# Correlations of the Parameters of Carbohydrate Metabolism and Saturated Fatty Acids in the Blood Serum of Elderly People

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**Abstract**—The study involves 106 elderly subjects (61−74 years old) living in the Arctic; 42 of them are residents of the Subarctic region (SR) and 64, of the Arctic region (AR). The contents of saturated fatty acids (SFAs) comprising short chain (SCFA), medium chain (MCFA), and long chain (LCFA) fatty acids, are determined by gas liquid chromatography of the blood serum. The parameters of the carbohydrate metabolism are assessed by spectrophotometry. Correlation analysis demonstrates the absence of statistically significant correlations of glucose, lactate, and pyruvate levels with the contents of SCFAs, MCFAs, and LCFAs ($r = 0.2−0.29$, $p = 0.08−0.786$) among the examined elderly SR residents compared with the AR residents, who show lower rates of excess glucose and lactate and lower rates of deficient pyruvate. On the background of higher excess glucose and deficiency rates, the examined AR cohort shows the strongest correlations with LCFAs (hexadecanoic, heptadecanoic, octadecanoic, behenic, and tricosanoic acids), somewhat more moderate correlations with MCFAs (tetradecanoic and pentadecanoic acids) and SCFAs (pelargonic acid), correlations of pyruvate deficiency with MCFAs (dodecanoic and tetradecanoic acids and total MCFA content) and SCFAs (decanoic acid), and correlations of an insignificant decrease in the rate of excess lactate and lactate/pyruvate with LCFAs (hexadecanoic, heptadecanoic, octadecanoic, and tricosanoic acids), MCFAs (dodecanoic and tridecanoic acids), and SCFAs (hexanoic and caprylic acids).

*Keywords*: saturated fatty acids, short-chain fatty acids, medium-chain fatty acids, long-chain fatty acids, glucose, lactate, pyruvate, body mass index, age, Subarctic region, Arctic region, intersystem reactions

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## INTRODUCTION

With age, excess feeding and, especially, low physical activity promote the accumulation of glucose (Glu) in the blood and its deposition as saturated fatty acids (SFAs) in adipose tissue [2, 6, 11]. Since Glu and SFAs are major energy sources in the human body, proper alternation of their utilization ensures a normal course of physiological processes in ontogenesis. On the other hand, a deficiency of essential polyunsaturated fatty acids (PUFAs), proteins, vitamins, mineral substances, etc., in elderly patients may cause disadaptation of enzyme systems and associated disturbances in oxidative processes, leading to hyperglycemic and dyslipidemic states [1, 5, 9, 18, 20].

Although the specific features in metabolic profiles of the working-age population in the North have been described [4, 14], SFA metabolic pathways and their interaction with Glu and its metabolites in elderly cohorts are still vague. This is a relevant challenge, since they are both basic and applied problems for health care and increased life expectancy for the Arctic population.

The aim of this work was to determine the levels of SFAs and carbohydrate metabolites in the blood of the elderly (61−74 years old) Arctic residents and to clarify their interaction.

## MATERIALS AND METHODS

In total, 106 Arctic residents aged 61−74 were examined; 42 of them live in the Subarctic region (SR), and 64, in the Arctic region (AR). Blood was drawn from the cubital vein after an overnight fast using Becton Dickinson vacutainers. The volunteers were men and women aged 61−74 who permanently reside in the SR or AR and showed no exacerbation of chronic diseases during examination.

The contents of the following SFAs were determined by gas liquid chromatography with pre-extraction of lipids from blood serum [21] and subsequent generation of fatty acid methyl esters at the facilities of the Institute of Environmental Physiology, Federal Center for Integrated Arctic Research, Rus-

