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ORIGINAL RESEARCH

Epidemiology of Isolated Impaired Glucose Tolerance Among Adults Aged Above 50 Years in Rural China

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Introduction: Isolated impaired glucose tolerance (i–IGT) is a subtype of prediabetes in which an individual demonstrates elevated 2-h post-glucose load glucose levels but normal fasting plasma glucose levels. However, few studies have explored the prevalence and risk factors of i–IGT among adults in rural China. Thus, we aimed to explore the prevalence and risk factors of i–IGT among adults ≥50 years old in a low-income, rural population in China.
Materials and Methods: Individuals aged ≥50 years with normal fasting plasma glucose levels were included in the final analysis. Fasting and 2-h venous blood samples were collected to assess the selected parameter measurements.
Results: A total of 2175 individuals were included in this study. The i–IGT prevalence was 22.9% and significantly higher among females than among males ($P<0.05$). Older age [odds ratio (OR), 1.606; 95% confidence interval (CI), 1.101–2.342; P=0.014), hypertension (OR, 1.554; 95% CI, 1.152–2.019; P=0.004), and central obesity (OR, 1.395; 95% CI, 1.099–1.771; P=0.006) were associated with i–IGT. Moreover, white blood cell (OR, 1.089; 95% CI, 1.009–1.175; P=0.029), high-sensitivity C-reactive protein (OR, 1.049; 95% CI, 1.020–1.078; P=0.001), serum uric acid (OR, 1.0003; 95% CI, 1.001–1.004; P=0.001), triglyceride (OR, 1.540; 95% CI, 1.105–2.147; P=0.011), and alanine aminotransferase (OR, 1.012; 95% CI, 1.004–1.021; P=0.004) levels were also linked to i–IGT in the analyzed population.
Conclusion: Health promotion education and a standardized approach to managing body weight, BP, and lipid and uric acid levels would benefit this low-income population in rural China for reducing the risk of cardiovascular disease.
Keywords: impaired glucose tolerance, prevalence, risk factors, normal fasting plasma glucose, epidemiology

Introduction

Isolated impaired glucose tolerance (i–IGT) is a subtype of prediabetes that manifests as elevated 2-h post- glucose load plasma glucose (2-h PG) levels in individuals who also exhibit normal fasting plasma glucose (FPG) levels. Prediabetic individuals are of interest to clinicians because they have an increased risk of developing type 2 diabetes.[1] A nationally representative survey carried out in 2013 showed that the prevalence of diabetes and prediabetes in China was 10.9% and 35.7%, respectively; thus, approximately 200.4 million males and 187.7 million females were estimated to have prediabetes in China.[2] Prediabetes increases the risk of hyperglycemia, cardiovascular disease, cognitive impairment, and dementia.[3–5] Moreover, young people with i–IGT

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have a 2-fold to 32-fold higher risk of developing hypertension and metabolic syndrome.[6]

Previous studies have shown the estimated prevalence of i–IGT to be between 6.2% and 9.3% worldwide.[7–9] However, in rural areas of Korea, the i–IGT prevalence was 3.7% for adults ≥20 years old.[10] By comparison, a nationally representative survey conducted in China in 2010 demonstrated that the prevalence of i–IGT was 11.0% in males and 10.9% in females,[11] with a higher prevalence among rural residents than among urban ones.[2] However, this study lacks information on i–IGT prevalence among low-income adults in China. Numerous studies have shown that the conventional risk factors, which include older age, family history of diabetes, hypertension, obesity, and hypertriglyceridemia, are also associated with i–IGT development.[6,12–14] Although 2-h PG levels rise sharply with advancing age,[15] few studies have reported the factors associated with i–IGT development among low-income, poorly educated populations, and particularly the elderly. In China, more than 50% of the population resides in rural areas; detecting the prevalence and associated factors of i–IGT in this sub-population is crucial in reducing the burden of diabetes in China. Thus, this study aimed to explore the prevalence and risk factors of i–IGT among adults ≥50 years old in a low-income, poorly educated population in rural China.

