

Determinants of Inefficient Glycemic Control in Adults with Type 2 Diabetes Mellitus: An Urban Sample from Siberia

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Article

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Abstract

We aimed to identify non-pharmacological factors associated with inefficient glycemic control (IGC) among individuals with type 2 diabetes (T2D) in a Siberian urban sample. A cross-sectional data from a representative sample in Novosibirsk (HAPIEE Project), focusing on the individuals with T2D receiving glucose-lowering therapy (GLT) selected from wave-3 participants ($n = 476$ from 3898, 55–84 years) were analyzed. We have assessed diabetes history and duration, GLT use, cardiovascular disease (CVD) history, menopausal status, behavioral risk factors, self-rated health, sociodemographic characteristics, and objective measures. Associations with IGC were assessed using logistic regression. Glycemic targets were achieved in 35.3% of participants. In multivariable-adjusted model, IGC was positively associated with male sex, systolic blood pressure, diabetes duration ≥ 10 years and its family history, and inversely associated with smoking, independently of other factors. In sex-stratified analysis, IGC odds ratio was 3.5-fold higher in men with low physical activity versus high activity. In women, IGC odds ratio was 4.6-fold higher in those with diabetes duration ≥ 10 years, 2-fold higher in those with a diabetes family history, and consuming alcohol < 1 time/month versus abstainers. IGC was inversely related to smoking in women. We identified determinants of IGC in Siberians aged 55–84, informing region-specific diabetes management strategies.

1 Introduction

Diabetes mellitus is a global problem, accompanied by systemic vascular complications, which are the leading cause of disability and mortality in affected patients [1]. According to the NCD-RisC analysis of 1,108 population-based studies (141 million persons with assessed levels of fasting plasma glucose (FPG) and glycated hemoglobin (HbA1c)), the increase in diabetes prevalence from 1990 to 2022 ranged 2–22% in women and 2–18% in men, further compounding the burden of diabetes-related consequences [2].

Among evidence-based approaches to reducing diabetes complication risk, achieving target glycemic control is of greatest importance. The UKPDS study showed that a 1.0% absolute reduction in HbA1c reduces the risk of diabetes-related death, myocardial infarction (MI), and microvascular complications by 21%, 14%, and 37%, respectively [3]. However, treatment coverage varies considerably across countries: in 2022, age-standardized treatment coverage was estimated at 5–10% in sub-Saharan African countries (e.g., Burkina Faso, Angola, Niger, Liberia, Benin), versus a high of 86% in women and 77% in men in Belgium [2].

Most clinical guidelines (ADA, EASD and others) recommend a target HbA1c of $< 7.0\%$ or $\leq 6.5\%$, depending on individual factors (age, diabetes duration, comorbidities, hypoglycemia risk) [4, 5]. Despite these recommendations, 40–70% of patients with type 2 diabetes worldwide fail to achieve target HbA1c [2, 6]. This "translational gap" — the disconnect between evidence-based recommendations and routine clinical practice — remains poorly understood. Glycemic control is primarily regulated through glucose-lowering therapy (GLT); however, beyond disease-specific treatment, type 2 diabetes control is

influenced by non-modifiable factors (genetic, sex, age, disease duration) and modifiable ones (obesity, diet, behavioral, and socioeconomic factors).

In this regard, an analysis of the broad spectrum of potential non-pharmacological determinants of glycemic control across diverse samples is highly relevant, and is critically important for developing targeted, context-sensitive interventions and informing health systems on improving type 2 diabetes outcomes in resource-limited settings.

2 Objective

We aimed to identify non-pharmacological factors associated with inefficient glycemic control (IGC) among individuals with type 2 diabetes in a Siberian urban sample.

3 Research Design and Methods

The study was conducted using the data from a representative sample in Novosibirsk (the international project "Health, Alcohol and Psychosocial factors In Eastern Europe: a multi-centre cohort study", HAPIEE project). The baseline random sample of men and women aged 45–69 years was drawn from residents of two districts representative of Novosibirsk in terms of infrastructure, demographic characteristics, and migration rates. The sample was formed from electoral registers using a random number table and stratified by 5-year age groups; the study design and protocol have been published previously [7]. A total of 9,360 individuals were examined at baseline in 2003/05 (98% of participants were of European ethnicity, response rate 61%), with two repeated survey conducted in 2006/08 (wave2) and 2015/18 (wave3, response rate 60.1%). The present analysis was focused on the individuals with type 2 diabetes receiving GLT selected from participants of the wave3 ($n = 476$, aged 55–84 years). The present study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Research Institute of Internal and Preventive Medicine (IIPM) (protocol No. 33, dated 20.06.2024). All participants provided written informed consent.

The study was conducted as a cross-sectional analysis. The protocol included an assessment of type 2 diabetes and risk factors using standardized questionnaires and measurements [7], encompassing diabetes history, GLT use, diabetes duration and family history, history of cardiovascular disease (CVD) and other chronic conditions, menopausal status, behavioral risk factors for CVD and type 2 diabetes (smoking, alcohol consumption, physical activity — PA), self-rated health, sociodemographic characteristics, and objective measurements (blood pressure (BP), anthropometry, lipid and blood glucose levels).

