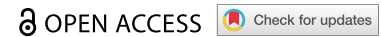


Original Research Article



No association of BMI and body adiposity with cardiometabolic biomarkers among a small sample of reindeer herders of sub-Arctic Finland

Cara Ocobock^{a,b}, Päivi Soppela^c and Minna T. Turunen^c

^aDepartment of Anthropology, University of Notre Dame, Notre Dame, IN, USA; ^bEck Institute for Global Health, Institute for Educational Initiatives, University of Notre Dame, Notre Dame, IN, USA; ^cArctic Centre, University of Lapland, Rovaniemi, Finland

ABSTRACT

The rising global obesity rate is alarming due to its real health and socioeconomic consequences. Finland, like other circumpolar regions, is also experiencing a rise in obesity. Here we assess BMI, body adiposity, and measures of cardiometabolic health among a small population of reindeer herders in sub-Arctic Finland. We collected anthropometric and biomarker measures at two different time points: October 2018 (N = 20) and January 2019 (N = 21) with a total of 25 unique individuals across the data collection periods (ages 20–64). Anthropometric measures included height, weight, age, and body composition. Biomarkers included measures of cholesterol, fasting glucose, HDL cholesterol, LDL cholesterol, and triglyceride levels. Over 70% of this sample was classified as “overweight” and “obese” as categorised by BMI and 64% classified as “overfat” based on body fat percentage. However, there was no significant relationship between BMI and body fat percentage with any of the measured biomarkers. Although the sample size is small, the results of this study suggest there might not be a strong correlation between BMI, body adiposity, and cardiometabolic health indices within this population – a pattern that has been documented elsewhere. However, further study is needed to confirm this lack of a correlation.

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Introduction

In 2016, over 39% of the global adult population was considered “overweight” (based on body mass index, BMI kg/m², of 25 to <30) and over 13% were considered “obese” (BMI ≥ 30), and percentages have since increased [1]. This accelerating rise in the global obesity rate is alarming due to the very real health and socioeconomic consequences [2,3]. Socioeconomic consequences include rising hospital, medical intervention, and prescription medication costs, to name a few [3]. Obesity often also carries numerous comorbidities such as hypertension, hyperlipidaemia, high cholesterol, type 2 diabetes, osteoarthritis, some cancers, and coronary heart disease among others [1,4–6]. In order to assess if an individual has obesity and/or suffers from poor cardiometabolic health, BMI is calculated along with measuring various biomarkers (fasting glucose, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein, and triglyceride levels) [7,8]. However, it should be noted that BMI does not take body composition, particularly body adiposity vs. fat-free mass, into account [9–11], and there is a growing body of evidence that BMI does not accurately indicate obesity nor metabolic risk factors similarly across different populations [12–14]. As such, there are also body fat percentage cut-offs

to determine “overfat”, which often has a similar relationship to cardiometabolic risk factors as does BMI [1,15].

Cardiometabolic health among circumpolar populations largely follows a global pattern of rising obesity rates and obesity comorbidities. However, a unique relationship between obesity and cardiometabolic markers among circumpolar populations has been documented in the recent past. For example, despite a high rate of obesity, numerous Indigenous circumpolar populations exhibited fasting glucose and lipid levels within the normal range, but also commonly exhibited hypertension [16–22]. Some have suggested that this mosaic pattern is driven by a combination of cold climate adaptations and behaviour such as increased metabolic rate, which may increase blood pressure, and participation in traditional subsistence activities that would keep cardiometabolic biomarkers within normal ranges [8,19,23–26]. More recently, work among the Yakut of Siberia found evidence that comorbidities often associated with obesity may be mediated by lifestyle such that individuals who more regularly participate in subsistence activities and consume more traditional diets have more favourable cardiometabolic

profiles [8,27,28]. However, greater market integration, which leads to reduced physical activity and a greater reliance on processed, refined foods, is driving a higher incidence of poor cardiometabolic health among circumpolar populations [8,24,25,27,29–31].

Finland, the site of the present study, is no exception to the global obesity trend with over 22% of the Finnish population considered “obese” [32]. Furthermore, Finland has some of the highest rates of cardiovascular disease in the world, though this is declining [33–35]. However, less is known about reindeer herders in Finland who are highly physically active due to participation in subsistence practices [36,37], and exhibit an unusual metabolic pattern with females having higher resting metabolic rates than males [38]. Here we examine the relationship between BMI, body adiposity, and cardiometabolic health biomarkers (fasting glucose, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein, and triglyceride levels) among a small sample of highly active cold climate population of reindeer herders from sub-Arctic Finland. Due to the small sample size, this work is descriptive in nature, but adds to the complicated picture of circumpolar population health and helps inform hypotheses regarding the relationship between obesity and health.

Methods

This study is part of a larger project, “The metabolic cost of living among reindeer herders in northern Finland, 2017–2020” assessing the biological and cultural mechanisms for coping with a highly demanding occupation in an extreme cold environment. This larger project incorporated measurements of resting metabolic rate [38], brown adipose tissue activity [39], total energy expenditure [36], and ethnographic interviews [37]. Reindeer herders in Finland are both Indigenous Sami and Finnish, and their herding work blends traditional and modern technologies and practices [37]. The data presented here are from two different time points: October of 2018 just prior to the autumn herd roundup and January 2019.

This study was conducted with Institutional Review Board approval from the University at Albany (17-E-165) and with the approval of the Northern Ostrobothnian Health Care District from the University of Oulu, Finland (EETMK: 4/2018). Participants were provided with an oral introduction and a written information sheet about the study, and informed written consent (written in Finnish) was obtained from all participants [40].

Participant population

Participants (October 2018: 20–62 years old, $N = 20$, 5 females and 15 males; January 2019: 20–64 years old, $N = 21$, 6 females and 15 males) were recruited from herding districts within 180 km Rovaniemi, Finland (66.5°N, 25.7°E). Four females and 12 males took part in both data collection periods. Participating females in this study were not pregnant or lactating at the time of data collection; menstrual cycle data were not collected at this time. The disproportionate number of males in this sample is representative of the female-to-male ratio among active herders [41]. Data collection took place in the mornings at either the Arctic Centre of the University of Lapland in Rovaniemi, Finland or in herders’ homes, cabins, or a hotel room near the herding district of interest when participants were fasted.

