.62 (2.00; 3.65)	2.49 (1.87; 3.17)	2.80 (2.33; 3.46)	26.1; <0.001 (2)–(3)<0.001
C21:0, µg/mL	0.83 (0.60; 1.00)	0.89 (0.64; 1.13)	0.93 (0.78; 1.14)	13.6; 0.001 (1)–(3)=0.01; (2)–(3)=0.006

C22:0, µg/mL	2.21 (1.61; 3.89)	2.47 (1.59; 3.74)	2.34 (1.71; 3.09)	1.7; 0.429
C23:0, µg/mL	0.93 (0.69; 1.42)	0.87 (0.60; 1.35)	0.76 (0.60; 1.07)	9.7; 0.008 (1)–(3)=0.018
C24:0, µg/mL	4.80 (2.67; 8.03)	3.66 (2.10; 5.84)	4.86 (3.41; 6.72)	29.7; <0.001 (1)–(2)=0.043; (2)–(3)<0.001
∑VLC, µg/mL	12.54 (8.02; 16.10)	11.39 (7.86; 15.96)	12.26 (9.93; 15.25)	6.5; 0.039 (2)–(3)=0.034
∑SFA, µg/mL	865.02 (732.36; 1036.94)	871.86 (715.54; 1065.22)	932.11 (785.52; 1111.43)	11.3; 0.004 (2)–(3)=0.006

† *p*-values were obtained using Dunn's test; $p<0.05$ values are shown. CP, Caucasian population. ∑LC, total long-chain saturated fatty acid content. ∑MC, total medium-chain saturated fatty acid content. NIP, Indigenous reindeer herders leading a nomadic lifestyle. ∑SFA, total saturated fatty acid content. SIP, Indigenous people leading a sedentary lifestyle. TG, triglycerides. ∑VLC, total very-long-chain saturated fatty acid content.

Table 3: BMI, triglycerides and saturated fatty acid levels in Arctic males, by ethnicity and lifestyle

Parameter	Measurement (median (25th percentile; 75th percentile))			*H*-test and *p*-value†
	NIP (1) (*n*=62)	SIP (2) (*n*=113)	CP (3) (*n*=138)	
BMI, kg/m^2	24.8 (23.2; 28.5)	25.4 (23.1; 29.3)*	27.1 (24.2; 29.7)	8.6; 0.014 (1)–(3)=0.043; (2)–(3)=0.047
TG, mmol/L	1.09 (0.77; 1.51)*	1.03 (0.79; 1.35)	1.12 (0.88; 1.52)	3.5; 0.173
C6:0, µg/mL	0.79 (0.48; 1.48)	0.94 (0.40; 1.68)	0.47 (0.26; 1.10)	14.3; <0.001 (1)–(3)=0.048; (2)–(3)=0.001
C8:0, µg/mL	0.84 (0.53; 1.21)	1.15 (0.64; 1.79)	0.52 (0.38; 0.85)	36.2; <0.001 (1)–(3)=0.026; (2)–(3)<0.001
C10:0, µg/mL	1.00 (0.67; 1.66)	1.37 (0.80; 2.12)	1.15 (0.77; 1.66)*	5.5; 0.060
C11:0, µg/mL	0.47 (0.25; 0.68)	0.65 (0.42; 1.26)	0.48 (0.36; 0.73)	12.3; 0.002 (1)–(2)=0.003; (2)–(3)=0.035
C12:0, µg/mL	5.68 (3.54; 9.84)	8.06 (4.23; 13.80)	5.59 (3.83; 9.38)	9.3; 0.009 (1)–(2)=0.036; (2)–(3)=0.023
∑MC, µg/mL	9.22 (5.85; 15.17)	12.83 (7.25; 19.76)	8.54 (6.02; 13.03)	12.7; 0.002 (1)–(2)=0.018; (2)–(3)=0.003
C13:0, µg/mL	3.56 (1.80; 5.72)	4.08 (2.37; 9.50)	4.07 (2.95; 6.43)	3.0; 0.222
C14:0, µg/mL	29.09 (17.16; 43.77)	29.94 (20.77; 40.08)	34.79 (24.55; 48.30)	11.5; 0.003 (1)–(3)=0.013; (2)–(3)=0.017
C15:0, µg/mL	7.58 (5.23; 11.31)	9.31 (6.52; 13.53)	9.95 (7.87; 12.22)	10.1; 0.007 (1)–(3)=0.005
C16:0, µg/mL	583.41 (447.04; 717.59)	541.91 (452.12; 675.49)	597.94 (483.37; 758.04)	4.4; 0.113
C17:0, µg/mL	11.09 (7.29; 13.90)	10.95 (7.61; 13.54)	10.93 (7.64; 14.06)	0.1; 0.95
C18:0, µg/mL	250.90 (176.36; 305.26)	221.61 (173.25; 265.41)	235.24 (187.74; 287.29)	5.5; 0.063
∑LC, µg/mL	915.33 (664.33; 1094.68)	829.13 (646.0; 990.17)	907.69 (738.11; 1112.63)	4.3; 0.116
C20:0, µg/mL	2.72 (1.91; 3.89)	2.51 (1.66; 3.13)	3.05 (2.51; 3.88)*	21.7; <0.001 (2)–(3)<0.001
C21:0, µg/mL	0.67 (0.54; 0.90)*	0.88 (0.64; 1.13)	0.98 (0.68; 1.21)	19.9; <0.001 (1)–(2)=0.006; (1)–(3)<0.001
C22:0, µg/mL	1.80 (1.21; 2.41)*	2.48 (1.31; 3.60)	2.00 (1.05; 3.12)*	7.1; 0.029 (1)–(2)=0.040
C23:0, µg/mL	0.78 (0.63; 0.99)*	0.83 (0.57; 1.15)	0.89 (0.62; 1.26)*	1.6; 0.453
C24:0, µg/mL	3.81 (1.91; 6.24)	3.31 (2.46; 6.82)	4.39 (3.15; 5.90)	5.6; 0.062
∑VLC, µg/mL	10.45 (7.36; 13.83)	11.99 (7.48; 17.16)	11.90 (9.14; 16.0)	4.6; 0.103
∑SFA, µg/mL	931.59 (681.73; 1113.24)	873.30 (665.09; 1017.0)	937.71 (758.80; 1141.03)	3.5; 0.17

* Statistically significant differences by gender: for BMI in the SIP $p=0.005$, for TG in the NIP $p=0.003$, for C10:0 in the CP $p=0.041$, for C20:0 in the CP $p=0.016$, for C21:0 in the NIP $p=0.012$, for C22:0 in the NIP $p=0.013$ and in the CP $p=0.024$, for C23:0 in the NIP $p=0.037$ and in the CP $p=0.048$.