Type 2 diabetes was established by a history of type 2 diabetes with treatment and/or a FPG level ≥ 7 mmol/L [8]. All individuals with a history of type 2 diabetes or newly identified type 2 diabetes were included in the analysis. Regular use of GLT was defined as daily intake over the preceding 12 months, irrespective of dosage. Medication coding was performed according to the Anatomical Therapeutic

Chemical (ATC) classification system [9]. The GLT profile in this sample has been described previously [10].

In studied sample, we defined two categories:

- Efficient glycemic control (EGC) — persons with type 2 diabetes receiving GLT with FPG < 7.0 mmol/L;
- IGC — persons with type 2 diabetes receiving GLT with FPG $\geq$ 7.0 mmol/L.

Two categories of type 2 diabetes duration were defined: ≥ 10 years and < 10 years, based on data from 3 survey waves. Family history of type 2 diabetes was assessed based on the presence of type 2 diabetes in first-degree relatives. Women were classified as postmenopausal or premenopausal.

Current smoking was defined as smoking at least 1 cigarette per day. Alcohol consumption was assessed using a graduated frequency questionnaire [11] and categorized into 5 groups: non-drinkers, drinking less than once a month, 1–3 times per month, 1–4 times per week, and 5 or more times per week.

Leisure-time PA was assessed using a standard questionnaire. The mean number of hours per week (h/week) spent on physical work or sport was determined. Three groups were defined according to tertiles of leisure-time PA (h/week) distribution, separately for men and women [12].

Marital status was categorized as "married" (cohabiting) or "single." Educational level was categorized as university, secondary, vocational, and primary. Economic activity was dichotomized as "economically active", including working retirees, and "economically inactive".

Material deprivation was assessed using 3 questions on the frequency with which respondents experienced financial difficulties in purchasing food, clothing, and paying utility bills. Responses were coded from 0 to 4 points; a summary material deprivation scale was calculated and classified into 4 groups: 0 points (no deprivation), 1–3 points, 4–8 points, and 9–12 points, in accordance with the HAPIEE project categorization [13].

BP was measured three times using an Omron M-5 device and the mean value was calculated. In accordance with the 2024 European Society of Cardiology guidelines hypertension (HT) was defined by epidemiological criteria as systolic blood pressure (SBP) or diastolic blood pressure (DBP) $\geq$ 140/90 mmHg and/or use of antihypertensive therapy within the preceding 2 weeks.

Height, waist circumference (WC), and hip circumference were measured to the nearest 0.1 cm; body weight to the nearest 0.1 kg. The waist-to-hip ratio (WHR) and body mass index (BMI, kg/m²) were calculated. Obesity was defined as BMI $\geq$ 30 kg/m² (ESC, 2021); abdominal obesity (AO) was defined as WC $\geq$ 94 cm in men and $\geq$ 80 cm in women (WHO, 2008).

Fasting serum levels of total cholesterol (TC), triglycerides, high-density lipoprotein cholesterol, and glucose were measured (KoneLab 300i, USA; enzymatic method); low-density lipoprotein cholesterol was calculated using the Friedewald equation. Fasting serum glucose was converted to FPG (EASD, 2007).

A combined CVD category was established in the presence of coronary artery disease (Rose angina [14], ischemic ECG changes, myocardial infarction, acute coronary syndrome, or history of coronary revascularization) or stroke/transient ischemic attack, confirmed by hospitalization records.

A total of 3,898 individuals were examined, of these, 803 (20.8%) subjects had type 2 diabetes. First, we selected complete sample of subjects with type 2 diabetes receiving GLT – 476 (59.3%). Subsequently, 6 individuals with incomplete data were excluded, resulting in a final analytic sample of 470 participants with either EGC or IGC.

A preliminary calculation of the sample size for this analysis (in each group) was performed to ensure a minimum odds ratio $OR = 2$ (when $a = 0.05$; $b = 0.10$ and 0.20) for the prevalence of the tested factor of 10% and 20% in the control. We addressed potential selection, information and confounding biases by ensuring random sampling, appropriate response rate, standardized tools/personnel and quality control, multivariable-adjusted analysis.

Statistical analysis was performed using SPSS v.13.0 and v.23.0. First, we compared general characteristics in the groups with EGC and IGC. Results are presented as mean $\pm$ standard deviation ($M \pm SD$) or as absolute number (percentage) – n (%). Between-group comparisons of categorical variables were performed using Pearson's chi-square test. Comparisons of continuous variables between the groups were performed using Student's t-test under the assumption of normality. In cases of non-normal distribution Mann–Whitney test was used.

Second, we assessed the associations between studied factors and status of IGC in logistic regression models. Factors were tested as dichotomized or categorical variables (3 or more categories). Model 1 was adjusted for sex and age; Model 2 included sex, age, obesity, abdominal obesity, CVD, HT, and dyslipidemia, and smoking; Model 3 included the aforementioned covariates plus alcohol consumption frequency, PA, type 2 diabetes duration, family history of type 2 diabetes, self-rated health, marital status, educational level, economic activity, and material deprivation.

Third, for sensitivity analysis we also performed logistic regression analysis separately for men and women using the same models. We tested all hypotheses at a 95% confidence level (95% CI) for two-tailed tests.

Artificial Intelligence. The authors used Claude (accessed July 2026) to design the figure. All outputs were critically reviewed and revised by the authors.