The autumn data collection took place during the second week of October 2018, when the mean temperature was 1°C [42]. This occurred just before the autumn herd roundup during which herders gather reindeer from their summer pastures, administer preventative parasite medication, ear mark calves, return stray reindeer to their proper herding districts, separate animals to be slaughtered from those spared, and process the meat from slaughtered reindeer [37,41]. The winter data collection took place in the final 2 weeks of January 2019, when the mean temperature was –16.5°C [42]. During the winter, herders are occupied with daily reindeer feeding in the winter enclosures, bookkeeping, and sometimes tourism [37]. We have provided a more detailed description of reindeer herding and of the herders elsewhere [37,38].

Anthropometrics

All anthropometric measures were taken in the morning before participants had eaten or consumed coffee. Participants were asked to refrain from alcohol consumption the day before scheduled measurements. Height, weight, and body composition measurements were all performed according to the standard protocol [43]. We used a portable stadiometer (Seca Corporation, Hanover, MD) to record height to the nearest 1 mm. We used an electronic scale (AccuWeight, New York, NY) to record weight to the nearest 0.1 kg. We measured body composition using bioelectrical impedance (RJL systems, Clinton, MI), for which participants were in a supine position either on a cot or the floor. We placed small electrodes on the dorsum of the wrist, middle finger, ankle, and middle toe all on the right side of the body. We recorded reactance and resistance and used preset standard NHANES-III equations to determine fat-free mass and body fat percentage

[44]. Four-site skinfold thicknesses were also collected and measured. However, there was no significant difference between the bioelectric impedance values and skinfold measures [38]. Only bioelectrical impedance results were used for further analysis.

Biomarkers

For both October 2018 and January 2019 data collection periods, we measured blood fasting glucose, total cholesterol, and high-density lipoprotein (HDL) cholesterol using a CardioChek PA. The CardioChek portable professional blood test device was fitted with fasting glucose and lipid panel test strips (Polymer Technology Systems, Inc., Indianapolis, IN). Finger-stick capillary whole blood samples were taken in the morning before participants had eaten. Blood samples were analysed using the CardioChek PA manufacturer's instructions and standard procedure [8,45,46]. Validations of the CardioChek PA have demonstrated that the system provides accuracy within 10% of serum reference values [45]. Fasting glucose, total cholesterol, and HDL cholesterol results from the CardioChek PA were reported and recorded in mmol/L.

For the January 2019 data collection, we had the opportunity to collect and analyse venous whole blood samples to measure fasting glucose, total cholesterol, HDL cholesterol, low-density lipoprotein cholesterol, and triglyceride levels. As such, there were fewer overall participants with measures of LDL cholesterol and triglyceride levels. Blood samples were collected in 6 mL EDTA tubes (BD Vacutainer), plasma separated by centrifuging the samples at 1700 g for 10 minutes (+4°C), aliquoted to 1.5 mL Eppendorf tubes and frozen at -20°C and stored in a -70°C freezer until analysed at a clinical lab (NordLab, Oulu, Finland). One female and two male participants declined having their blood drawn.

We used paired t-tests to compare January 2019 measurements conducted with the CardioChek PA to the whole blood sample analysis. We found a significant difference (reported in results) for total cholesterol and HDL cholesterol levels with the CardioChek underestimating total cholesterol levels by 18.33% and overestimating HDL cholesterol by 10.9%, as such we used these percentages as correction factors to apply to all of the CardioChek total and HDL cholesterol values. We used these corrected values for the analysis.

Statistical analysis

Data were normally distributed ($p > 0.06$ in all cases) and are presented as min-max ranges in the text and as means \pm the standard deviation in tables. We used

one-way ANOVA with a Bonferroni correction for repeat participants across the two measurement periods to compare anthropometric and biomarker values between the two data collection periods. Power analysis was performed using G* Power 3.1 open-source software. A sample size of 20 subjects provides over 78% power to detect significant differences ($\alpha = 0.05$, effect size = 0.65). There were no significant differences found in any of the measures between the two data collection periods (reported in results), and as such, the data from both periods were pooled to conduct multiple linear regression analyses to determine the effect BMI, age, sex, and body fat percentage on cholesterol ($N = 25$), fasting glucose ($N = 25$), and HDL cholesterol ($N = 25$). Measures from repeat participants were averaged and treated as a single individual for regression analysis. We performed the same multiple regression analysis of LDL ($N = 18$) and triglyceride level ($N = 18$) data from January 2019. We also performed simple linear regressions to determine the effect of just BMI alone and just body fat percentage alone on total cholesterol, fasting glucose, HDL cholesterol, LDL cholesterol, and triglyceride levels. We conducted all the analyses using SPSS version 26 (IBM, Armonk, NY), and the results were considered significant at the $p = 0.05$ level.

Results

Participant anthropometrics

Participant anthropometrics for the October and January data collections can be found in Table 1. There was no significant difference between the two measurement periods (fall $N = 20$, winter $N = 21$) for age ($p = 0.41$), weight ($p = 0.78$), height ($p = 0.68$), BMI ($p = 0.89$), body fat percentage ($p = 0.63$), or fat-free mass ($p = 0.65$). For the pooled sample of $N = 25$, age ranged from 20 to 64 years old, weight ranged from 46.7 to 129.6 kg, height ranged from 154.8 to 195.0 cm, BMI ranged from 19.5 to 34.2 kg/m², body fat percentage ranged from 17.7% to 40.6%, and fat-free mass ranged from 34.2 to 91.3 kg. When comparing the sexes, there was no significant difference for BMI ($p = 0.155$). Females had a significantly higher body fat percentage than males ($F(1,40) = 35.109$, $p < 0.001$). Males were significantly heavier ($F(1,40) = 21.004$, $p < 0.001$), taller ($F(1,40) = 72.759$, $p < 0.001$), had more fat-free mass ($F(1,40) = 56.080$, $p < 0.001$), and were significantly older than females ($F(1,40) = 11.705$, $p = 0.001$).