sian Academy of Sciences: short-chain fatty acids (SCFAs), including hexanoic ($C_{6:0}$), caprylic ($C_{8:0}$), pelargonic ($C_{9:0}$), decanoic ($C_{10:0}$), and undecanoic ($C_{11:0}$) acids; medium-chain fatty acids (MCFAs), including dodecanoic ($C_{12:0}$), tridecanoic ($C_{13:0}$), tetradecanoic ($C_{14:0}$), and pentadecanoic ($C_{15:0}$) acids; and long chain fatty acids (LCFAs), including hexadecanoic ($C_{16:0}$), heptadecanoic ($C_{17:0}$), octadecanoic ($C_{18:0}$), arachidonic ($C_{20:0}$), heneicosanoic ($C_{21:0}$), behenic ($C_{22:0}$), tricosanoic ($C_{23:0}$), and lignoceric ($C_{24:0}$) acids. The total content ($\Sigma$) was calculated for SFAs ($\Sigma$SFAs), as well as for individual SFA classes ($\Sigma$SCFAs, $\Sigma$MCFAs, and $\Sigma$LCFAs). The SFA methyl derivatives were analyzed on an Agilent 7890A gas chromatograph (equipped with a flame ionization detector and an Agilent DB 23 capillary column, 60 × 0.25 × 0.15) using a programmed temperature and carrier gas (nitrogen) rate. The Superleco 37 FAME $C_4C_{24}$ standard (United States) was used to identify fatty acids. SFAs were quantified using an internal standard (nonadecanoic acid) and Agilent ChemStation B.03.01 (United States) software. The Glu and lactate (Lac) levels in the blood were determined in a MARS biochemical analyzer using Chronolab AG kits (Switzerland). Pyruvate (Pyr) levels were determined by the Umbreit method with 2,4-dinitrophenylhydrazine. These were used to calculate the Lac/Pyr coefficient. Volunteers were questioned and examined to determine height and weight, and BMI and other characteristics were calculated. All results were obtained with certified equipment; these data were compared to earlier data on metabolic properties in peripheral blood. The statistical significance of the data and conclusions is based on examination of a sufficient number of subjects, the use of state-of-the-art methods, proper data analysis, and appropriate statistical processing.

The data were statistically processed using SPSS 13.0 for Windows and Statistica 5.0 [8]. The critical significance level ($p$) for testing statistical hypotheses was set at 0.05. Descriptive analysis (calculation of the mean and its standard error; $M \pm m$) was performed. The Mann–Whitney test was used to assess the significance of differences between groups. The $z$ test was used to estimate the significance of differences in rates of deviations from physiological norms of the studied parameters. According to the manufacturer's protocols for test kits, the levels of Glu, its metabolites, and SFAs that exceeded the physiological norm were considered excess and those that were below the physiological norm, as deficient. BMI values of <18 kg/m² were regarded as low body weight; ≥18–25 kg/m², as normal body weight; ≥25–30 kg/m², as overweight; ≥30–35 kg/m², as obesity class 1; and ≥35–40 kg/m², as obesity class 2.

The correlation between the carbohydrate metabolism parameters and SFAs were assessed by correlation analysis taking into account Spearman's rank correlation. The correlations were regarded as significant at $p \leq 0.05$.

## RESULTS AND DISCUSSION

Adequate alternation in utilization of energy source types (Glu and SFAs) is one of the markers of aging in elderly subjects, especially those living in the extreme conditions of the North [3, 10, 11]. Our results demonstrate that the SR and AR residents aged 61–74 show no statistically significant differences from the mean values of Glu, Pyr, Lac, and Lac/Pyr (Table 1).

On the other hand, the AR residents showed a more frequent Glu excess and deficiency (20.3 and 12.5%, respectively) in comparison to the SR residents (17.5 and 5%); however, the differences are statistically insignificant ($p = 0.721$ and $p = 0.212$, respectively). Pyr deficiency was observed in 7.5 and 17.5% of the SR and AR residents ($p = 0.045$), respectively; high yet statistically insignificant Lac and Lac/Pyr levels in the AR cohort were observed at a rate of 84.1 and 77.4% and in the SR cohort, at a rate of 94.4 and 80.6% ($p = 0.132$ and $p = 0.716$); this may suggest the prevalence of anaerobic over aerobic processes in the elderly cohorts of both regions (Fig. 1a).

The $\Sigma$SFAs showed an increase among the AR residents compared with the SR residents ($p = 0.9$) with elevated $\Sigma$SFAs above the norm in up to 15% of the AR residents and 10.8% of the SR residents without statistical significance ($p = 0.125$). Taking into account the specific features in metabolism and transfer, all SFAs are divided into SCFAs ($C_4–C_{11}$), MCFAs ($C_{12}–C_{15}$), and LCFAs ($C_{16}–C_{24}$). The SCFAs and MCFAs are esterified to short triglycerides (TGs) not associated with apoproteins, while LCFAs form long TGs, structured by apoB48 into chylomicrons in enterocytes. In this process, the SCFAs and MCFAs from enterocytes flow out to the portal venous system, in particular, to omental veins, whereas the LCFAs flow to large veins of the greater circulation circuit, which may be directly associated with isolated alimentary obesity and development of metabolic syndrome [10, 12, 13, 19].