† *p*-values obtained using Dunn's test; $p<0.05$ values are shown. CP, Caucasian population. ∑LC, total long-chain saturated fatty acid content. ∑MC, total medium-chain saturated fatty acid content. NIP, Indigenous reindeer herders leading a nomadic lifestyle. ∑SFA, total saturated fatty acid content. SIP, Indigenous people leading a sedentary lifestyle. TG, triglycerides. ∑VLC, total very-long-chain saturated fatty acid content.

In relation to ethnicity and lifestyle, there were no statistically significant differences in BMI among the females in the three groups, although BMI was slightly lower in the NIP (Table 2). In the males, the BMIs were significantly higher in the CP (Table 3). Among the females, the incidence of overweight was more frequent in the NIP (in 38.9% of cases compared to 29.6% and 28.3% in the SIP and the CP respectively), while obesity was less frequent in the NIP (25.3% of cases compared to 35.8% and 37.7%, respectively), but these differences were not statistically significant (Table 4). Among the SIP and CP males, the incidence of overweight was significantly higher than among the females (in 41.7% and 45% of cases respectively), while obesity was significantly less frequent (in 15.7% and 24.3% of cases respectively). Among the NIP males, the frequency of overweight was not significantly lower (30.8% compared to the SIP and CP), and the frequency of obesity was 18.2%. However, there were no gender differences in the total frequency of overweight and obesity: they were recorded in two-thirds of the surveyed females (64% in the NIP, 65.4% in the SIP and 66% in the CP), were slightly less frequent in the Indigenous males (49.3% in the NIP and 57.4% in the SIP) and were significantly higher in the CP males (69.3%) (Table 4).

The females showed significant differences in triglyceride levels, which were higher in the CP, while in the males the differences were not of statistical significance (Tables 2 and 3). In relation to this, analysis of the prevalence of hypertriglycerides showed that the lowest frequency of hypertriglycerides was found in the NIP females (5.4%), and it was higher in the SIP (11.1%) and significantly higher in the CP (17.6%) (Table 4). In the males, the prevalences of hypertriglycerides were 18.5%, 12.4% and 19.8%, respectively. Therefore, in the NIP, a significant difference was found by both gender and levels of triglycerides.

Table 4: Prevalence of hypertriglyceridemia, overweight and obesity in females and males in the Arctic depending on ethnicity and lifestyle

Parameter	M/F	NIP (1)	SIP (2)	CP (3)	*p*-value for differences in lifestyle†	*p*-value for sex

Hypertriglyceridemia, %	M	18.5	12.4	19.8	>0.017	(1)=0.016
	F	5.4	11.1	17.6	(1)–(3)=0.009; (2)–(3)=0.013	
Overweight, %	M	30.8	41.7	45	>0.017	(2)=0.014 (3)=0.001
	F	38.9	29.6	28.3	>0.017	
Obesity, %	M	18.2	15.7	24.3	>0.017	(2)<0.001 (3)=0.006
	F	25.3	35.8	37.7	>0.017	
Overweight + obesity, %	M	49.3	57.4	69.3	(1)–(3)=0.006	>0.05
	F	64	65.4	66	>0.017	

† *p*-values were statistically significant after Bonferroni adjustment for multiple testing: $p<0.017$.

CP, Caucasian population. F, female. M, male. NIP, Indigenous reindeer herders leading a nomadic lifestyle. SIP, Indigenous people leading a sedentary lifestyle.

When considering features of the fatty acid profiles in the three groups, certain differences were found depending on the length of the carbon chain of fatty acids.

The highest levels of MCFAs were found in the SIP, therefore the total ∑MC was the highest in this group in both males and females (Tables 2 and 3). With an increase in the length of the C-chain, the highest levels of the main SFAs (C14:0, C16:0 and C18:0) and the minor VLCSFA (C20:0) in the females were recorded in the CP, whereas in the males a similar trend was only observed for C14:0 and C20:0. As for other LCSFAs and VLCSFAs, statistically significant differences were due to the fact that the lowest levels of C15:0, C21:0 and C22:0 were recorded in the NIP, of C23:0 in the CP females, and of C24:0 in the SIP females.

In accordance with the described differences in the levels of individual fatty acids, the maximum values of the total content of ∑LC and ∑SFA were found in the CP females; in the males, the insignificantly raised values were observed in the CP and the NIP. ∑VLC was the lowest in the SIP females; in the males, it was insignificantly reduced in the NIP (Tables 2 and 3).

The consumption of some types of food is represented in Table 5. Indigenous people consumed more vegetable oils, fatty dairy products, meat, carbohydrate-rich products and traditional foods, and less milk and sour-milk products. The female NIP and SIP differed in the consumption of traditional foods, milk and sour-milk products.