Table 1. Summary of the anthropometrics for the herders in the October 2018 and January 2019 data collection periods. The age and sex categories have been removed to protect participant confidentiality.

Participant	Height (cm)	Weight (kg)	BMI (kg/m ²)	Body Fat %	Fat-free mass (kg)
<i>October 2018 Data Collection</i>					
4	163	81.3	30.6	37.9	50.5
5	194.6	128.6	34	29	91.3
7	178	78	24.6	21.4	50.9
8	179	87	27.2	28.6	61.9
9	195	88	23.1	21.5	68.1
10	173	65	21.7	22.1	52.2
11	183.5	83.9	24.9	21.5	65.9
12	179.5	107.1	33.2	38.2	66.1
13	168	74.7	26.5	23.2	57.4
14	161	61.5	23.7	31.8	41.9
15	179	88.7	27.7	28.2	63.7
16	186.7	87.3	25	17.7	71.8
17	184.5	104	30.6	26	77
18	175.5	101.1	32.8	27.1	73.7
19	181.5	84.1	25.5	24.1	63.8
20	172	82.8	28	25.8	61.5
21	183.2	96.4	28.7	27.1	70.3
22	161.5	58.9	22.6	30.8	40.7
23	161	65.4	25.2	38.1	40.5
24	163.8	76.9	28.7	40.6	45.7
Female Means ± SD	162.1 ± 1.3	68.6 ± 9.8	26.2 ± 3.4	35.8 ± 4.3	43.9 ± 4.3
Male Means ± SD	180.9 ± 7.6	90.5 ± 15.3	27.6 ± 3.7	25.4 ± 4.8	66.4 ± 10.1
Overall Means ± SD	176.2 ± 10.6	85.0 ± 16.9	27.2 ± 3.6	28.0 ± 6.5	60.8 ± 13.4
<i>January 2019 Data Collection</i>					
2	174.6	95.5	31.3	29.6	67.2
4	163	78.9	29.7	40.5	46.9
5	194.6	129.6	34.2	33.6	86
6	181	96.8	29.5	22.4	75.1
7	178.8	74	23.1	20.8	50.7
8	178.5	82.2	25.8	25.5	61.3
9	192.4	84.5	22.8	21.1	66.7
10	170.2	62.9	21.7	23.3	48.2
12	180.4	106	32.6	36.8	66.9
13	169.5	75.5	26.3	25.5	56.3
14	162.4	64.6	24.5	35	42
15	180.5	91.9	28.2	31	63.4
16	186.8	80.2	23	20.4	63.9
17	183.4	102	30.3	26.6	74.9
18	174.6	100.5	33	28.2	72.1
21	183.2	94.2	28.1	25.3	70.3
23	161.2	62.3	24	34.8	40.6
24	162.9	71.4	26.9	38	44.2
28	161.5	72.6	27.8	37.3	45.5
29	154.8	46.7	19.5	26.8	34.2
25	176.2	80.2	25.8	26.4	59
Female Means ± SD	161.0 ± 3.1	66.1 ± 11.2	25.4 ± 3.6	35.4 ± 4.7	42.2 ± 4.6
Male Means ± SD	180.3 ± 7.2	90.4 ± 16.2	27.7 ± 4.1	26.4 ± 4.8	65.5 ± 9.8
Overall Means ± SD	174.8 ± 10.9	83.5 ± 18.5	27.1 ± 4.0	29.0 ± 6.2	58.8 ± 13.7

In terms of BMI classification, 29.3% of participants fell within the “normal” BMI range, 48.8% within the “overweight” range, and 21.9% fall within the “obese” range. This results in 70.7% of participants be classified as either “overweight” or “obese”. Standard body fatness range norms differ by sex – males with <25% body fat are considered normal and ≥25% body fat are considered “overfat”, while females with <35% body fat are considered normal and ≥35% body fat are considered “overfat” [15]. Just over 70% of females and 60% of males would be classified as “overfat” with the rest considered having a “normal” body fat percentage.

Biomarkers

Normal biomarker reference values for Finland are 4.0–6.0 mmol/L for fasting blood glucose, <5.0 mmol/L for total cholesterol, >1.2 mmol/L for HDL cholesterol for women and >1.0 mmol/L for men, <3.0 mmol/L for LDL cholesterol, and <1.7 mmol/L for triglycerides [47]. Participant biomarkers for the October and January data collections can be found in Table 2. Paired t-tests between the CardioChek PA values and whole blood values revealed that the CardioChek PA produced significantly lower values (by 18.33%) for total cholesterol and significantly higher (by 10.9%) HDL

Table 2. Summary of the cardiometabolic biomarker measures for the herders from the October 2018 and January 2019 data collections. The age and sex categories have been removed to protect participant confidentiality.