4 Results

4.1 General characteristics

In the Siberian urban sample of individuals aged 55–84 years with type 2 diabetes receiving GLT (n = 476), glycemic targets were achieved in 35.3% of participants. The number of persons included for analysis ranged from 470 (complete main variables) to 464 due to missing data for some variables. The main characteristics of the EGC and IGC groups are presented in Table 1.

Table 1

The general characteristics of subjects with type 2 diabetes receiving GLT, stratified by groups with EGC and IGC

Parameters	Observed (n)	Efficientglycaemic control	Inefficient glycaemic control	<i>p</i>
Examined subjects with DM receiving GLT, n (%)	476	166 (34.9)	310 (65.1)	-
Included in analysis (complete data), n (%)	470	166 (35.3)	304 (64.7)	-
Sex: male/female, n (%)	470	38(22.9)/128 (77.1)	103 (33.9)/201 (66.1)	0,013
Age, years	470	69.3 ± 6.3	70.1 ± 6.4	0.215
SBP, mmHg	466	143.5 ± 19.7	148.3 ± 18.7	0.009
DBP, mmHg	466	80.9 ± 10.2	83.2 ± 10.8	0.024
HR, b/min	465	72.4 ± 10.2	74.9 ± 11.5	0.018
BMI, kg/m ²	467	31.4 ± 4.6	32.8 ± 6.0	0.006
Obesity (BMI > 30 kg/m ²), n (%)	467	101 (61.2)	193 (63.9)	0.564
WHR, unit	465	0.92 ± 0.08	0.94 ± 0.07	0.015
Abdominal obesity, n (%)	466	158 (96.3)	282 (93.4)	0.183
TC, mmol/L	470	5.2 ± 1.1	5.2 ± 1.2	0.606
LDL-C, mmol/L	470	3.3 ± 1.0	3.1 ± 1.1	0.103
HDL-C, mmol/L	470	1.2 ± 0.3	1.2 ± 0.4	0.125
TG, mmol/L	470	1.6 ± 0.8	2.0 ± 1.2	0.001
GGT, U/L	470	31.8 ± 23.5	42.2 ± 45.5	0.001
FPG, mmol/L	470	6.2 ± 0.6	10.2 ± 3.3	0.001
Duration of T2DM, years	464	6.2 ± 4.2	8.6 ± 4.2	0.001

In Tables 1 results are presented as mean ± standard deviation (M ± SD) or absolute number and percentage (n(%)). SBP – systolic blood pressure; DBP – diastolic blood pressure; HR – heart rate; BMI – body mass index; WHR – waist-to-hip ratio; TC – total cholesterol; LDL-C – low-density lipoprotein cholesterol; HDL-C – high-density lipoprotein cholesterol; TG – triglycerides; FPG – fasting plasma glucose; GGT – gamma-glutamyl transferase; T2DM – type 2 diabetes mellitus; HT – hypertension; CVD – cardiovascular diseases; CHD – coronary heart disease; HRT – hormone replacement therapy; PA – physical activity. P-values in bold indicate statistically significant differences.

Parameters	Observed (n)	Efficientglycaemic control	Inefficient glycaemic control	p
Duration of T2DM ≥ 10 years, n (%)	260	43 (26.5)	161 (53.3)	0.001
Family history of T2DM, n (%)	469	29 (17.5)	89(29.4)	0.005
HT, n (%)	469	153 (92.2)	281 (92.7)	0.822
CVD, n (%)	470	47 (28.3)	88 (28.9)	0.885
CHD, n (%)	470	31 (18.7)	73 (24.0)	0.183
Menopause, n (%)	328	128 (100%)	195 (97.5)	0.197
Age at menopause, years	325	48.8 ± 4.4	49.6 ± 4.7	0.116
Smoking status	468			
Current smokers, n (%)	36	20 (12.0)	16 (5.3)	0.012
Former smokers, n (%)	75	20 (12.0)	55 (18.2)	
Non-smokers, n (%)	357	126(75.9)	231(76.5)	
Alcohol consumption frequency, n (%)	468			
≥ 5 times/week	3	1 (0.6)	2 (0.7)	0.670
1–4 times/week	34	11 (6.6)	23 (7.6)	
1–3 times/month	86	30 (18.1)	56 (18.5)	
< 1 time/month	207	68 (41.0)	139 (46.0)	
Non-drinkers	138	56 (33.7)	82 (27.2)	
PA (leisure), hours/week	467	12.1 ± 6.3	11.1 ± 6.1	0.078
PA (terciles), n (%)	467			
Low (T1)	188	58 (34.9)	130 (43.2)	0.162
Moderate (T2)	145	53 (31.9)	92 (30.6)	
In Tables 1 results are presented as mean ± standard deviation (M ± SD) or absolute number and percentage (n(%)). SBP – systolic blood pressure; DBP – diastolic blood pressure; HR – heart rate; BMI – body mass index; WHR – waist-to-hip ratio; TC – total cholesterol; LDL-C – low-density lipoprotein cholesterol; HDL-C – high-density lipoprotein cholesterol; TG – triglycerides; FPG – fasting plasma glucose; GGT – gamma-glutamyl transferase; T2DM – type 2 diabetes mellitus; HT–hypertension; CVD – cardiovascular diseases; CHD–coronary heart disease; HRT – hormone replacement therapy; PA – physical activity. P-values in bold indicate statistically significant differences.				