Analysis of the $\Sigma$SCFAs in the northern residents aged 61–74 years demonstrates that the SR residents show higher than average values when compared to the AR residents, in a statistically significant manner ($p = 0.004$). The values were 33.1% above average for the SR residents and 24.6% for the AR residents ($p = 0.014$). Presumably, this is associated with more active use of these SFAs on the background of a decrease in the use of carbohydrates as an energy substrate in the AR cohort. Correspondingly, we analyzed the levels of individual SCFAs (Table 1; Fig. 1b). It has been

**Table 1.** Average BMI values and levels of the parameters carbohydrate metabolism and fatty acids in the blood of elderly residents of the Subarctic (SR) and Arctic (AR) regions of northern Russia

| Parameter | Parameter in norm | Region | $n$ | $M \pm m$ | $p$ |
|---|---|---|---|---|---|
| Age, years | – | SR | 42 | 64.93 ± 0.54 | 0.581 |
|  |  | AR | 64 | 64.72 ± 0.47 |  |
| BMI | 18.5–24.9 kg/m$^2$ | SR | 39 | 29.6 ± 0.82 | 0.544 |
|  |  | AR | 61 | 30.38 ± 0.83 |  |
| ΣSFAs | 0.09–5.54 μg/mL | SR | 37 | 538.96 ± 32.62 | 0.09 |
|  |  | AR | 60 | 603.25 ± 27 |  |
| ΣSCFAs | Up to 5.89 μg/mL | SR | 16 | 4.89 ± 0.66 | 0.004* |
|  |  | AR | 54 | 3.62 ± 0.46 |  |
| hexanoic ($C_{6:0}$) | 0.09–5.54 μg/mL | SR | 15 | 1.56 ± 0.44 | 0.011* |
|  |  | AR | 51 | 1.05 ± 0.25 |  |
| caprylic ($C_{8:0}$) | 0.06–2.02 μg/mL | SR | 15 | 0.97 ± 0.13 | 0.041 |
|  |  | AR | 55 | 1.09 ± 0.22 |  |
| pelargonic ($C_{9:0}$) | 0.56–1.64 μg/mL | SR | 15 | 1.33 ± 0.13 | $p < 0.001$* |
|  |  | AR | 47 | 0.82 ± 0.04 |  |
| decanoic ($C_{10:0}$) | 0.25–1.83 μg/mL | SR | 35 | 1.01 ± 0.1 | 0.185 |
|  |  | AR | 60 | 0.92 ± 0.09 |  |
| undecanoic ($C_{11:0}$) | 0.068–1.04 μg/mL | SR | 32 | 0.61 ± 0.09 | 0.022* |
|  |  | AR | 59 | 0.39 ± 0.05 |  |
| ΣMCFAs | Up to 28.33 μg/mL | SR | 38 | 24.02 ± 1.38 | 0.153 |
|  |  | AR | 59 | 29.02 ± 1.96 |  |
| dodecanoic ($C_{12:0}$) | 1.13–4.07 μg/mL | SR | 37 | 2.95 ± 0.35 | 0.136 |
|  |  | AR | 60 | 2.61 ± 0.26 |  |
| tridecanoic ($C_{13:0}$) | 0.092–1.02 μg/mL | SR | 34 | 0.45 ± 0.04 | 0.162 |
|  |  | AR | 59 | 0.6 ± 0.06 |  |
| tetradecanoic ($C_{14:0}$) | 5.7–28.3 μg/mL | SR | 37 | 16.2 ± 1.05 | 0.04* |
|  |  | AR | 60 | 20.77 ± 1.48 |  |
| pentadecanoic ($C_{15:0}$) | 1.88–7.92 μg/mL | SR | 37 | 4.26 ± 0.27 | 0.004* |
|  |  | AR | 60 | 5.64 ± 0.31 |  |
| ΣLCFAs | Up to 577.66 μg/mL | SR | 38 | 506.06 ± 30.18 | 0.073 |
|  |  | AR | 60 | 569.55 ± 25.34 |  |
| hexadecanoic ($C_{16:0}$) | 217.4–570.3 μg/mL | SR | 37 | 370.53 ± 22.97 | 0.174 |
|  |  | AR | 60 | 407.88 ± 19.64 |  |
| heptadecanoic ($C_{17:0}$) | 2.88–9.17 μg/mL | SR | 37 | 5 ± 0.32 | $p < 0.001$* |
|  |  | AR | 60 | 7.14 ± 0.39 |  |
| octadecanoic ($C_{18:0}$) | 83.44–197.16 μg/mL | SR | 37 | 130.56 ± 8.60 | 0.022* |
|  |  | AR | 60 | 148.72 ± 5.82 |  |
| arachidonic ($C_{20:0}$) | 0.56–2.86 μg/mL | SR | 37 | 1.86 ± 0.16 | 0.651 |
|  |  | AR | 60 | 1.72 ± 0.09 |  |
| heneicosanoic ($C_{21:0}$) | 0.254–1.11 μg/mL | SR | 34 | 1.06 ± 0.18 | 0.367 |
|  |  | AR | 59 | 1.01 ± 0.08 |  |
| behenic ($C_{22:0}$) | 0.1–2.22 μg/mL | SR | 36 | 1.47 ± 0.19 | 0.674 |
|  |  | AR | 59 | 1.23 ± 0.11 |  |
| tricosanoic ($C_{23:0}$) | 0.28–2.46 μg/mL | SR | 30 | 0.66 ± 0.06 | 0.538 |
|  |  | AR | 56 | 0.69 ± 0.04 |  |
| lignoceric ($C_{24:0}$) | 0.46–4.73 μg/mL | SR | 33 | 1.16 ± 0.13 | 0.043* |
|  |  | AR | 60 | 1.55 ± 0.15 |  |
| Glucose | 3.9–6.1 mmol/L | SR | 40 | 5.03 ± 0.12 | 0.691 |
|  |  | AR | 63 | 5.08 ± 0.17 |  |