Participant	Fasting glucose (mmol/L)	Total cholesterol (mmol/L)	HDL cholesterol (mmol/L)	LDL cholesterol (mmol/L)	Triglycerides (mmol/L)
<i>October 2018 Data Collection</i>					
4	5.8	5.11	1.13	-	-
5	5.9	7.38	1.84	-	-
7	4.3	6.95	1.82	-	-
8	6.3	5.34	0.85	-	-
9	5.8	8.18	1.78	-	-
10	5	5.69	2.27	-	-
11	4	3.73	1.74	-	-
12	4	9.58	1.07	-	-
13	4	4.38	1.87	-	-
14	4.5	4.76	1.19	-	-
15	4.2	5.15	1.08	-	-
16	4.8	5.67	1.59	-	-
17	4.8	5.66	1.62	-	-
18	5.7	3.06	2.22	-	-
19	4.8	4.24	2.07	-	-
20	6.3	5.66	2.29	-	-
21	4.8	4.54	1.37	-	-
22	5.1	4.95	1.66	-	-
23	4.0	5.11	2.31	-	-
24	4.0	3.86	1.26	-	-
Female Means ± SD	4.7 ± 0.8	4.76 ± 0.52	1.51 ± 0.49	-	-
Male Means ± SD	5.0 ± 0.8	5.68 ± 1.73	1.70 ± 0.45	-	-
Overall Means ± SD	4.9 ± 0.8	5.45 ± 1.56	1.65 ± 0.45	-	-
<i>January 2019 Data Collection</i>					
2	5.2	5.82	1.24	-	-
4	6.7	6.45	0.95	-	-
5	5.9	4.73	1.34	-	-
6	3.7	4.69	1.56	2.6	0.86
7	4.4	6.71	2.31	4.5	0.68
8	4.9	5.04	0.97	3.5	1.63
9	3.3	8.65	2.08	4.5	1.44
10	4.4	5.23	1.75	4.8	0.98
12	4.6	3.33	1.14	3.5	0.63
13	6.8	3.06	1.56	2.9	0.59
14	2.0	4.18	1.85	2.8	1.18
15	1.1	5.75	0.83	3.3	2.95
16	4.1	4.07	1.14	2.6	0.70
17	5.1	5.18	1.65	2.8	0.61
18	5.2	3.23	1.43	1.4	0.70
21	4.7	4.41	1.49	1.8	0.62
23	5.5	4.53	2.31	1.6	1.15
24	2.6	3.82	1.61	1.7	0.48
28	4.5	5.10	1.55	2.3	1.18
29	6.0	4.40	1.67	1.6	1.39
25	5.5	7.34	2.14	3.3	0.64
Female Means ± SD	4.6 ± 1.9	4.74 ± 0.93	1.66 ± 0.44	2.0 ± 0.54	1.08 ± 0.35
Male Means ± SD	4.6 ± 1.30	5.15 ± 1.55	1.51 ± 0.43	3.2 ± 1.0	1.00 ± 0.67
Overall Means ± SD	4.6 ± 1.4	5.03 ± 1.39	1.55 ± 0.43	2.9 ± 1.05	1.02 ± 0.59

values ($p < 0.002$ in both). There was no significant difference between the two measurement periods for corrected total cholesterol values ($p = 0.38$), fasting glucose ($p = 0.38$), and corrected HDL cholesterol ($p = 0.47$). Corrected total cholesterol ranged from 3.06 to 9.56 mmol/L, fasting glucose ranged from 1.1 to 6.80 mmol/L, corrected HDL cholesterol ranged from 0.83 to 2.31 mmol/L, LDL cholesterol ranged from 1.4 to 4.80 mmol/L, and triglycerides ranged from 0.48 to 2.95 mmol/L (Figure 1). There were no significant differences between the sexes for corrected total cholesterol ($p = 0.21$), fasting glucose ($p = 0.67$), corrected HDL cholesterol ($p = 0.93$), and triglycerides

($p = 0.82$). However, females had significantly lower LDL cholesterol levels than males ($p = 0.025$). Prevalence of overweight, obesity, and cardiometabolic biomarkers outside of the recommended range can be found in Table 3.

The relationship between biomarkers to BMI and body fat percentage

For multiple regression models, age, sex, BMI, fat-free mass, and body fat percentage were not significant predictors of corrected total cholesterol levels, fasting glucose, corrected HDL cholesterol, and triglycerides

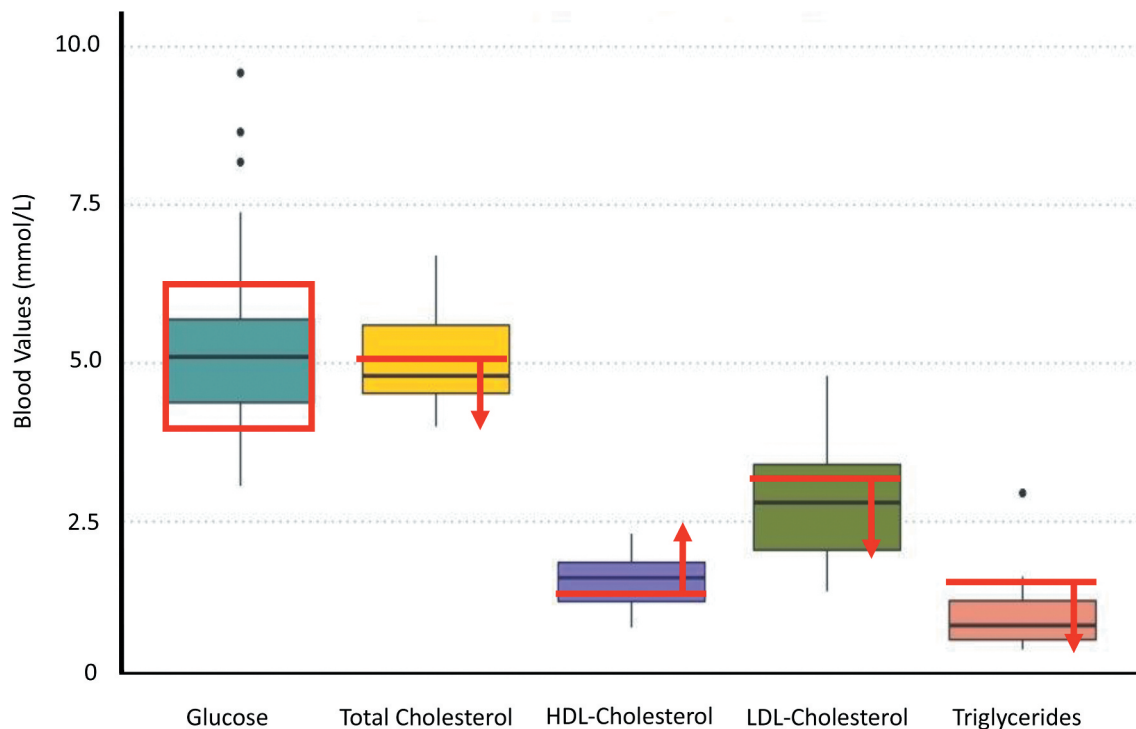


Figure 1. These are the pooled values for glucose (N = 25), corrected total cholesterol (N = 25), corrected HDL-cholesterol (N = 25), LDL-cholesterol (N = 18), and triglycerides (N = 18). The red box and lines indicate the normal, healthy values for each measure. For HDL cholesterol, only the normal value for females is presented (>1.2 nmol/L). The health value for males in Finland is >1.0 nmol/L.