Parameters	Observed (n)	Efficientglycaemic control	Inefficient glycaemic control	<i>p</i>
High (T3)	134	55 (33.1)	79 (26.2)	
Education level, n (%)	470			
Primary	37	14 (8.4)	23 (7.6)	0.965
Professional	133	48 (28.9)	85 (28.0)	
Secondary	164	58 (34.9)	106 (34.9)	
University	136	46 (27.7)	90 (29.6)	
Marital status, n (%)	470			
Single	219	84 (50.6)	135 (44.4)	0,198
Married	251	82 (49.4)	169 (55.6)	
Economic activity, n (%)	467			
Economically active	90	37 (22.3)	53 (17.6)	0.220
Economically inactive	377	129 (77.7)	248 (82.4)	
Material deprivation (0–12 score)	467	1.52 ± 2.0	1.76 ± 2.2	0.239
Material deprivation (0–12 score), n (%)	467			
0 points	241	90 (54.2)	151 (50.2)	0.711
1–2 points	111	39 (23.5)	72 (23.9)	
3–5 points	114	37 (22.3)	77 (25.6)	
6–12 points	1	0 (0)	1 (03)	
Self-rated health, n (%)	470			
Very good/good/average	378	137 (82.5)	241 (79.3)	0.395
Very poor/poor	92	29(17.5)	63 (20.7)	
In Tables 1 results are presented as mean ± standard deviation (M ± SD) or absolute number and percentage (n(%)). SBP – systolic blood pressure; DBP – diastolic blood pressure; HR – heart rate; BMI – body mass index; WHR – waist-to-hip ratio; TC – total cholesterol; LDL-C – low-density lipoprotein cholesterol; HDL-C – high-density lipoprotein cholesterol; TG – triglycerides; FPG – fasting plasma glucose; GGT – gamma-glutamyl transferase; T2DM – type 2 diabetes mellitus; HT–hypertension; CVD – cardiovascular diseases; CHD–coronary heart disease; HRT – hormone replacement therapy; PA – physical activity. P-values in bold indicate statistically significant differences.				

In the IGC group, the proportion of women was lower than in the EGC group (66.1% vs. 77.1%, $p = 0.013$). SBP, DBP, heart rate (HR), BMI, WHR, triglyceride levels, GGT, FPG, type 2 diabetes duration, frequency of type 2 diabetes duration ≥ 10 years and family history of type 2 diabetes were all higher in the IGC group compared to the EGC group ($p = 0.001-0.018$). Current smoking was more common in the EGC group than in the IGC group.

4.2 Multivariable logistic regression analyses

At the second stage, we examined associations between IGC and potential determinants of control inefficiency (Table 2). In multivariable-adjusted Model IGC was positively associated with male sex (OR = 2.32; 95% CI 1.16–4.63), family history of type 2 diabetes (OR = 3.11; 95%CI 1.95–4.96), type 2 diabetes duration ≥ 10 years (OR = 2.02; 95%CI 1.19–3.43), and SBP (OR = 1.01; 95%CI 1.00-1.02), and inversely related to current smoking (OR = 0.25; 95%CI 0.11–0.61) independent of age, obesity, history of CVD, and behavioral and social factors.

Table 2

The associations between non-pharmacological factors and IGC in a Siberian urban sample combined by sex (multivariable-adjusted model, logistic regression)

Parameters	Observed (n)	Model 1, OR(95% CI); p	Model 2, OR(95% CI); p	Model 3, OR(95% CI); p
Age, per 1 year	470	1.02 (0.989–1.050); 0.229	1.01 (0.978–3.912); 0.537	0.99 (0.958–1.036); 0.848
Sex				
Female	329	1.0	1.0	1.0
Male	141	1.72(1.116–2.657); 0.014	2.17 (1.210–3.912); 0.009	2.32 (1.158–4.633); 0.018
Obesity				
Obesity (BMI $\geq$ 30 kg/m ²): no	173	1.0	1.0	1.0
Obesity (BMI $\geq$ 30 kg/m ²): yes	294	1.27 (0.848–1.905); 0.245	1.25 (0.813–1.911); 0.311	1.47 (0.914–2.369); 0.112
Abdominal obesity				
Abdominal obesity: no	26	1.0	1.0	1.0
Abdominal obesity: yes	440	0.75 (0.281–1.982); 0.556	0.67 (0.235–1.904); 0.451	0.75 (0.244–2.308); 0.617
CVD				
CVD: no	335	1.0	1.0	1.0
CVD: yes	135	0.93 (0.603–1.427); 0.733	0.92 (0.591–1.429); 0.707	0.77 (0.466–1.280); 0.317
HT				
HT: no	35	1.0	1.0	1.0
HT: yes	434	1.34 (0.641–2.808);	1.29 (0.597–2.825);	1.49 (0.638–3.472);