**Table 1.** (Contd.)

| Parameter | Parameter in norm | Region | $n$ | $M \pm m$ | $p$ |
|---|---|---|---|---|---|
| Pyruvate | 0.03–0.1 mmol/L | SR | 40 | $0.033 \pm 0.001$ | 0.533 |
| | | AR | 62 | $0.035 \pm 0.002$ | |
| Lactate | 0.44–2.22 mmol/L | SR | 36 | $3.17 \pm 0.18$ | 0.671 |
| | | AR | 62 | $3.09 \pm 0.11$ | |
| Lac/Pyr | Up to 75 arbitrary units | SR | 36 | $96.07 \pm 6.52$ | 0.974 |
| | | AR | 61 | $96.22 \pm 4.37$ | |

* Statistically significant differences between the parameters of carbohydrate and fatty metabolisms of the elderly SR and AR residents ($p \leq 0.05$).

shown that the average levels of hexanoic ($C_{6:0}$), pelargonic ($C_{9:0}$), and undecanoic ($C_{11:0}$) acids among the SR residents were higher in a statistically significant manner compared with the AR cohort ($p = 0.011$, $p < 0.001$, and $p = 0.022$, respectively). The rates of excess contents of $C_{9:0}$ and $C_{11:0}$ (40 and 18.8%, respectively) were also significantly higher in the SR residents compared with AR residents (4.3 and 5.1%; $p < 0.001$ and $p = 0.014$, respectively). The level of caprylic ($C_{8:0}$) acid in the AR cohort was higher in a statistically significant manner compared with the SR residents ($p = 0.041$). The content of decanoic ($C_{10:0}$) acid in the examined cohorts showed no statistically significant differences ($p = 0.185$). The AR cohort showed a higher rate of $C_{8:0}$ deficiency compared with the SR residents (10.9 and 6.7%; $p = 0.632$) on the background of similar rates of $C_{10:0}$ excess (11.7 and 11.4%; $p = 0.186$); however, these data are statistically insignificant.

According to the published data, SCFAs, on the one hand, can rapidly oxidize to give energy and ketone bodies and, on the other hand, their excess intake can increase oxygen spending in body tissues and thereby increase metabolic acidosis, as suggested by a decrease in Pyr and an increase in Lac and Lac/Pyr on the background of an increase in the SCFA level in SR and AR residents observed in our study and by other researchers [4, 7, 12, 13] (Figs. 1a, 1b).

The SR residents showed no statistically significant correlations of the Glu, Pyr, Lac, and Lac/Pyr levels with the SCFA content ($r = 0.2$–$0.29$, $p = 0.08$–$0.676$); however, this does not exclude cause-and-effect relationships. Note that the AR cohort shows a negative correlation between Glu and $C_{9:0}$ levels ($r = -0.34$, $p = 0.023$); positive correlations between Pyr and $C_{10:0}$ levels ($r = 0.39$, $p = 0.003$), Lac and $C_{6:0}$ ($r = 0.37$, $p = 0.01$), and Lac/Pyr and $C_{6:0}$ ($r = 0.37$, $p = 0.01$); and a negative correlation of Lac/Pyr with $C_{10:0}$ ($r = -0.3$, $p = 0.031$). All these correlations are moderate ($r = 0.3$–$0.49$; $p = 0.023$–$0.003$). The negative correlation of Glu level with the content of SCFAs is well explainable since the formed short TGs are more

rapidly hydrolysable and mobilizable during energy homeostasis maintenance and adaptation processes.