Table 5: Food intake in females and males in the Arctic, by ethnicity and lifestyle

Sex	Product(s)	Product intake (g/day) (median (25th percentile; 75th percentile))			*H*-test and *p*-value†
		NIP (1) 73 F, 49 M	SIP (2) 328 F, 86 M	CP (3) 201 F, 87 M	
Female	Carbohydrate-rich products	828.4 (476.3; 2282.3)	722.9 (511.2; 1651.9)	574.9 (398.9; 1049.6)	23.4; <0.001 (1)–(3), (2)–(3)<0.001
	Traditional foods	399.8 (199.3; 1266.7)	268.3 (137.4; 814.1)	95.5 (36.7; 228.6)	107.9; <0.001 (1)–(2)=0.013; (1)–(2), (2)–(3)<0.001
	Meat products	210.0 (135.3; 613.4)	188.9 (104.6; 548.6)	131.6 (79.1; 239.8)	28.6; <0.001 (1)–(3), (2)–(3)<0.001
	Dairy and sour-milk products	57.1 (0; 85.7)	85.7 (26.7; 171.4)	85.7 (57.1; 257.1)	40.2; <0.001 (1)–(2)=0.004; (1)–(3), (2)–(3)<0.001
	Fatty dairy products	26.4 (7.6; 101.4)	28.3 (12.7; 114.0)	22.5 (10.1; 88.1)*	3.0; 0.227
	Vegetable oils	29.1 (2.3; 200)	29.1 (2.5; 100)	5.9 (2.5; 100)	7.70; 0.021 (1)–(3)=0.034
Male	Carbohydrate-rich products	828.4 (549.6; 1881.6)	993.1 (593.0; 1911.4)*	636.8 (383.9; 933.0)	14.4; 0.001 (2)–(3)=0.001
	Traditional foods	254.6 (185.7; 840.9)	361.5 (124.0; 1281.9)	93.0 (34.2; 214.2)	40.6; <0.001 (1)–(3), (2)–(3)<0.001
	Meat products	200.0 (129.7; 313.2)	180.7 (88.5; 637.4)	122.2 (80.8; 225.6)	8.7; 0.013 (1)–(3)=0.027
	Dairy and sour-milk products	57.1 (13.3; 114.3)	66.7 (26.7; 114.3)	85.7 (57.1; 228.6)	8.5; 0.015 (1)–(3)=0.020
	Fatty dairy products	29.8 (13.1; 87.7)	27.8 (10.0; 200.0)	13.5 (6.8; 37.8)*	6.4; 0.042
	Vegetable oils	8.7 (1.6; 100)	29.1 (2.5; 200)	4.1 (1.7; 14.6)	7.4; 0.025 (2)–(3)=0.040

* Statistically significant differences by gender: for carbohydrate-rich products in the SIP $p=0.049$, for fatty dairy products in the CP $p=0.043$.

† *p*-values obtained using Dunn's test; $p<0.05$ values are shown.

CP, Caucasian population. F, female. M, male. NIP, Indigenous reindeer herders leading a nomadic lifestyle. SIP, Indigenous people leading a sedentary lifestyle.

The regression analysis confirmed the dependence of lipid parameters on ethnicity (Indigenous/Caucasian) and lifestyle (nomadic/sedentary) (Table 6). At the same time, the predictor of ethnicity has an inverse relationship for ∑MC, and a direct relationship for ∑LC, ∑VLC and triglycerides. The lifestyle was a significant factor only for MCSFAs. However, in females, triglycerides and LCSFA levels were also associated with age, and to a lesser extent with BMI. In males, age had almost no effect, and BMI was associated with triglycerides and LCSFA levels. Except for vegetable oils, the consumption of the considered product categories had little effect on the content of SFAs; separate dependencies were found for MCSFAs and VLCSFAs. The consumption of vegetable oils had a positive effect on the content of LCSFAs and VLCSFAs, especially in females, while males showed fewer significant dependencies (Table 7).

Table 6: Multiple linear regression coefficients (β) of lipid parameters (dependent variables) by ethnicity, lifestyle, age and BMI (predictor variables) in Arctic residents ($p<0.05$)

Dependent variable	Predictor variable							
	Ethnicity		Lifestyle		Age		logBMI	
	Female	Male	Female	Male	Female	Male	Female	Male

logBMI	–	–	–	–	0.30	–	–	–
logTG	0.11	–	–	–	0.20	–	0.30	0.18
logC6:0	–0.34	–0.29	0.09	–	–	–	0.09	–
logC8:0	–0.39	–0.44	0.13	0.22	–	–	–	–
logC10:0	–0.22	–	0.14	0.15	0.11	0.14	–	–
logC11:0	–0.19	–0.16	0.16	0.23	–	–	–	–
logC12:0	–0.15	–0.17	0.14	0.16	–	–	0.08	0.12
log∑MC	–0.23	–0.23	0.17	0.19	0.08	0.13	–	–
logC13:0	0.11	–	–	–	–	–	–	–
logC14:0	0.16	0.15	–	–	0.11	–	0.23	0.19
logC15:0	0.12	–	–	0.14	0.14	0.17	0.08	0.12
logC16:0	0.09	–	–	–	0.14	–	0.17	0.20
logC17:0	0.09	–	–	–	0.12	–	–	0.12
logC18:0	0.12	0.15	–	–	0.15	–	–	0.20
log∑LC	0.10	0.13	–	–	0.15	–	0.14	0.20
logC20:0	0.21	0.31	–	–0.19	–	–	–	0.12
logC21:0	0.11	–	–	0.18	–	–	–	–
logC22:0	–	–	–	–	–	–	–	–
logC23:0	–0.09	–	–	–	0.10	–	–	–
logC24:0	0.21	–	–0.09	–	–	–	–	–
log∑VLC	0.11	–	–	–	–	–	–	–
log∑SFA	0.10	–	–	–	0.15	–	0.14	0.21

∑MC, total medium-chain saturated fatty acid content. ∑LC, total long-chain saturated fatty acid content. ∑SFA, total saturated fatty acid content. ∑VLC, total very-long-chain saturated fatty acid content.