Parameters	Observed (n)	Model 1, OR(95% CI); p	Model 2, OR(95% CI); p	Model 3, OR(95% CI); p
		0.436	0.510	0.358
Dyslipidemia				
Dyslipidemia: no	74	1.0	1.0	1.0
Dyslipidemia: yes	396	1.03 (0.604–1.761); 0.911	1.01 (0.585–1.734); 0.979	0.96 (0.531–1.722); 0.882
Smoking status				
Non-smokers	357	1.0	1.0	1.0
Former smokers	75	0.92 (0.477–1.787); 0.813	0.90 (0.456–1.764); 0.979	0.83 (0.398–1.719); 0.611
Current smokers	36	0.30 (0.135–0.658); 0.003	0.31 (0.141–0.685); 0.004	0.25 (0.106–0.607); 0.002
Alcohol consumption frequency				
Non-drinkers	138	1.0	(-)	1.0
< 1 time/month	207	1.46 (0.929 – 2.300); 0.101	(-)	1.58 (0.939–2.660); 0.085
1–3 times/month	86	1.11 (0.623–1.995); 0.715	(-)	1.40 (0.717–2.736); 0.323
1–4 times/week	34	1.10 (0.473–2.546); 0.828	(-)	1.61 (0.612–4.223); 0.335
≥ 5 times/week	3	0.98 (0.083–11.639); 0.988	(-)	1.36 (0.090–20.298);

Parameters	Observed (n)	Model 1, OR(95% CI); p	Model 2, OR(95% CI); p	Model 3, OR(95% CI); p
				0.826
PA (terciles)				
High (T3)	134	1.0	(-)	1.0
Moderate (T2)	145	1.20 (0.733–1.955); 0.472	(-)	1.32 (0.759– 2.292); 0.326
Low (T1)	188	1.51 (0.942–2.418); 0.087	(-)	1.68 (0.995– 2.851); 0.052
Duration of T2DM				
Duration of T2DM < 10 years	260	1.0	(-)	1.0
Duration of T2DM ≥ 10 years	204	3.02 (1.977–4.602); 0.001	(-)	3.11 (1.952– 4.962); 0.001
Family history of T2DM				
Family history of T2DM:no	351	1.0	(-)	1.0
Family history of T2DM:yes	118	2.05 (1.270–3.295); 0.003	(-)	2.02 (1.194– 3.433); 0.009
Self-rated health,				
Very good/good/average	378	1.0	(-)	1.0
Very poor/poor	92	1.26 (0.768–2.076); 0.357	(-)	1.31 (0.735– 2.331); 0.361
Marital status				

Parameters	Observed (n)	Model 1, OR(95% CI); p	Model 2, OR(95% CI); p	Model 3, OR(95% CI); p
Married	251	1.0	(-)	1.0
Single	219	0.87 (0.582–1.305); 0.505	(-)	0.92 (0.571– 1.474); 0.720
Education level				
University	136	1.0	(-)	1.0
Secondary	164	1.03 (0.635–1.683); 0.895	(-)	1.09 (0.636– 1.882); 0.746
Professional	133	1.01 (0.604–1.681); 0.976	(-)	1.18 (0.666– 2.076); 0.576
Primary	37	0.79 (0.367–1.719); 0.559	(-)	0.74 (0.307– 1.787); 0.504
Economic activity				
Economically active	90	1.0	(-)	1.0
Economically inactive	377	1.35 (0.806–2.245); 0.256	(-)	1.49 (0.837– 2.635); 0.176
Material deprivation (0–12 score)				
0 points	241	1.0	(-)	1.0
1–2 points	111	1.24 (0.766–2.003); 0.383	(-)	1.32 (0.770– 2.275); 0.311

Parameters	Observed (n)	Model 1, OR(95% CI); p	Model 2, OR(95% CI); p	Model 3, OR(95% CI); p
3–5 points	114	1.40 (0.864–2.268); <i>0.171</i>	(-)	1.55 (0.898– 2.673); <i>0.116</i>
6–12 points	1	NA	(-)	NA
SBP, per 1 mmHg	466	1.01 (1.003–1.025); 0.010	(-)	(-)
In Table 2 results are presented as odds ratio (OR) and 95% confidence interval (95% CI); NA - not applicable Model 1 – adjusted for sex and age; Model 2 – Model 1 (+) adjusted for obesity, abdominal obesity, cardiovascular diseases, hypertension, dyslipidemia and smoking; Model 3 – Model 2 (+) adjusted for alcohol consumption frequency, physical activity, duration of T2DM, family history T2DM, self-rated health, education level, economic activity, marital status, and material deprivation. ORs for statistically significant associations are shown in bold.				

4.3 Sex-stratified multivariable logistic regression analyses

In the sex-stratified analysis (Supplement, Table 1s, 2s), in age-adjusted Model 1 and in Model 2 adjusted for age, obesity, CVD, HT, and dyslipidemia, the odds of IGC in men were reduced by 75% in current smokers (OR = 0.25; 95%CI 0.08–0.75); however, this inverse relationship was attenuated to insignificant after adjustment for type 2 diabetes history, behavioral and socio-economic factors in Model 3. The odds of IGC were 3.5-fold higher in men with low PA compared to counterparts with high PA (OR = 3.48; 95%CI 1.16–10.50), independent of other factors (Fig. 1).

In women, in age-adjusted Model 1 (Supplement, Table 2s), the odds of IGC were 3-fold higher in those with type 2 diabetes duration ≥ 10 years ($p = 0.001$) vs women with shorter history. After full adjustment, the odds of IGC were also 4.6-fold higher in women with type 2 diabetes duration ≥ 10 years (OR = 4.60; 95% CI 2.54–8.32), and about 2.0-fold higher in women with a family history of type 2 diabetes (OR = 1.94; 95% CI 1.04–3.63) vs their counterparts, and in those consuming alcohol < 1 time/month vs abstainers (OR = 1.85; 95% CI 1.01–3.36). IGC was inversely related to current smoking in women (OR = 0.14; 95%CI 0.30–0.67), independently of other factors (Fig. 1).