(Table 4). There was a significant regression model for LDL cholesterol with sex being a significant predictor. BMI, age, fat-free mass, and body fat percentage were not significant predictors and were removed from the model (final model statistics: $F(5,24) = 6.107$, $p = 0.025$, $\text{adj. } r^2 = 0.231$). However, given how few females participated in this study, this is likely an artefact of a small sample size.

Using a simple, single predictor linear regression, BMI and body fat percentage were not significant predictors for corrected total cholesterol (Figure 2(a&b)), fasting glucose (Figure 2(c&d)), corrected HDL cholesterol (Figure 2(e&f)), LDL cholesterol (Figure 2(g&h)), or triglyceride levels (Figure 2(i&j)) ($p > 0.07$ in all cases).

Table 3. Prevalence of overweight, obesity, and cardiometabolic biomarkers outside of the recommended range for the pooled sample.

Measure	Females	Males	Overall
Normal BMI (>25)	57.1%	27.8%	29.3%
Overweight BMI (>25, <30)	42.9%	44.4%	48.8%
Obese BMI (>30)	0%	27.8%	21.9%
Elevated Total Cholesterol (>5.0 mmol/L)	28.6%	61.1%	52.0%
Low HDL Cholesterol (<1.2 mmol/L)	14.3%	16.7%	16.0%
Elevated LDL Cholesterol (>3.0 mmol/L)	0%	38.9%	28.0%
Elevated Triglycerides (>1.7 mmol/L)	0%	5.6%	4.0%
Elevated Glucose (>6.0 mmol/L)	14.3%	5.6%	12.0%

Discussion

In this study, we measured BMI, body composition, and cardiometabolic biomarkers among a small sample of reindeer herders from sub-Arctic Finland between October 2018 and January 2019. We found BMI classified over 70% of this sample to be “overweight” or “obese” and 64% classified as “overfat”. We found a high level of total cholesterol but relatively normal values for other cardiometabolic biomarkers. However, there was no significant relationship between BMI and body fat percentage with any of the measured biomarkers, as would be predicted with high rates of overweight and obesity. The results here mirror the mosaic of results seen among other circumpolar populations. Here, we will focus on three reasons for this potential disconnect: BMI as a poor indicator of health, the role of physical activity in mitigating metabolic health risk factors, and cold climate adaptations.

BMI as a poor indicator of fat and cardiometabolic health

One of the biggest weaknesses of BMI is the inability of this metric to distinguish fat mass from fat-free mass. For example, in a study conducted among athletes and non-athletes, investigators found that BMI alone was able to distinguish between these two groups only 52%

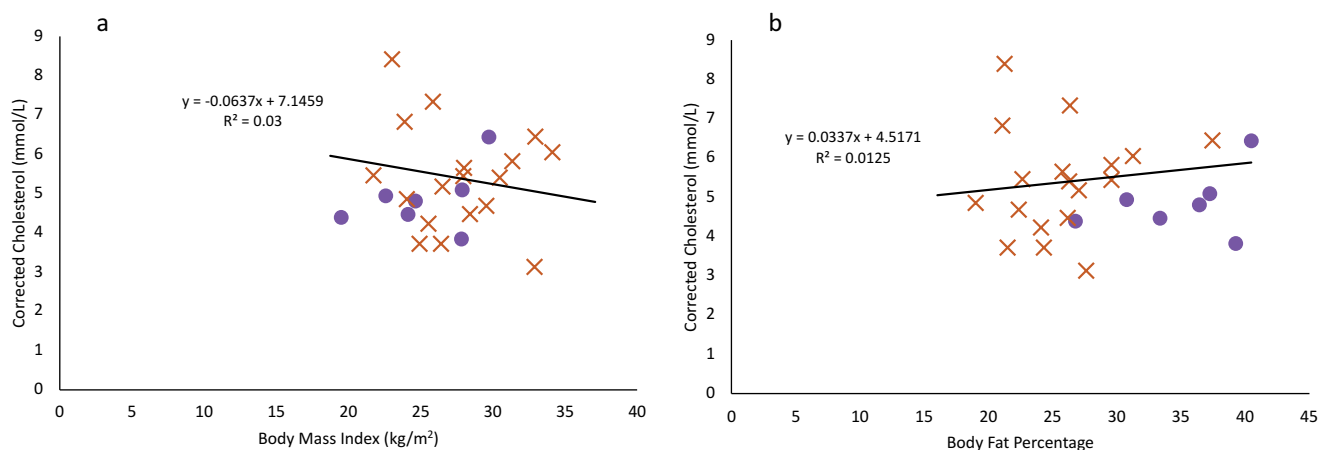


Figure 2. Females are indicated in purple circles and males in orange X's. **a & b:** Regression of the pooled corrected total cholesterol levels (N = 25) against body mass index (A) and body fat percentage (B). Neither BMI nor body fat percentage were a significant predictor of corrected total cholesterol levels. **c & d:** Regression of the pooled glucose levels (N = 25) against body mass index (C) and body fat percentage (D). Neither BMI nor body fat percentage were a significant predictor of glucose levels. **e & f:** Regression of the pooled corrected HDL cholesterol levels (N = 25) against body mass index (E) and body fat percentage (F). Neither BMI nor body fat percentage were a significant predictor of corrected HDL cholesterol levels. **g & h:** Regression of LDL cholesterol levels (N = 18) against body mass index (G) and body fat percentage (H). Neither BMI nor body fat percentage were a significant predictor of LDL cholesterol levels, though sex was a significant predictor. **i & j:** Regression of the triglyceride levels (N = 18) against body mass index (I) and body fat percentage (J). Neither BMI nor body fat percentage were a significant predictor of triglyceride levels.

of the time [10]. Measures of subcutaneous fat were far more accurate (81%) at distinguishing the more muscular athletes from less muscular non-athletes. An assessment of ~1.3 million patients who were part of the Patient Outcomes Research to Advance Learning consortium found that while being overweight and having obesity did increase cardiometabolic risk factors (blood pressure, triglyceride levels, LDL levels, and fasting glucose levels), there was a great deal of variation [48] – such variation was observed in the present study as well. Furthermore, it has been demonstrated that BMI does not accurately predict cardiometabolic health equally across all populations. BMI has been shown to inaccurately assess adiposity

and indicators of cardiometabolic health among Black women [12,49,50] as well as among Asian and Indigenous North American populations [13,51]. This, too, may be the case among the herders, who despite high degrees of overweight and obesity, have relatively normal cardiometabolic biomarker levels [52,53].