Table 7: Multiple linear regression coefficients (β) of lipid parameters (dependent variables) by food intake (predictor variables) in Arctic residents ($p<0.05$)

Dependent variable	Predictor variable[†¶]									
	Log (traditional foods)		Log (meat products)		Log (carbohydrate-rich products)		Log (fatty dairy products)		Log (vegetable oils)	
	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males
logBMI	–	–	–	–	–	–	–	–	–	–
logTG	–	–	–	–	–	–	–	–	–	–
logC6:0	–	0.37	–	–	–0.17	–	–	–	–	–0.28
logC8:0	–	0.29	–0.37	–0.25	–	–	–	–	–	–
logC10:0	–	0.30	–0.24	–0.23	–	–	–	–	0.20	–
logC11:0	–	–	–	–	–	–	0.12	–	–	–
logC12:0	–	–	–0.24	–0.29	–	–	–	–	0.26	–
log∑MC			–0.24	–0.31	–	–	–	–	0.21	–
logC13:0	–0.24	–	–	–	0.29	–	–	–	–	–
logC14:0	–	–	–	–	–	–	–	–	–	–
logC15:0	–	–	–	–	–	–	–	–	0.19	0.37
logC16:0	–	–	–	–	–	–	–	–	0.25	–
logC17:0	–	–	0.15	–	–	–	–	–	0.46	0.33
logC18:0	–	–	–	–	–	–	–	–	0.33	–
log∑LC	–	–	–	–	–	–	–	–	0.27	–
logC20:0	–	–	–	–	–	–	–	–	0.29	0.27
logC21:0	–	–	–	–0.26	–	–	–	–	0.29	–
logC22:0	–	–	–	–	–	–	–0.16	–	0.65	0.62
logC23:0	–	0.35	–	–	0.25	–	–0.15	–	0.17	–
logC24:0	–	–	0.18	–	0.21	–	–	–	0.22	0.40
log∑VLC	–	–	–	–	–	–	–	–	0.54	0.48
log∑SFA	–	–	–	–	0.11	–	–	–	0.28	–

[†] Consumption of dairy and sour-milk products has not become a significant predictor for lipid parameters.

[¶] In addition to food consumption, other predictors included in the models were ethnicity, lifestyle, age, and BMI.

∑LC, total long-chain saturated fatty acid content. ∑MC, total medium-chain saturated fatty acid content. ∑SFA, total saturated fatty acid content. ∑VLC, total very-long-chain saturated fatty acid content.

Discussion

One of the most notable features of lipid metabolism of the Indigenous people living in the North and the Arctic, compared with the Caucasian population, is considered to be a lower blood level of triglycerides[13,14,25-28]. Our study recorded such a difference only in the females; also, it recorded that the frequency of hypertriglycerides was the highest in the CP females. It should be noted that the prevalence of hypertriglycerides in the studied groups was lower than the average one for Russia, of 29.4%[29], and was similar to the data of other lipid metabolism studies performed among the Indigenous and non-Indigenous populations in the north of the Russian Federation[28,30,31], and the incidence of hypertriglycerides in the NIP females (5.4%) can be considered low. At the same time, according to some researchers, hypertriglyceridemia is more common among the Indigenous populations of Canada (25–38.6%) than among the Indigenous populations of the Russian North[32-34].

Lower levels of triglycerides in these Indigenous people might be explained by an increased activity of lipoprotein lipase, which hydrolyzes triglycerides that are part of chylomicrons and very-low-density lipoprotein cholesterol, while the latter are transformed into high-density lipoprotein cholesterol[13,14], and also due to changes in the activity of endothelial hormone-sensitive triglyceride lipases in connection with the changes in the endocrine system caused by living in the harsh conditions of the Arctic[3]. In addition, lower triglycerides may be connected with a high consumption of omega-3 polyunsaturated fatty acids with fish and marine mammal oil, which was observed in the Indigenous populations leading a traditional lifestyle[6,35,36]. According to our data, the higher the consumption of traditional foods, the lower the triglyceride levels; as a result, the maximum consumption of these products in the NIP females coincides with a minimal occurrence of hypertriglycerides. In part, this can also be due gender differences in the NIP, as well as the apparent different physical activity in women and men. In nomadic conditions, women's work is associated with fewer physically demanding subsistence practices[10]. The work of male reindeer herders in the tundra, often in difficult weather conditions (fogs, blizzards, winds, frosts), creates prerequisites for increased energy expenditure; higher levels of triglycerides may be an indicator of increased synthesis to reserve fat.

Studies of the Indigenous Peoples of the Arctic considering SFAs have described mainly C16:0 and C18:0. It should be noted that not only plasma/serum were studied, but also the fatty acid composition of erythrocytes, and lipids (phospholipids, triglycerides, cholesterol esters) of blood plasma/erythrocytes. A number of studies of Indigenous Peoples have shown that they tend to have higher SFA levels, primarily due to C16:0, compared with non-Indigenous populations[7,37-39]. Some studies did not establish ethnic differences in the SFA profile of the inhabitants of the Arctic[40], while others demonstrated a lower C16:0 content in Indigenous Peoples[7]. It was noted that as the consumption of traditional foods increased, the amount of SFAs consumed and the level of the main SFAs of the erythrocyte membrane (C16:0 and C18:0) remained unchanged, while blood triglyceride levels decreased[36]. Proust et al reported the invariance of serum SFAs with a shift away from traditional foods to more store-bought foods[8]. Lower triglyceride levels and BMI among females have been reported in Greenland in Indigenous people consuming a traditional diet compared to those consuming a western diet, with equally high levels of physical activity[41]. de Knijff et al reported that Inuit consuming a western diet showed lower relative contributions of C16:0 when compared with Inuit consuming a traditional Inuit diet[42]. Zhou et al, in contrast, argued that higher levels of SFAs as well as trans fatty acids in inland Canadian Inuit compared to coastal Inuit were associated with greater westernization of diet[43]. Thus, discrepancies are recorded when comparing the fatty acid profile of the Indigenous and non-Indigenous populations of the Arctic, as well as when assessing the impact of adherence to a traditional diet. We found an increase in the level of LCSFAs (C14:0, C16:0, C18:0) and triglycerides in the blood serum of non-Indigenous relative to Indigenous people.