5 Discussion

In the studied Siberian sample (2015–2018), the glycemic targets were achieved in 35.3% of treated individuals with type 2 diabetes – slightly below the national Russian estimate of 38.8–41.8% (2015–

2018, remained at 41.8% by 2023) [15], and lower than the European estimate of 44% (2010–2022) (2). An earlier HAPIEE study (n = 30,882, aged 45–69; Czech Republic, Russia, Poland, Lithuania; 2002–2008) found adequate control in $\leq 50\%$ of treated Polish participants but $\leq 30\%$ in other countries, including Russia [16]. This modest (around + 5%) improvement in the Russian sample likely reflects the impact of factors beyond pharmacotherapy contributing to glycemic control.

In our study, non-pharmacological factors positively associated with IGC were male sex, diabetes duration ≥ 10 years, family history of type 2 diabetes, elevated BP, low PA (in men), and rare alcohol consumption (in women), while current smoking was inversely associated with IGC. These findings are consistent with a health survey in Wuhan, China (376,702 individuals aged ≥ 65 years) reported 41% of diabetics achieved EDC, with sex, physical activity, alcohol consumption, BMI, abdominal obesity, educational level, and marital status identified as associated factors [17].

Men were more likely to have IGC in our study and in several other studies, including DISCOVER, NCD-RisC, and others [2, 18, 19], which may be related to women's greater engagement in health-seeking behaviors. In contrast, a large systematic review by Siddiquea et al. [20] encompassing 28 low- and middle-income countries (LMICs) (n = 176,349), found higher odds of IGC in women (OR: 1.74, 95% CI: 1.39–2.09), consistent with previous findings from Ethiopia [21]. A meta-analysis by Shahrestanaki et al. (233 studies, 1985–2022, 12,537,968 participants; China, the USA, Iran, India et al.), showed higher control in women in high-income countries (HICs) and urban settings compared to men in HICs and middle-income countries and rural areas, respectively, a finding broadly consistent with the NCD-RisC meta-analysis [2, 19]. The pronounced contradictions regarding sex and glycemic target achievement across large studies, likely reflect the role of socioeconomic and lifestyle factors (e.g., poor diet and lower physical activity), which may differentially affect the ability of men and women to manage diabetes.

Physical exercise is critical for lowering blood glucose levels. This occurs through activation of the GLUT4 transporter in skeletal muscle, increased insulin sensitivity, enhanced oxidative capacity and mitochondrial number, and reduced accumulation of excess lipids. Jansson et al. [22] reported a significant reduction in HbA1c with resistance training (weighted MD = – 0.39%), while Yuwen Wan et al. [23] observed reductions in both HbA1c (– 0.50%) and fasting blood glucose (FBG) (– 12.03 mg/dL). In our study, men with high PA were 3.5 times more likely to achieve EGC than men with low PA.

Physical inactivity and excessive caloric intake are primary risk factors for obesity and type 2 diabetes [24]. In EUROASPIRE V (2016–2017, 131 centers, 27 countries), only two-fifths of obese patients attempted weight loss through diet and exercise, and one in four with BMI ≥ 30 kg/m² received no information about excess weight; obesity was associated with worse BP and glycemic control and a higher prevalence of diabetes [25]. A meta-analysis of 11 studies similarly showed higher odds of IGC among overweight/obese participants (OR: 1.17, 95% CI: 1.11–1.22), though the obesity-vs-normal-BMI subgroup difference was not significant [20]. In our study, unadjusted analysis revealed higher BMI in individuals with IGC (p = 0.006); however, we did not find an independent association. Some studies

indicate that underweight patients also achieve poor diabetes control and frequently have low C-peptide levels [26], which cannot be excluded in patients with obesity and long-standing diabetes.

In our study, type 2 diabetes duration ≥ 10 years was associated with a 3-fold increase in the odds of IGC. In the cross-sectional study by Phuwilert, 2024 diabetes duration > 10 years increased the odds of IGC by 3.95-fold (95% CI: 1.90–8.22), while in the meta-analysis by Siddiquea, 2025 the odds were doubled (OR: 1.92, 95% CI: 1.68–2.16) compared to individuals with diabetes duration ≤ 10 years [21, 27]. This may be explained by the progressive nature of β -cell dysfunction and declining insulin secretion over time. Furthermore, individuals with longer disease duration are more likely to develop comorbidities and complications that may interfere with diabetes self-management, medication adjustment, and overall metabolic control.

Family history (FH) of diabetes is frequently associated with earlier disease onset and higher diabetes prevalence in the population [28]. However, the relationship between FH of diabetes and glycemic control in patients with established diabetes remains controversial [29]. We found a two-fold increase in the risk of IGC compared to those without a FH of diabetes, and this association comprised in women. The NHANES study was demonstrated that maternal FH, but not paternal FH, exerted a significant negative effect on glycemic control in patients with type 2 diabetes aged < 60 years, and that individuals with early-onset diabetes more frequently experienced difficulties in achieving glycemic control. Individuals with early-onset diabetes were found to have greater difficulties in glycemic control and a higher rate of microvascular complications [30].