Age could also be an important factor in interpreting the result of the present study. Although there was a large age range (20–64 years) among participants in this study, it is possible with a small sample size that we were unable to detect the impact of age on the emergence of a poor cardiometabolic profile. This could explain why no females were categorised as obese in

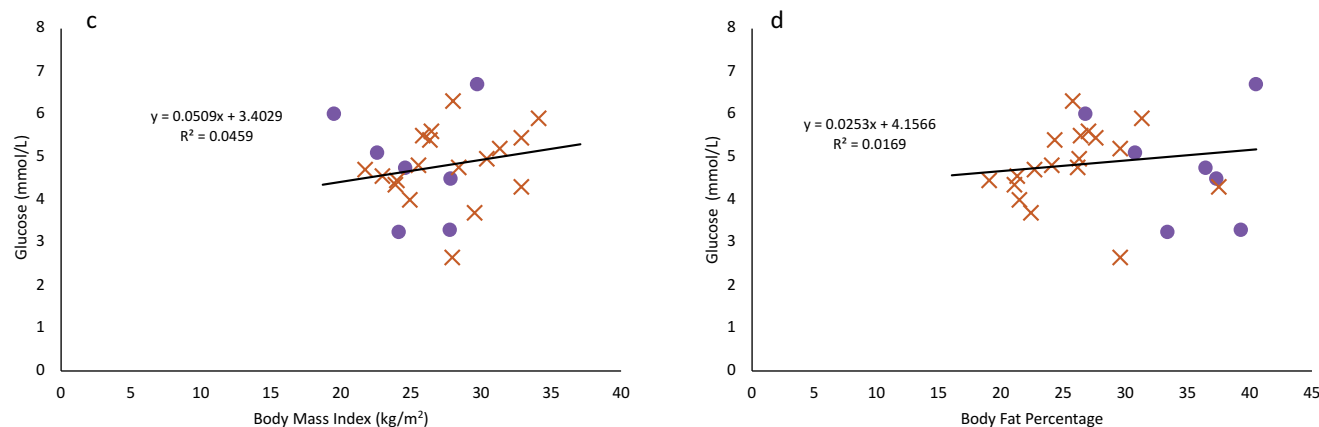


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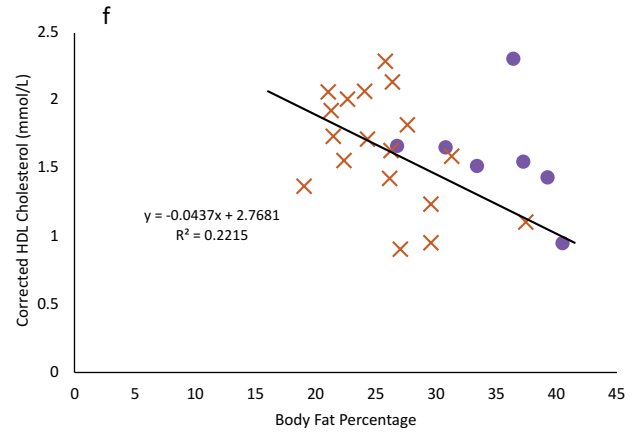
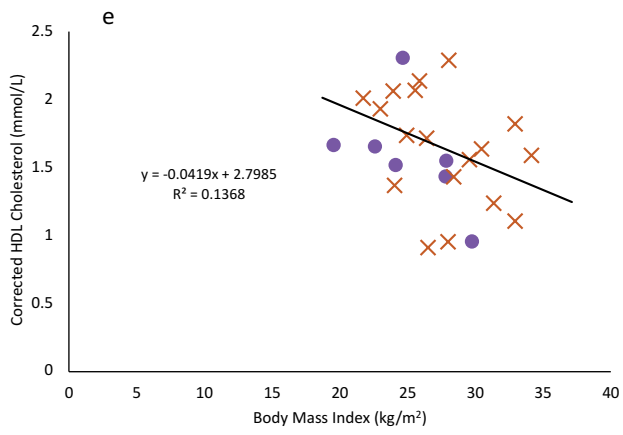


Figure 2. Continued.

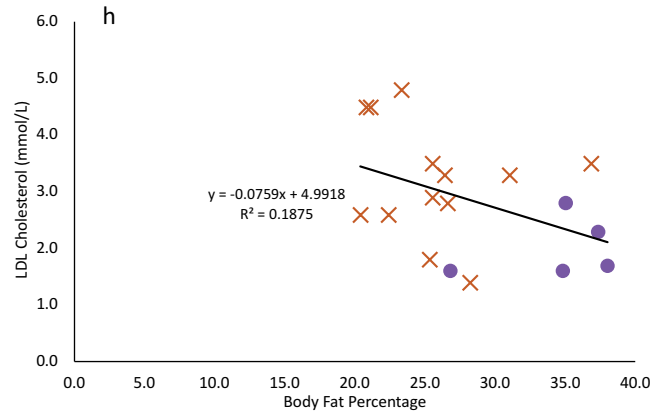
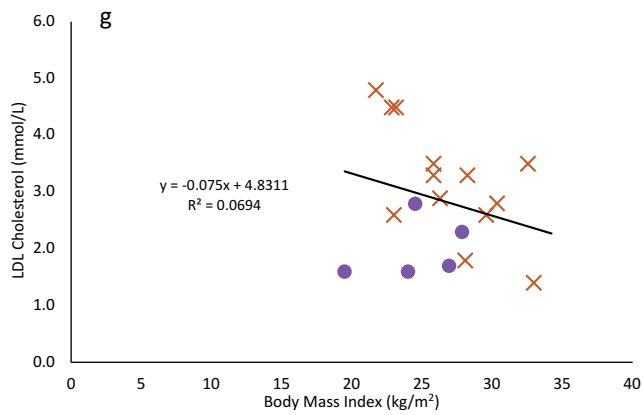


Figure 2. Continued.