Plasma lipid concentrations are the net result of the balance between two opposite processes: loading (entry of new lipids into the plasma compartment through ingestion (diet) and/or endogenous synthesis) and unloading (energy utilization, incorporation into cell membranes, and storage)[44]. Despite the fact that SFAs are synthesized in the body, a dietary component is also important. The qualitative composition of incoming fats, the amount of carbohydrates, proteins, and their ratio, play a role in the formation of the fatty acid profile. Saturated fats and carbohydrates are the main dietary components that stimulate the accumulation of lipids[44]. It has been shown that carbohydrates stimulate de novo lipogenesis, increase plasma fasting and postprandial very-low-density lipoprotein triacylglycerols, and decrease lipolysis and whole-body lipid oxidation[45,46]. Saturated fats, by contrast, increase adipose tissue lipolysis, and they induce an increase in intrahepatic triglycerides. Excessive consumption of SFAs can cause insulin resistance and raise serum low-density lipoprotein cholesterol level[47], whereas diets containing unsaturated fat and high protein appear to play a protective role[47,48]. Dietary polyunsaturated fatty acids have beneficial effects in maintaining lipid homeostasis, promoting loss of adiposity by increasing lipolysis and fatty acid oxidation, and inhibiting lipogenesis[46].

The main dietary sources of SFAs are meat and dairy products. However, our regression analysis showed that their consumption is not a significant predictor for serum SFAs; only consumption of meat products negatively affected the levels of MCSFAs. At the same time, the maximum concentrations of MCSFAs in the SIP may partly be mediated by high consumption of dairy products, since they have a higher level of SCSFAs and MCSFAs compared to other food products[49]. The revealed positive associations of consumption of vegetable oils (sources of omega-6 fatty acids) with SFAs are unexpected, but the links with VLCSFAs and their high values of β coefficients can be explained by the fact that vegetable oils are distinguished by the content of these acids[24]. In part, these associations may be due to the high consumption of vegetable oils in the NIP and SIP groups, especially among women. However, given the low consumption of plant foods by the northern Indigenous population, the opposite trend might have been expected. The observed characteristic probably reflects a higher use of vegetable oils for cooking compared to animal fats by the Indigenous groups. This, together with the high consumption of carbohydrate foods, may indicate a change in dietary patterns among the nomadic and sedentary populations of the Arctic. In addition, the seasonal dependence of food

consumption may have had an effect. Among the Indigenous Peoples of the North, the availability of certain products may be determined by the season of the year, partly due to the level of participation in subsistence farming[16,50].

Thus, we can say that the CP predominantly had a westernizing diet (commercial foods), with low consumption of a traditional diet, whereas the diet of the Indigenous population could be described as a mixed traditional–western diet, based on market foods (excess of simple carbohydrates and saturated fat) and traditional products, including traditional fish (omega-3 polyunsaturated fatty acids and proteins).

Considering what has been written above about the formation of a lipid pool, it can be summarized that a higher level of serum LCSFAs and triglycerides in the CP is probably due to a violation of the balance of lipolytic and lipogenic pathways of metabolism of fatty acids, including mitochondrial and peroxisomal β-oxidation, and the non-esterified fatty acids uptake, which may partly be due to differences in diet.

The established features of fat metabolism were mainly found in the females in our study, although they did not have a statistically significant difference in the BMI, whereas BMI was significantly higher in the Caucasian males compared to the Indigenous populations due to a higher frequency of overweight and obesity. These differences may be due to the 'gender specificity' of obesity, which is caused by the different effects of sex hormones[51]. This is reflected in the significant gender differences in the populations leading a sedentary lifestyle (the SIP and the CP) in relation to overweight and obesity, with overweight being more common in the males and obesity in the females.

It is noteworthy that changes in the levels of both triglycerides and LCSFAs (C16:0 and C18:0) in the males did not reach statistical significance, despite the fact that concentrations of C16:0 and C18:0, ∑LC and the frequency of hypertriglycerides in the NIP males were the same as in the CP males. However, the NIP males tended to have the lowest BMI and frequency of overweight and obesity. The features of lipid metabolism found in the study, as well as the distribution of metabolic parameters in the three groups shown in Table 1, may indicate the preservation of an adaptive type of metabolism (with intensification of lipid metabolism and balance of its main indicators) aimed at reducing the deposition of LCFAs in triglycerides and the storage of the latter in adipose tissue when there is a high demand for energy resources to live and do traditional jobs in the harsh and cold climate of the Arctic. Indeed, Indigenous circumpolar populations have exhibited an elevated basal metabolic rate and, as a result, may have a higher total energy expenditure and be less likely to deposit excess energy in adipose tissue[4,52].

The prevailing lipid component in the SIP energy metabolism can be expressed in an increased contribution of MCFAs when oxidation of LCSFAs becomes more intense. Growing concentrations of MCFAs when there is a reduction in the levels of the main LCSFAs C16:0 and C18:0 may be of a compensatory nature, compared to the NIP. The effect of MCSFAs on lipid metabolism is manifested by an increase in fatty acid β-oxidation following an increase in energy expenditure and thermogenesis due to stimulation of brown adipose tissue activity. It has been shown that mature white adipocytes can transform into brown fat-like adipocytes when exposed to specific stimuli such as cold[53]. This may explain the growing role of MCFAs in the SIP, who are experiencing a transition from a traditional lifestyle, with a change in diet and a decrease in physical activity. In general, higher levels of MCSFAs in the SIP can be considered favorable manifestations of fatty acid metabolism. Since MCFAs are metabolized differently than long-chain fatty acids, they are predominantly used as energy carriers, while LCFAs are more likely to be stored in adipose tissue, especially when they are consumed in excess[54].