Regarding diabetes-related complications, in the meta-analysis by Siddiquea, 2025 [20] (62 studies, 28 countries, $n = 176,349$), participants with retinopathy had the highest rate of inadequate control, followed by those with neuropathy, nephropathy, and coronary artery disease, respectively. In our study, we found no association between IGC and CVD or HT; however, we identified a positive association between SBP and IGC (95% CI: 1.003–1.025). This may reflect worse diabetes control among individuals with comorbid conditions.

We found no association between dyslipidemia and poor glycemic control. However, in unadjusted analysis, triglyceride (TG) levels were significantly higher in individuals with IGC ($p = 0.001$). This finding is supported by another prospective study, which showed that elevated blood TG levels increase the risk of developing diabetes, impaired fasting glucose, and impaired glucose tolerance [31].

Another biochemical marker in our study, serum GGT levels were significantly higher in the IGC group ($p = 0.001$), a finding corroborated by 6-year follow-up study from China [32]. There was found that elevated serum GGT may predict glucose intolerance through hepatic insulin resistance; the authors identified an association between reduced insulin sensitivity and increased hepatic fat content, which may explain the elevated risk of diabetes in individuals with elevated serum GGT [32].

At the same time, there is no consensus on alcohol's effect on diabetes development, as earlier study showed a U-shaped relationship, with moderate consumption potentially protective and heavy

consumption a risk factor [33]. The dual effect may stem from improved insulin sensitivity at low-to-moderate doses versus pancreatic damage and alcohol-induced obesity at high doses. A meta-analysis of 13 randomized trials (1945–2015) found no significant effect of light-to-moderate consumption on glycemic control or hypoglycemic events [34]. Our study found rare alcohol consumption to be associated with IGC in women compared to non-drinkers, partially consistent with a Guangzhou study (n = 101,914), showing non-drinkers had better glycemic control than drinkers [35], but contrasting with other findings that moderate consumption improves control relative to abstinence [36]. This discrepancy may reflect heterogeneity in consumption patterns and sex-specific differences in ethanol metabolism, as women's lower alcohol dehydrogenase activity and smaller volume of distribution yield higher blood ethanol concentrations at comparable doses. Additionally, infrequent drinking may reflect broader behavioral clustering of risk factors, including dietary inadequacies and lower treatment adherence, independently affecting glycemic control.

Smoking is a recognized modifiable risk factor in diabetes, associated with IGC and increased morbidity and mortality in type 1 and type 2 diabetes [37]. In our study, current smoking was associated with better glycemic control. Smoking in type 2 diabetes exemplifies the "clustering" of risk factors affecting diabetes course, a concept increasingly recognized by behavior change theorists: better overall health may facilitate continued smoking, while serious health events more often prompt cessation, so more physically active individuals may manage diabetes more effectively—partly explaining the inverse smoking–IGC association. Additionally, participants' age and comorbid burden likely reduced smoking prevalence in this sample, diminishing its effect on diabetes control. A further paradox is that weight gain after smoking cessation can promote obesity and diabetes, remaining a concern despite the health benefits of quitting [38].

In our sample, socioeconomic status (SES) was not associated with glycemic control. Nevertheless, data from large epidemiological studies indicate heterogeneity in this relationship. In the observational DISCOVER study (15,983 patients with type 2 diabetes, 38 countries), the association between SES and IGC was most pronounced at the country level in low-income settings, while individual patient-level SES characteristics showed a considerably weaker association [39]. This is consistent with the notion that the effect of SES on glycemic control is largely mediated through behavioral and systemic factors — access to healthcare, self-management capacity, and depression — and may be attenuated in older age groups with established behavioral patterns.

6 Limitations and Strengths

This study has several limitations. During the screening, HbA1c could not be assessed, and blood glucose was measured at a single visit, which may affect T2D identification. However, a standardized blood collection procedure (8-hour fasting, uniform staff and storage protocol) and uniform analyses performed on a single KoneLab 300i autoanalyzer (Thermo Fisher Scientific Inc., USA) with standardized Thermo Fisher reagent kits in the certified IIPM laboratory minimize this limitation. Medication regimen and dosage could not be assessed in this study, but this did not affect the evaluation of GLT frequency

and profile or the identified IGC overall. About 70% of GLT recipients named specific medications; ATC coding was performed by 3 certified specialists (cardiologists and an endocrinologist), with double-blind coding in a 10% subsample (agreement coefficient 0.84), excluding substantial result bias. The findings are limited to the Novosibirsk sample and cannot be extrapolated to other Russian regions.

At the same time, the study has significant strengths. The investigated cohort is a typical urban sample with an epidemiological profile, healthcare utilization patterns, and mortality rates typical of the country, allowing the findings to characterize glycemic control effectiveness in a defined Siberian urban sample. Our large-sample study provides new data for older patients, which limits the generalizability of the results; however, given that type 2 diabetes prevalence is highest in older age groups, the findings informatively reflect the level of glycemic control and its determinants among the individuals most affected by the disease.