Another factor influencing Glu homeostasis is the content of SCFAs, which are able to affect pancreatic β-cells by changing insulin secretion [12, 13, 17]. In our study, the ΣSCFAs in AR cohort was insignificantly higher ($p = 0.153$) compared to the SR residents, while the levels of tetradecanoic ($C_{14:0}$) and pentadecanoic ($C_{15:0}$) acids in SR cohort was lower compared with the AR residents ($p = 0.04$ and $p = 0.004$, respectively) in a statistically significant manner. The rates of excess $C_{14:0}$ and $C_{15:0}$ levels amounted to 23.3 and 23% among the AR residents versus 10.8 and 5.4% of the SR residents, respectively ($p = 0.003$ and 0.002). No differences between the examined cohorts were observed in the contents of dodecanoic ($C_{12:0}$) and tridecanoic ($C_{13:0}$) acids ($p = 0.136$ and $p = 0.162$). The rate of deficient $C_{12:0}$ in the AR residents (17%) was higher compared with the SR residents (5.9%) at $p = 0.132$ on the background of similar rates of excess $C_{12:0}$ in both cohorts (16.2% for the SR residents and 15% for the AR residents; $p = 0.871$); these differences are statistically insignificant. The excess $C_{13:0}$ values were observed only in AR cohort at a rate of 18% versus 3 and 2% of deficient $C_{13:0}$ ($p = 0.858$) in AR and SR cohorts, respectively (Table 1; Fig. 1c).