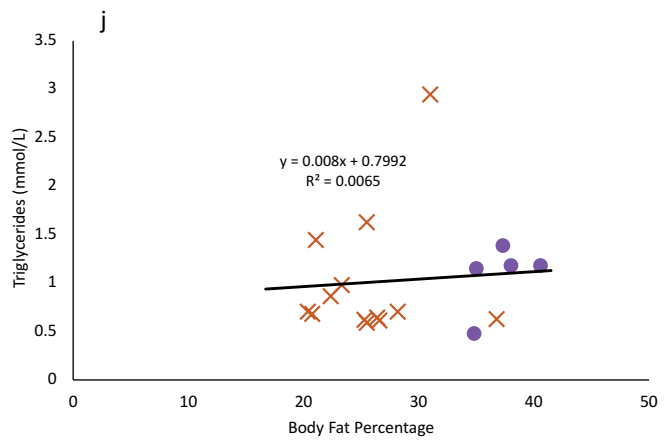
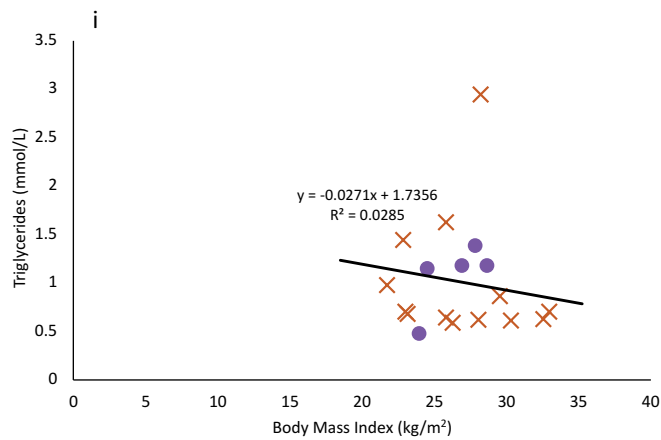


Figure 2. Continued.

Table 4. Results of the multiple regression models for the relationship between BMI, body adiposity, and the cardiometabolic biomarkers of corrected total cholesterol, glucose, corrected HDL cholesterol, LDL cholesterol, and triglycerides.

Dependent variables	Independent variables	β	Standard error	t	p	F	R ²	Adjusted R ²	p
<i>Corrected Cholesterol</i>	Constant	3.258	2.236	1.457	0.161	1.105	0.225	0.021	0.390
	Age	-0.001	0.027	-0.02	0.984				
	Sex	2.384	1.422	1.677	0.11				
	BMI	-0.379	0.213	-1.776	0.092				
	Fat-Free Mass	0.058	0.057	1.026	0.318				
	Body Fat%	0.249	0.122	2.042	0.055				
<i>Glucose</i>	Constant	3.666	1.872	1.959	0.065	0.613	0.139	-0.088	0.691
	Age	0.034	0.023	1.462	0.16				
	Sex	-1.102	1.19	-0.926	0.366				
	BMI	0.068	0.179	0.379	0.709				
	Fat-Free Mass	-0.004	0.048	-0.086	0.932				
	Body Fat%	-0.039	0.102	-0.383	0.706				
<i>Corrected HDL Cholesterol</i>	Constant	3.007	0.734	4.097	0.001	1.117	0.227	0.024	0.385
	Age	0.004	0.009	0.409	0.687				
	Sex	-0.166	0.467	-0.355	0.726				
	BMI	0.011	0.07	0.157	0.877				
	Fat-Free Mass	-0.01	0.019	-0.546	0.592				
	Body Fat%	-0.039	0.04	-0.984	0.337				
<i>LDL Cholesterol</i>	Constant	4.922	1.601	3.074	0.01	4.731	0.633	0.523	0.013
	Age	-0.019	0.019	-0.986	0.344				
	Sex	3.686	0.966	3.816	0.002				
	BMI	-0.218	0.138	-1.581	0.14				
	Fat-Free Mass	-0.021	0.041	-0.517	0.614				
	Body Fat%	0.111	0.076	1.462	0.169				
<i>Triglycerides</i>	Constant	1.931	1.199	1.61	0.133	1.655	0.408	0.162	0.220
	Age	-0.032	0.015	-2.205	0.05				
	Sex	1.17	0.723	1.617	0.132				
	BMI	-0.123	0.103	-1.197	0.254				
	Fat-Free Mass	0.018	0.031	0.594	0.563				
	Body Fat%	0.065	0.057	1.15	0.273				

this sample, as could the higher resting metabolic rate documented among females in this sample previously [38]. However, female representation in this study is poor, and a greater number of female participants would provide a better indicator if there are true sex differences in the prevalence of obesity. It is possible that individuals in this study have not encountered the ill effects of overweight and obesity but will in the years to come. However, numerous studies have shown that negative health impacts associated with a high BMI, though exacerbated by age, do appear at younger ages [48,54–56]. Along with ethnic background, age, sex, and body fat distribution, physical activity fitness levels may also explain the inability of BMI to accurately and consistently predict present and future health status [52,53].

The mitigating role of fitness & physical activity

Physical activity and/or intentional exercise are known to have numerous health benefits such as improved cardiovascular health, reduced risk of certain cancers, and

reduced inflammation [see review by 57]. As such, physical activity and high cardiorespiratory fitness may mitigate the potentially negative health impacts typically associated with being overweight or obese. A number of studies have addressed this concern and have found that risks associated with a high BMI are greatly reduced by high levels of physical activity. Data from over 4,600 adults ages 20–49 who took part in the National Health and Nutrition Examination Survey revealed that roughly 17.4% of the adults classified as “overweight” and 8.9% of adults classified as “obese” had a high degree of cardiovascular fitness [58]. Other work has looked specifically at physical activity levels and health outcomes. Among over 47,200 Finnish women and men [59] and almost 40,000 women, part of the Women’s Health Study [60], regular physical activity was strongly associated with reduced all-cause mortality or coronary heart disease in these studies, respectively.