Conclusion

The surveyed males and females living in the Russian Arctic showed different metabolic adaptations depending on ethnicity (Indigenous or Caucasian) and lifestyle (nomadic or sedentary). In the CP, an increase in serum LCSFAs and triglycerides could serve as a manifestation of an imbalance in the processes of accumulation and expenditure of lipids.

The Indigenous Peoples, despite some changes in diet towards an increased consumption of carbohydrate-rich products, preserved an adaptive metabolism, with the predominant use of lipids as energy resources. This was accompanied by a lower total incidence of overweight and obesity in the Indigenous males and by low frequency of hypertriglycerides with a decrease in LCSFA level in the females. Compared to the NIP, higher serum levels of MCSFAs in the SIP – who led a sedentary lifestyle, were less adherent to a traditional diet and did not do traditional jobs – may be compensatory, with the growing role of such fatty acids in energy consumption and thermogenesis.

Maintaining the necessary metabolic organization is at risk among the Indigenous populations, as among the males there were identical concentrations of triglycerides and C16:0 in the NIP and the CP, while among the females there was an identical frequency of overweight and obesity in the Indigenous and Caucasian populations. As a result, the risk of the appearance and development of various metabolic diseases that were previously unusual for Arctic populations may increase.

A strength of the study is the focus on SFA metabolism in the Indigenous and Caucasian populations of the Arctic. SFAs are not often in focus, as much attention is paid to the metabolism of polyunsaturated fatty acids, especially omega-3, and their effects on the physiology and health of Indigenous Peoples. A wide range of SFAs has been studied, including fatty acids with an odd number of C-atoms of the hydrocarbon chain. Also, the fatty acid profile of the Indigenous populations of the Russian Arctic is an underresearched area, and its definition was carried for the first time among the Nenets. Since the SFA level is determined by both endogenous synthesis and exogenous intake with food, the study demonstrated the consumption of food products that can contribute to the formation of the characteristics of the considered indicators of lipid metabolism: triglycerides and SFAs. The results show the importance of traditional nutrition for the metabolic health of Arctic populations. Two groups of Indigenous populations with differing lifestyles were also considered, one of which continues to do traditional jobs established over centuries of living in the conditions of the North.

A limitation of this study is the smaller number of participants who underwent dietary questionnaires compared to those with biochemical indicators, as well as the uneven distribution of

subjects among the three groups, as there were fewer participants in the NIP than in the SIP and the CP, and a smaller number of male participants compared to female participants in the sedentary lifestyle groups. In addition, a limitation of the frequency method for studying nutrition is that study participants may not have mentioned the consumption of certain foods, and portion sizes may have been underestimated or overestimated.

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Conflicts of interest

The authors report no conflicts of interest.

Data availability

Data described in the manuscript will not be made available due to confidentiality and ethical restrictions.

References

1 Panin LE. Homeostasis and problems of circumpolar health (methodological aspects of adaptation). [In Russian]. *Bulletin of Siberian Branch Russian Academy of Medical Sciences* 2010; **30(3):** 6-11.

2 Boyko ER, Bichkaeva FA. Metabolic patterns in humans in the conditions of the Far North. In: Yu.G. Solonin (Ed.). *Physiological patterns of hormonal, metabolic and immunological changes in the human body in the European North.* [In Russian]. Syktyvkar: Institute of Biology of Komi Scientific Centre of the Ural Branch of the Russian Academy of Sciences, 1997; 34-43.

3 Boyko ER. *Physiological and biochemical bases of human life in the North.* [In Russian]. Ekaterinburg: Ural Branch of the Russian Academy of Sciences, 2005.

4 Leonard WR, Snodgrass JJ, Sorensen MV. Metabolic adaptation in indigenous Siberian populations. *Annual Review of Anthropology* 2005; **34:** 451-471. DOI link

5 Tkachev AV, Boyko ER, Gubkina ZD, Ramenskaya EB, Sukhanov SG. *Endocrine system and metabolism in humans in the North.* [In Russian]. Syktyvkar: Institute of Biology of Komi Scientific Centre of the Ural Branch of the Russian Academy of Sciences, 1992.

6 Young TK, Nikitin Y, Shubnikov EV, Astakhova TI, Moffat MEK, O'Neil JD. Plasma lipids in two Indigenous Arctic populations with low risk for cardiovascular diseases. *American Journal of Human Biology* 1995; **7:** 223-236. DOI link, PMid:28557210

7 Young TK, Gerrard JM, O'Neil JD. Plasma phospholipid fatty acids in the central Canadian Arctic: biocultural explanations for ethnic differences. *American Journal of Physical Anthropology* 1999; **109(1):** 9-18. DOI link

8 Proust F, Lucas M, Dewailly E. Fatty acid profiles among the Inuit of Nunavik: current status and temporal change. *Prostaglandins, Leukotrienes and Essential Fatty Acids* 2014; **90(5):** 159-167. DOI link, PMid:24582818

9 Vloschinsky PE, Panin LE. Dietary patterns, state of energy metabolism and endocrine status in organized groups in the North. [In Russian]. *Bulletin of Ural Medical Academic Science* 2014; **2:** 11-15.

10 Yakovleva NV. *Traditional diet of residents of the North.* [In Russian]. Arkhangelsk: Pomor University, 2005.

11 Johnson JS, Nobmann E, Asay E, Lanier AP. Dietary intake of Alaska Native people in two regions and implications for health: the Alaska Native Dietary and Subsistence Food Assessment Project. *International Journal of Circumpolar Health* 2009; **68(2):** 109-122. DOI link, PMid:19517871

12 Sevostyanova YeV. Some features of human lipid and carbohydrate metabolism in the North. [In Russian]. *Bulletin of Siberian Medicine* 2013; **12(1):** 93-100. DOI link

13 Polyakov LM, Rozumenko AA, Osipova LP, Kunitsyn VG, Goltsova TV. Serum lipid spectrum of indigenous and alien population of Yamalo-Nenets Autonomous Okrug. [In Russian]. *Siberian Scientific Medical Journal* 2015; **35(6):** 66-69.