Any statistically significant correlations of the Glu, Pyr, Lac, and Lac/Pyr levels with the MCFAs content in SR cohort were undetectable ($r = 0.2$–$0.29$; $p = 0.095$–$0.876$). However, the AR residents showed positive correlations of the Glu level with $C_{14:0}$ ($r = 0.36$, $p = 0.01$) and $C_{15:0}$ ($r = 0.34$, $p = 0.01$) and of Pyr with $C_{12:0}$ ($r = 0.43$, $p = 0.001$), $C_{14:0}$ ($r = 0.32$, $p = 0.021$), and ΣMCFAs ($r = 0.35$, $p = 0.012$) as well as negative correlations of Lac/Pyr with $C_{12:0}$ ($r = -0.3$, $p = 0.043$), $C_{13:0}$ ($r = -0.44$, $p = 0.001$), $C_{14:0}$ ($r = -0.31$, $p = 0.021$), and ΣMCFAs ($r = -0.32$, $p = 0.02$). The revealed correlations of the carbohydrate metabolism components with the levels of the MCFAs $C_{12:0}$, $C_{13:0}$, $C_{14:0}$, and $C_{15:0}$ among the AR residents may be associated with their active involvement in the aerobic ATP formation. In particular, MCFAs are able to readily
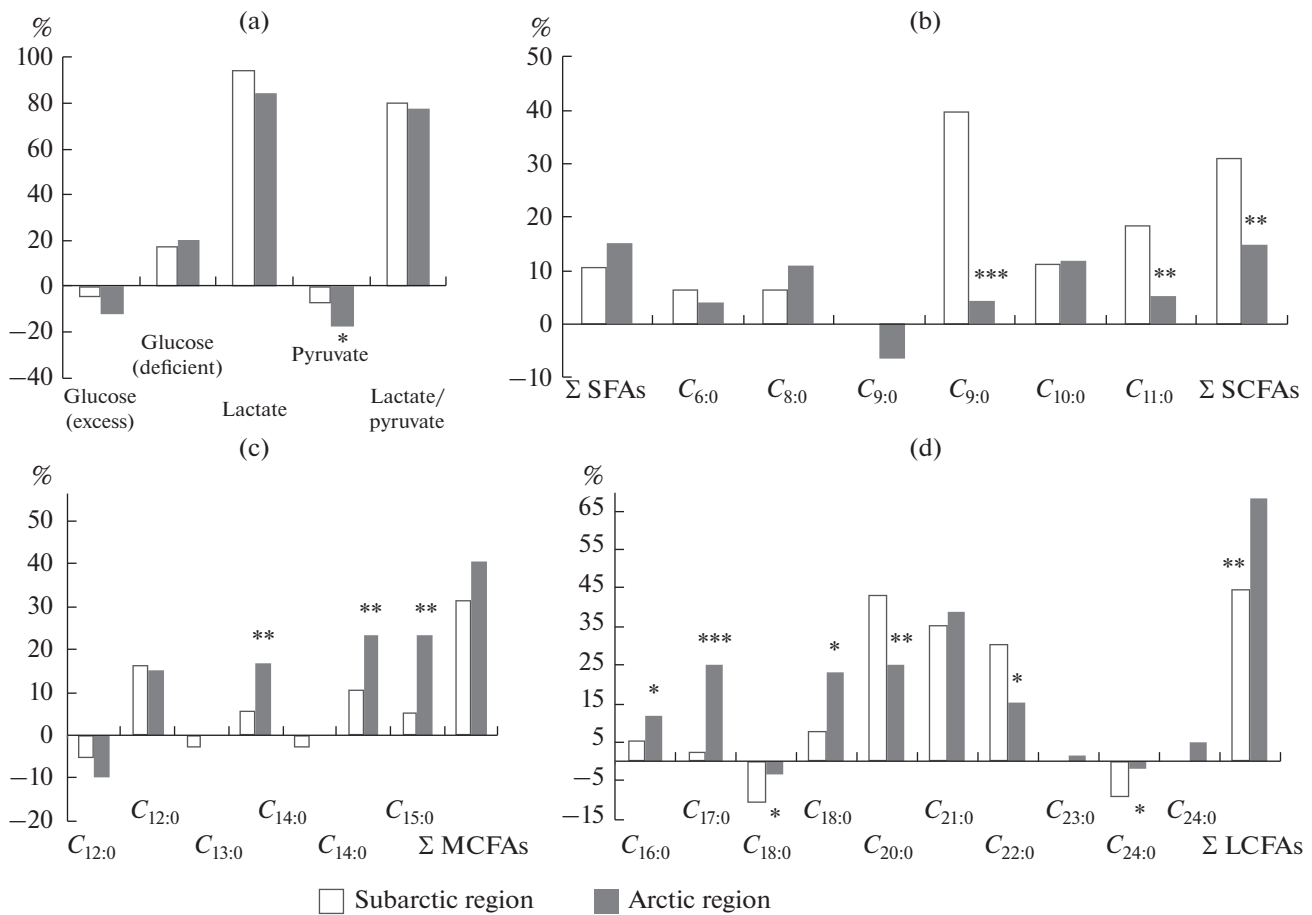
**Fig. 1.** Distribution of the rates of deviations from the physiological norm of the parameters of (a) carbohydrate metabolism and (b) short-chain (SCFAs), (c) medium-chain (MCFAs), and (d) long-chain (LCFAs) SFAs in residents of the Subarctic and Arctic regions; Σ, total content; *, **, and *** are statistical significance of the differences between the corresponding values for the residents of the examined regions.

penetrate the inner mitochondrial membrane, where they undergo β-oxidation [13]. The intensity of these processes is determined by the level of oxygen debt products (ketone bodies), which in our study defines the strength of negative correlations of Lac/Pyr with $C_{12:0}$, $C_{13:0}$, and $C_{14:0}$. The revealed positive correlations of the Glu level with $C_{14:0}$ and $C_{15:0}$ suggest an increase in the risk for type 2 diabetes mellitus and a decrease in the antiatherogenic protection, earlier untypical of the AR residents.

The content of LCFAs in the blood was assessed according to the levels of hexadecanoic ($C_{16:0}$), heptadecanoic ($C_{17:0}$), octadecanoic ($C_{18:0}$), arachidonic ($C_{20:0}$), heneicosanoic ($C_{21:0}$), behenic ($C_{22:0}$), tricosanoic ($C_{23:0}$), and lignoceric ($C_{24:0}$) acids. Unlike SCFAs and MCFAs, these SFAs associate with lipoproteins, circulate in the blood, and are stored in the fat depot, that is, they can act as a marker of an increased blood glucose level and atherogenicity of

lipids, which correlates with the risk of somatic diseases.