Though it would require further study, high physical activity levels among the reindeer herders may be in part responsible for the lack of association between BMI and body adiposity with cardiometabolic biomarkers. Total energy expenditure (kcal day^{-1}) and physical

activity levels were measured among the herders during the 2018 autumn herd round up, which occurred during the 1–2 weeks just after the biomarker data were collected (Ocobock *et al.*). During the round up, herders expended a mean of 4183 kcal day⁻¹ (as measured by the doubly labelled water method) with females expending a mean of 3371 kcal day⁻¹ and males 4530 kcal day⁻¹.

This is one of the most physically demanding periods of the herding year and may not be representative of energy expenditure across seasons. However, it is possible this high level of physical activity could be mitigating some of the potential negative health benefits associated with the high BMI and degree of adiposity exhibited among the reindeer herders in this study as has been seen elsewhere [59–61].

Work among Yakutia men found that those who took part in more traditional subsistence activities resulting in greater physical activity levels had higher total cholesterol driven by higher HDL levels [8,62], which was also true in the present study. Yakutia females displayed a less favourable cardiometabolic profile, which has been attributed to taking part in fewer physically demanding subsistence practices, further suggesting that factors other than BMI and adiposity can impact cardiometabolic biomarkers. Further, physical activity alone appears to have a relatively rapid dose-dependent effect on cardiometabolic biomarkers [63–65], such that the high physical activity levels associated with herding may have altered their cardiometabolic profile.

Total energy expenditure and cardiometabolic biomarker measurements across seasons and years would elucidate whether the herders in this study truly exhibit a unique cardiometabolic profile – one altered by their high levels of physical activity. However, physical activity levels may not be the only factor driving this observed disconnect between BMI, body adiposity, and indicators of cardiometabolic health as the herders also inhabit a harsh, cold climate.

Cardiometabolic profiles in cold climates

Sub-Arctic Finland can be described as a cold, snowy environment. The mean annual temperature ranges from 0.1°C to 1.6°C and snow that reaches a depth of 72 cm [66], though the temperature has significantly risen and the weather has become more unpredictable in the last 50–100 years due to climate change [67,68]. Numerous well-known cold climate

adaptations that appear in circumpolar populations include high resting metabolic rates [27,38,69–72], shivering thermogenesis and brown adipose activity [39,73,74], oscillating vasoconstriction and vasodilation [75,76], as well as numerous cultural mitigation strategies [37].

There is evidence that seasonality shifts resting metabolism substrate utilisation such that more carbohydrates are utilised in the winter as opposed to summer, which can alter lipid and glucose profiles [8,31]. Brown adipose tissue (BAT), a type of mitochondria dense fat, has received a great deal of recent attention both for its ability to increase heat production during cold exposure and for how it may alter metabolic rate and circulating blood glucose and lipid levels [73,74,77–80]. BAT has been identified among cold climate [39,73,81] and temperate climate populations [74,82,83] during acute cold exposure, and has been shown to increase metabolic rate from 3% to 9.5% depending on the population. The reindeer herders in this study trended on the higher end of that metabolic rate increase [39]. Furthermore, BAT activity seems to significantly alter blood glucose and lipid levels. In a small study conducted among seven men, acute cold exposure elicited a 63% increase in lipid utilisation and a 588% increase in glucose utilisation [84]. Among the Yakutia, glucose levels, but not lipid levels, were positively correlated with BAT activity [73]; a similar preference for glucose utilisation was also found among a population of women and men in Albany, NY [83], and among the reindeer herders included in this study lipids were utilized [39]. As the measures for this study took place in fall when temperatures were beginning to drop and in Winter when temperatures are consistently cold, it was likely that seasonal BAT activity influenced reindeer herder cardiometabolic profiles.

However, despite the potential for a disconnect between BMI, body adiposity, and cardiometabolic health indices among the herders as documented among other circumpolar populations, recent drastic changes in diet and physical activity levels could be altering this pattern [22,73,85,86]. Though older work among circumpolar populations revealed relatively low mortality from cardiovascular disease and incidence of diabetes as well as lower fasting blood glucose and lipid levels, this pattern is changing [16,21,22,85,87–8889]. Finland has high rates of cardiovascular disease [33–35], and more broadly cardiovascular disease is a leading cause of death among circumpolar populations [25,87]. A great deal more research measuring

seasonal total energy expenditure, resting metabolic rates, BAT activity, diet composition, adherence to traditional subsistence practices, and associated cardiometabolic biomarker levels, as well as data on cardiovascular disease mortality and diabetes are needed.

Limitations

Although the results of this study demonstrate a unique cardiometabolic profile among reindeer herders of sub-Arctic Finland, there are a number of limitations. First, the sample size of this study is small with only 25 unique participants across the two data collection periods. Second, females are underrepresented, making up only ~25% of the participant pool, though this reflects the sex ratio among herders. Third, it would have been ideal to include blood pressure measurements, fitness assessments, a more detailed personal medical history, and a detailed family medical history, particularly as that history pertains to cardiometabolic disorders to more accurately evaluate individual and population health trends. Such measures should be included in any future study. Fourth, it is possible that the participant population is not old enough to display the negative effects of a high BMI or high adiposity. Fifth, biomarker analysis should be completed with whole blood samples as total and HDL cholesterol levels were significantly different between the CardioChek PA and whole-blood analysis. Finally, it would be informative to have seasonal participant observation and detailed physical activity data to assess the role of physical activity and more traditional subsistence practices on cardiometabolic biomarkers.

Conclusion

This study measured cardiometabolic biomarkers, body mass index, and body adiposity among a small sample of reindeer herders from sub-Arctic Finland. Participants in this study exhibited high BMIs and high body adiposity. Biomarker results were mixed with a high level of total cholesterol, but fasting glucose, HDL cholesterol, LDL cholesterol, and triglyceride levels were largely within the healthy range. However, there was no relationship between BMI and body adiposity in cardiometabolic lipids and fasting glucose biomarkers. It is possible that highly active lifestyles and even cold climate adaptations such as brown adipose tissue activity can mitigate the negative health effects associated with high body adiposity. The results of this study add to a growing body of the literature, suggesting that BMI does not accurately assess health equally across different populations. Finally, this work

highlights a potentially unique interaction among subsistence lifestyle, climate, and cardiometabolic health indices – an area ripe for future research.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

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