14 Kim LB, Osipova LP, Rozumenko AA, Putyatina AN, Russkikh GS, Kozaruk TV, et al. Lipid spectrum features and relationship between specific classes of lipids and sex hormone levels in Asian North men. [In Russian]. *Yakut Medical Journal* 2019; **3:** 27-31. DOI link

15 Sharma S. Assessing diet and lifestyle in the Canadian Arctic Inuit and Inuvialuit to inform a nutrition and physical activity intervention programme. *Journal of Human Nutrition and Dietetics* 2010; **23:** 5-17. DOI link, PMid:21158957

16 McCartan J, van Burgel E, McArthur I, Testa S, Thurn E, Funston S, et al. Traditional food energy intake among Indigenous populations in select high-income settler-colonized countries: a systematic literature review. *Current Developments in Nutrition* 2020; **4(11):** nzaa163. DOI link, PMid:33274307

17 Little M, Hagar H, Zivot C, Dodd W, Skinner K, Kenny T-A, et al. Drivers and Health Implications of the dietary transition among Inuit in the Canadian Arctic: A scoping review. *Public Health Nutrition* 2021; **24(9):** 2650-2668. DOI link, PMid:32914743

18 Akande VO, Hendriks AM, Ruiter RAC, Kremers SPJ. Determinants of dietary behavior and physical activity among Canadian Inuit: a systematic review. *International Journal of Behavioral Nutrition and Physical Activity* 2015; **12:** 84. DOI link, PMid:26104152

19 Young TK, Bjerregaard P. Towards estimating the indigenous population in circumpolar regions. *International Journal of Circumpolar Health* 2019; **78(1):** 1653749. DOI link, PMid:31438808

20 Martinchik AN, Baturin AK, Baeva VS, Peskova EV. Study of actual nutrition by analyzing the frequency of food consumption: creating a questionnaire and evaluating the reliability of the method. [In Russian]. *Russian Journal of Preventive Medicine* 1998; **5:** 14-19.

21 Martinchik AN, Baturin AK, Baeva VS, Peskova EV, Larina TI, Zaburkina TG. *Food portion and dish album.* [In Russian]. Moscow: Institute of Nutrition of the Russian Academy of Medical Sciences, 1995.

22 Bichkaeva FA, Baranova NF, Vlasova OS, Tretyakova TV, Nesterova EV, Shengof BA, et al. *Measurement procedure for mass concentration of fatty acid methyl esters (FAME) in blood serum by gas-liquid chromatography method.* Certificate of Attestation of Measurement procedure № 88-16365-004-75 RA. RU.31065- 21 February 2019, FR.1.31.2019.33472.

23 Huang L, Gao L, Chen C. Role of medium-chain fatty acids in healthy metabolism: a clinical perspective. *Trends in Endocrinology and Metabolism* 2021; **32(6):** 351-366. DOI link, PMid:33832826

24 Lemaitre RN, King IB. Very long-chain saturated fatty acids and diabetes and cardiovascular disease. *Current Opinion in Lipidology* 2022; **33(1):** 76-82. DOI link, PMid:34907969

25 Boyer BB, Mohatt GV, Plaetke R, Herron J, Stanhope KL, Stephensen C, et al. Metabolic syndrome in Yup'ik Eskimos: the Center for Alaska Native Health Research (CANHR) Study. *Obesity (Silver Spring)* 2007; **15(11):** 2535-2540. DOI link, PMid:18070741

26 Voevoda MI, Romanova AN, Ragino YI, Semaeva EV. Some features of coronary atherosclerosis risk factors in the inhabitants of Yakutia. [In Russian]. *Siberian Scientific Medical Journal* 2010; **30(3):** 52-57.

27 Ryabova TI, Popova TV, Sirotin BZ. The characteristics of lipid spectrum of blood serum in native and alien population in Amur region. [In Russian]. *Russian Clinical Laboratory Diagnostics* 2012; **2:** 25-27.

28 Krivoshapkina ZN, Mironova GE, Semyonova EI, Olesova LD. Biochemical spectrum of blood serum as indicator of Yakutia residents adaptedness to northern conditions. [In Russian]. *Human Ecology* 2015; **11:** 19-24. DOI link

29 Karpov YuA, on behalf of the participants of the PROMETHEUS Study. Prevalence of hypertriglyceridemia: new data across the Russian population. [In Russian]. *Kardiologiia* 2016; **56(7):** 63-71.

30 Lyudinina AY, Potolitsyna NN, Solonin YG, Osadchuk LV, Gutorova NV, Petrova PG, et al. Lipid profile in men of Komi and Yakut ethnic groups with overweight and obesity. [In Russian]. *Human Ecology* 2014; **1:** 13-19. DOI link

31 Klimova TM, Egorova AG, Zakharova RN, Ammosova EP, Baltakhinova ME, Fedorov AI, et al. Metabolic syndrome among Yakutia's indigenous female population. [In Russian]. *Yakut Medical Journal* 2019; **3:** 66-69. DOI link

32 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. *Canadian Medical Association Journal* 2011; **183(9):** E553-E558. DOI link, PMid:21555386

33 Proust F, Drescher O, Laouan-Sidi EA, Robinson E, Lucas M, Dewailly E. Omega-3 polyunsaturated fatty acid profiles and relationship with cardiometabolic risk factors in Cree (Eeyouch) of Northern Québec. *International Journal of Circumpolar Health* 2016; **75(1):** 30361. DOI link, PMid:27427488

34 Lavigne-Robichaud M, Moubarac JC, Lantagne-Lopez S, Johnson-Down L, Batal M, Laouan-Sidi AE, et al. Diet quality indices in relation to metabolic syndrome in an Indigenous Cree (Eeyouch) population in northern Québec. *Public Health Nutrition* 2018; **21(1):** 172-180. DOI link, PMid:28683844