These data support the contribution of specific determinants to inadequate diabetes control in older age, do not confirm the role of several previously established factors, but identify novel associations in the context of aging. With respect to studies conducted in European, US, Chinese, and other populations, inherent heterogeneity exists, and the present Siberian study contributes to a broader understanding of the spectrum of determinants of inadequate glycemic control, taking into account region-specific characteristics in the context of climatic, geographic, ethnic, and other sources of variability.

Declarations

Conflicts of Interest:

The authors declare no conflict of interest.

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Author Contribution

E.S.M. researched data, contributed to discussion, and wrote the first draft of the manuscript. S.K.M. and E.S.M. provided data curation and analysis. A.N.R. and S.K.M. reviewed and edited the manuscript. E.S.M., E.V.M., A.N.R. and S.K.M. researched data and reviewed and edited the manuscript. E.S.M., E.V.M., A.N.R. and S.K.M. contributed to discussion and reviewed and edited the manuscript.

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Data Availability

The data sets generated during and/or analyzed in this study are available from the corresponding author upon reasonable request and if in compliance with applicable data protection legislation. Study protocol is available at doi:10.1186/1471-2458-6-255.

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Figures

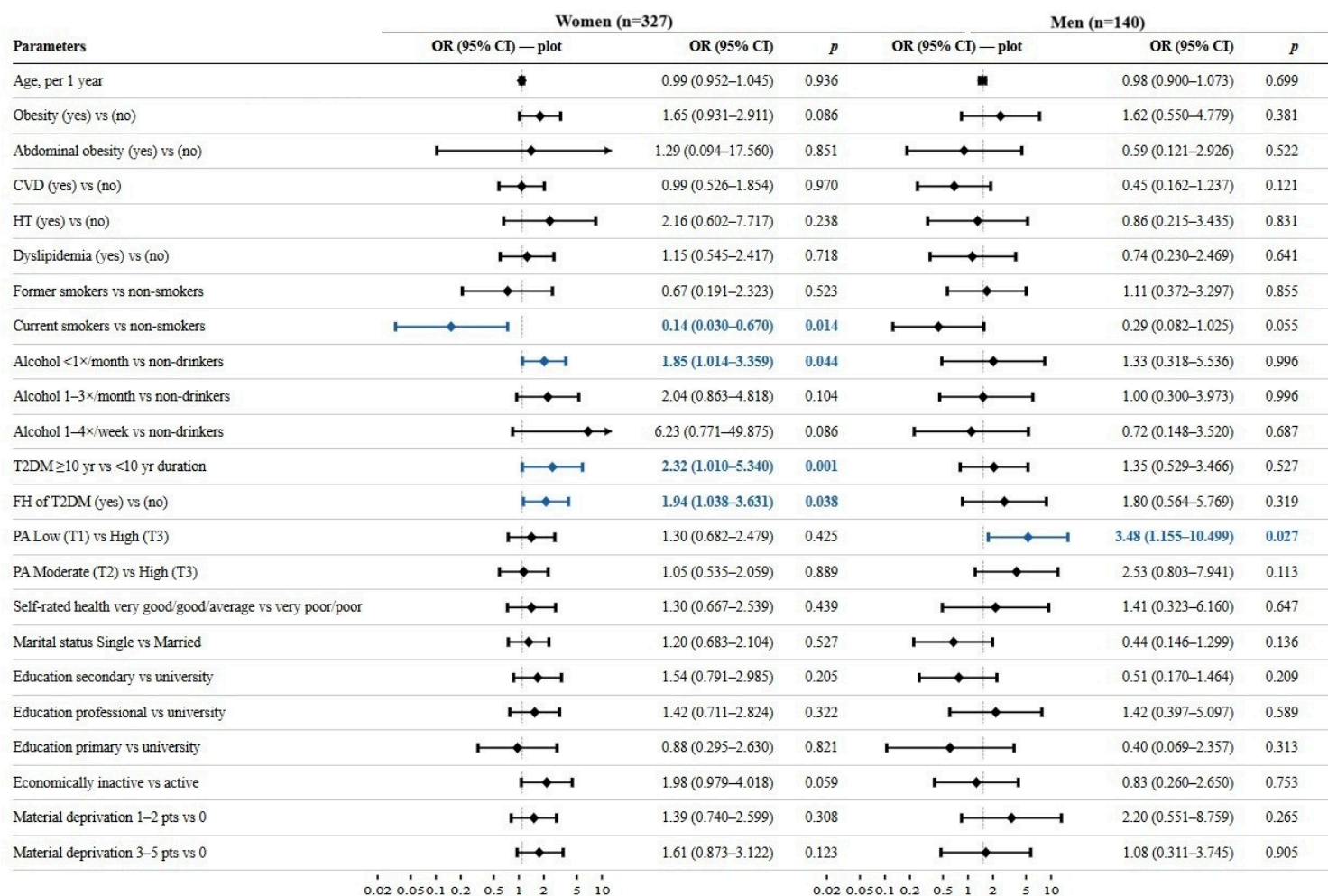


Figure 1

The associations between non-pharmacological factors and IGC in men and in women (multivariable-adjusted models, logistic regression) Model 3 adjusted for age, obesity, abdominal obesity, cardiovascular diseases, hypertension, dyslipidemia and smoking alcohol consumption frequency, physical activity, duration of T2DM, family history T2DM, self-rated health, education level, economic activity, marital status, and material deprivation. ORs for statistically significant associations are shown in bold.

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