Estimation of ΣLCFAs demonstrated higher values among the AR residents compared with the SR cohort ($p = 0.073$). The SR and AR cohorts show no statistically significant differences in the contents of hexadecanoic ($C_{16:0}$), arachidonic ($C_{20:0}$), heneicosanoic ($C_{21:0}$), behenic ($C_{22:0}$), and tricosanoic ($C_{23:0}$) acids (Table 1). However, the rates of excess amounts of ΣLCFAs and $C_{16:0}$ were higher among the AR residents (67 and 11.7%, respectively) in a statistically significant manner compared with the SR residents (45 and 5.4%; $p = 0.002$ and $p = 0.045$); on the contrary, the rates of excess $C_{20:0}$ and $C_{22:0}$ were higher in SR cohort (43.2 and 30.6%, respectively) compared with the AR residents (25 and 15.3%; $p = 0.01$ and $p = 0.05$), whereas the rates of excess $C_{21:0}$ were similar in both regions (35.3 and 39% in SR and AR, respectively; $p = 0.721$) although in a statistically insignificant manner (Fig. 1d).

Note that the average contents of heptadecanoic ($C_{17:0}$), octadecanoic ($C_{18:0}$), and lignoceric ($C_{24:0}$) acids among the AR residents were higher compared with the SR cohort ($p < 0.001$, $p = 0.022$, and $p = 0.043$) in a statistically significant manner (Table 1). The rates of excess $C_{17:0}$ and $C_{18:0}$ levels were also significantly higher among the AR residents (25 and 24%) compared with SR cohort (2 and 8%; $p < 0.001$ and $p = 0.05$) on the background of similar rates of $C_{18:0}$ deficiency (7 and 8%, respectively; $p = 0.862$) but in a statistically insignificant manner.

Among the SR residents, any correlations of Glu, Pyr, Lac, and Lac/Pyr values with the LCFAs as well as SCFAs and MCFAs were unobservable. However, the AR cohort showed moderate positive correlations of the Glu level with the contents of $C_{16:0}$ ($r = 0.45$, $p = 0.001$), $C_{17:0}$ ($r = 0.30$, $p = 0.045$), $C_{18:0}$ ($r = 0.36$, $p = 0.01$), $C_{22:0}$ ($r = 0.3$, $p = 0.03$), $C_{23:0}$ ($r = 0.3$, $p = 0.042$), and $\Sigma$LCFAs ($r = 0.43$, $p = 0.001$) as well as negative correlations of Lac/Pyr value with the contents of $C_{16:0}$ ($r = -0.3$, $p = 0.044$), $C_{17:0}$ ($r = -0.34$, $p = 0.012$), $C_{18:0}$ ($r = -0.37$, $p = 0.011$), $C_{23:0}$ ($r = -0.3$, $p = 0.040$), and $\Sigma$LCFAs ($r = -0.32$, $p = 0.021$). Positive correlations of Glu and negative correlations of Lac/Pyr with the contents of LCFAs confirm the active involvement of these SFAs in energy metabolism and their active utilization in adipose tissue formation. The observed positive correlations between the Glu level and LCFAs, presumably resulting from an imbalance in the intake of LCFAs and their oxidation, may act as a factor contributing to increased body weight.

Excess body weight and obesity considerably influence aging processes; these factors are associated with a decrease in both the body's energy demand and physical activity [3, 10, 15, 16]. Our data suggest that the rate of individuals (61−74 years old) with a normal body weight is lower in the examined AR cohort (19.7%) compared with the SR cohort (23.1%, $p = 0.681$), as well as the rate of overweight individuals (31.2 and 33.3%; $p = 0.843$); however, the rates of class 1 and 2 obese individuals were higher in the AR cohort, amounting to 26.2 and 24.6% versus 23.1 and 20.5% in the SR cohort ($p = 0.862$ and $p = 0.763$, respectively). Although these differences are statistically insignificant, this suggests a higher risk for metabolically determined diseases.

## CONCLUSIONS

Elderly SR and AR residents show no statistically significant differences in the levels of Glu, Pyr, Lac, and Lac/Pyr. The rate of residents with Pyr deficiency is significantly higher among the AR residents; the rates of Glu excess and deficiency are higher in AR as well, but in a statistically insignificant manner; the rates of excess Lac and Lac/Pyr individuals are higher in the SR.

Among the AR residents, the trend toward an increase in $\Sigma$SFAs was accompanied by a statistically insignificant increase in the share of MCFAs and LCFAs and a decrease in the share of SCFAs; the trend in the SR was opposite. Presumably, this is associated with more active SCFA utilization as an energy substrate by AR residents on the background of a decrease in the role of carbohydrates. A statistically insignificant increase in the shares of MCFAs and LCFAs is most likely associated with an imbalance in their intake and oxidation, which may increase body weight as well as the risk for somatic diseases previously atypical of the region.