35 Ebbesson SOE, Risica PM, Ebbesson LOE, Kennish JM, Tejero ME. Omega-3 fatty acids improve glucose tolerance and components of the metabolic syndrome in Alaskan Eskimos: the Alaska Siberia project. *International Journal of Circumpolar Health* 2005; **64(4):** 396-408. DOI link, PMid:16277123

36 Bersamin A, Luick BR, King IB, Stern JS, Zidenberg-Cherr S. Westernizing diets influence fat intake, red blood cell fatty acid composition, and health in remote Alaskan Native communities in the Center for Alaska Native Health Study. *Journal of the American Dietetic Association* 2008; **108(2):** 266-273. DOI link, PMid:18237575

37 Dyerberg J, Bang HO, Hjorne N. Fatty acid composition of the plasma lipids in Greenland Eskimos. *American Journal of Clinical Nutrition* 1975; **28:** 958-966. DOI link, PMid:1163480

38 Gerasimova EN, Levachev MM, Perova NV, Nikitin YP, Ozerova IN, Kulakova SN, et al. Specific characteristics of the fatty acids composition of phosphatidyl cholines and sphingomyelins in low density lipoproteins from blood plasma of Chukot aborigines. [In Russian]. *Voprosy Meditsinskoi Khimii* 1986; **32(2):** 66-72.

39 Innis SM, Kuhnlein HV, Kinloch D. The composition of red cell membrane phospholipids in Canadian Inuit consuming a diet high in marine mammals. *Lipids* 1988; **23:** 1064-1068. DOI link, PMid:3237006

40 Lyudinina A, Eseva TV, Potolitsyna NN, Chernykh AA, Bojko ER. Fatty acids composition and food consumption among reindeer herders and urban inhabitants of the European North of Russia. *Rural and Remote Health* 2014; **14(2):** 2539. DOI link, PMid:24959699

41 Munch-Andersen T, Olsen DB, Søndergaard H, Daugaard JR, Bysted A, Christensen DL, et al. Metabolic profile in two physically active Inuit groups consuming either a western or a traditional Inuit diet. *International Journal of Circumpolar Health* 2012; **71:** 17342. DOI link, PMid:22456044

42 de Knijff P, Johansen LG, Rosseneu M, Frants RR, Jespersen J, Havekes LM. Lipoprotein profile of a Greenland Inuit population. Influence of anthropometric variables, Apo E and A4 polymorphism, and lifestyle. *Arteriosclerosis, Thrombosis, and Vascular Biology* 1992; **12(12):** 1371-1379. DOI link, PMid:1450169

43 Zhou Y, Kubow S, Egeland GM. Highly unsaturated n-3 fatty acids status of Canadian Inuit: International Polar Year Inuit Health Survey, 2007-2008. *International Journal of Circumpolar Health* 2011; **70(5):** 498-510. DOI link, PMid:22005729

44 Visioli F, Crawford MA, Cunnane S, Rise P, Galli C. Lipid transport, dietary fats, and endogenous lipid synthesis: hypotheses on saturation and competition processes. *Nutrition and Health* 2006; **18(2):** 127-132. DOI link, PMid:16859175

45 Lê KA, Ith M, Kreis R, Faeh D, Bortolotti M, Tran C, et al. Fructose overconsumption causes dyslipidemia and ectopic lipid deposition in healthy subjects with and without a family history of type 2 diabetes. *American Journal of Clinical Nutrition* 2009; **89:** 1760-1765. DOI link, PMid:19403641

46 Saponaro C, Gaggini M, Carli F, Gastaldelli A. The subtle balance between lipolysis and lipogenesis: a critical point in metabolic homeostasis. *Nutrients* 2015; **7(11):** 9453-9474. DOI link, PMid:26580649

47 Hydes T, Alam U, Cuthbertson DJ. The impact of macronutrient intake on non-alcoholic fatty liver disease (NAFLD): too much fat, too much carbohydrate, or just too many calories? *Frontiers in Nutrition* 2021; **8:** 640557. DOI link, PMid:33665203

48 Luukkonen PK, Sädevirta S, Zhou Y, Lallukka S, Pelloux V, Gaggini M, et al. Saturated fat is more metabolically harmful for the human liver than unsaturated fat or simple sugars. *Diabetes Care* 2018; **41(8):** 1732-1739. DOI link, PMid:29844096

49 Schönfeld P, Wojtczak L. Short- and medium-chain fatty acids in energy metabolism: the cellular perspective. *Journal of Lipid Research* 2016; **57(6):** 943-954. DOI link, PMid:27080715

50 Levy SB, Leonard WR, Tarskaia LA, Klimova TM, Fedorova VI, Baltakhinova ME, et al. Lifestyle mediates seasonal changes in metabolic health among the Yakut (Sakha) of northeastern Siberia. *American Journal of Human Biology* 2016; **28(6):** 868-878. DOI link, PMid:27292232

51 Mauvais-Jarvis F. Sex differences in metabolic homeostasis, diabetes, and obesity. *Biology of Sex Differences* 2015; **6:** 14. DOI link, PMid:26339468

52 Levy SB, Klimova TM, Zakharova RN, Federov AI, Fedorova VI, Baltakhinova ME, et al. Brown adipose tissue, energy expenditure, and biomarkers of cardio-metabolic health among the Yakut (Sakha) of northeastern Siberia. *American Journal of Human Biology* 2018; **30:** e23175. DOI link, PMid:30368978

53 Gao Y, Liu Y, Han X, Zhou F, Guo J, Huang W, et al. Coconut oil and medium-chain fatty acids attenuate high-fat diet-induced obesity in mice through increased thermogenesis by activating brown adipose tissue. *Frontiers in Nutrition* 2022; **9:** 896021. DOI link, PMid:36386906

54 Montgomery MK, Osborne B, Brown SH, Small L, Mitchell TW, Cooney GJ, et al. Contrasting metabolic effects of medium- versus long-chain fatty acids in skeletal muscle. *Journal of Lipid Research* 2013; **54(12):** 3322-3333. DOI link, PMid:24078708