A statistically significant increase in $\Sigma$SCFAs among the SR residents compared with AR was combined with an increase in the levels of hexanoic ($C_{6:0}$), pelargonic ($C_{9:0}$), and undecanoic ($C_{11:0}$) acids and a decrease in caprylic ($C_{8:0}$) acid.

An increase in the $\Sigma$MCFAs in AR cohort is associated with a statistically significant increase in the content of pentadecanoic ($C_{15:0}$) acid and the trends of an increase in the content of tetradecanoic ($C_{14:0}$) acid; as for the contents of dodecanoic ($C_{12:0}$) and tridecanoic ($C_{13:0}$) MCFAs, the AR and SR residents show no statistically significant differences. The trend of an increase in $\Sigma$LCFAs in AR cohort was combined with a statistically significant increase in the blood level of heptadecanoic ($C_{17:0}$), octadecanoic ($C_{18:0}$), and lignoceric ($C_{24:0}$) acids. As for the contents of the hexadecanoic ($C_{16:0}$), arachidonic ($C_{20:0}$), heneicosanoic ($C_{21:0}$), behenic ($C_{22:0}$), and tricosanoic ($C_{23:0}$) LCFAs, the examined AR and SR cohorts do not differ in a statistically significant manner. The rates of excess contents of hexadecanoic ($C_{16:0}$), heptadecanoic ($C_{17:0}$), and octadecanoic ($C_{18:0}$) acids were significantly higher among the AR residents, while excess contents of arachidonic ($C_{20:0}$) and behenic ($C_{22:0}$) acids were more frequently encountered among the SR residents on the background of similar rates of excess heneicosanoic ($C_{21:0}$) acid content in both regions, which may be directly associated with development of metabolically determined diseases, especially in AR.

No statistically significant differences in BMI among the examined elderly SR and AR residents were observed. Note that 19.7% of the examined AR residents and 23.1% of the SR residents had normal body weight; the remaining individuals were overweight (31.2 and 33.3%, respectively), or in obesity class 1 (26.2 and 23.1%), and obesity class 2 (24.6 and 20.5%); however, the differences are statistically insig-

nificant. This increases the risk for metabolically determined diseases in both regions.

Correlation analysis has not found any statistically significant correlations of the Glu, Lac, and Lac/Pyr values with the contents of SCFAs, MCFAs, and LCFAs ($r = 0.2-0.29$; $p = 0.08-0.676$) in SR. As for AR relative to SR, a negative correlation of the Glu level with the level of pelargonic ($C_{9:0}$) acid and positive correlations with the levels of tetradecanoic ($C_{14:0}$), pentadecanoic ($C_{15:0}$), hexadecanoic ($C_{16:0}$), heptadecanoic ($C_{17:0}$), octadecanoic ($C_{18:0}$), behenic ($C_{22:0}$), and tricosanoic ($C_{23:0}$) acids and ΣLCFAs were revealed on the background of higher rates of Glu excess and deficiency. In addition, a higher rate of excess Pyr in the AR cohort was combined with its positive correlations with the contents of decanoic ($C_{10:0}$), dodecanoic ($C_{12:0}$), and tetradecanoic ($C_{14:0}$) acids and ΣMCFAs; an insignificant decrease in the rate of excess Lac/Pyr values in this region compared with SR was combined with a positive correlation with the content of hexanoic ($C_{6:0}$) acid and negative correlations with the levels of decanoic ($C_{10:0}$), dodecanoic ($C_{12:0}$), tridecanoic ($C_{13:0}$), tetradecanoic ($C_{14:0}$), hexadecanoic ($C_{16:0}$), heptadecanoic ($C_{17:0}$), octadecanoic ($C_{18:0}$), and tricosanoic ($C_{23:0}$) acids, as well as ΣMCFAs and ΣLCFAs.

Thus, the detected changes in the contents of the considered carbohydrate metabolism parameters and SFAs on the background of excess body weight and obesity classes 1 and 2 in the examined elderly residents of SR and AR suggest the actual stress of these components, as well as formed metabolic imbalances, which requires further studies.

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## COMPLIANCE WITH ETHICAL STANDARDS

*Conflict of interests.* The authors declare that they have no conflict of interest.

*Statement on the welfare of animals.* This article does not contain any studies with animals performed by any of the authors.

*Statement of compliance with standards of research involving humans as subjects.* Informed consent of the volunteers was obtained and the study was carried out in full agreement with the World Medical Association Declaration of Helsinki on the Ethical Principles of Medical Research Involving Human Subjects (2000).

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