Materials and Methods

Study Population

This population-based, cross-sectional study was performed between April and June 2019. The project was designed as previously described.[16] Briefly, all participants were recruited from the Atherosclerosis Cohort of Tianjin Brain Study, which was conducted in 2014. All residents aged 45 years were qualified to be recruited from 18 administrative villages in Yangjinzhuang Town, Jizhou District, Tianjin, China. Residents aged <45 years were not included in this study because many of them were working outside Tianjin. In 2019, we recruited all the survivors of the Atherosclerosis Cohort aged >50 years to detect the prevalence and risk factors of i–IGT; we excluded those with cancer, severe psychiatric disturbances, hepatic failure, and serious renal disease. The educational attainment and income of the residents in this area were relatively low. The average number of education years was 4.75 years in 1991 and 5.26 years in 2011. The per capita disposable income was less than 1600 US dollars in 2014.[17]

The present study was approved by the Ethics Committee of Tianjin Medical University General Hospital, and a written consent form was provided by each participant. This study was conducted in accordance with the Declaration of Helsinki.

Data Collection

A standard questionnaire was used to collect information regarding educational attainment, personal and family income, previous medical history, and lifestyle risk factors. The participants were interviewed face-to-face by professional researchers. Demographic information, such as sex and date of birth, was obtained from existing records.

Lifestyle risk factors included cigarette smoking, alcohol consumption, physical exercise, sleep duration, and snoring. Cigarette smoking was defined as smoking at least 1 cigarette/day for ≥1 year; participants were categorized as non-smokers, former smokers (those who had stopped smoking for ≥6 months), and current smokers. Alcohol consumption was defined as drinking at least 500 g of alcohol/week for ≥1 year; participants were categorized as non-drinkers, former drinkers (temperance for ≥6 months), and current drinkers. Physical exercise was defined as participation in a moderate or vigorous activity for ≥30 min/day on at least 3 days each week. Sleep durations and snoring habits were based on self-reports.

Measurements

Anthropometric measurements, including height, weight, waist circumference, blood pressure (BP), and heart rate, were performed by epidemiological researchers. Height and weight assessments were conducted with the participants wearing light clothing without hats or shoes; both measurements were determined using an appropriately prepared ultrasonic instrument with the participant in a fully vertical position. Waist circumference was measured using a non-stretch ruler along the horizontal plane at the midpoint between the top of the iliac crest and the bottom of the costal margin in the midaxillary line. Systolic (SBP) and diastolic (DBP) BPs were obtained using a sphygmomanometer. After 5 minutes of quiet rest, participants were asked to expose their arms to facilitate BP and heart rate measurements; the measurements were repeated 5 min later, and the average was reported.

Participants were required to follow a 10-h overnight fast before undergoing oral glucose tolerance tests (OGTTs). They were also required to provide venous blood samples for the determination of levels of FPG, total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), high-sensitivity C-reactive protein (hs-CRP), serum uric acid (SUA), white blood cells (WBCs), alanine aminotransferase (ALT), aspartate aminotransferase (AST), and total bilirubin (TBIL). Then, 75-g glucose (for 75-g OGTT) was administered to the participants, none of whom had a medical history of diabetes. Additional blood samples were obtained 120 min after the first glucose administration to measure the 2-h PG levels. All blood samples were immediately delivered to Guangzhou KingMed Diagnostics Group, an independent clinical laboratory, for analysis.

Definitions

Body mass index (BMI) was calculated as the participant's body mass (kg) divided by the height squared (m^2). According to the BMI, participants were categorized as normal weight (<24.0 kg/m^2), overweight (24.0–27.9 kg/m^2), or obese (≥28 kg/m^2).[18] Central obesity was defined as a waist circumference >90 cm for men and >85 cm for women.[19] Hypertension was defined as a SBP ≥140 mmHg, DBP ≥90 mmHg, or taking antihypertension medications.

Normal glucose tolerance was defined as an FPG level <5.6 mmol/L and a 2-h PG level <7.8 mmol/L. The 3 subtypes of prediabetes were defined as follows: isolated impaired fasting glucose (i–IFG; 5.6 mmol/L ≤ FPG < 7.0 mmol/L and 2-h PG < 7.8 mmol/L), i–IGT (FPG < 5.6 mmol/L and 7.8 mmol/L ≤ 2-h PG < 11.1 mmol/L), and combined IFG and IGT (IFG + IGT; 5.6 mmol/L ≤ FPG < 7.0 mmol/L and 7.8 mmol/L ≤ 2- h PG < 11.1 mmol/L).[11] Diabetes was defined as a FPG level ≥7.0 mmol/L, a 2-h PG level ≥11.1 mmol/L, a previous history of diagnosed diabetes, or use of antihyperglycemia drugs.[20]

Statistical Analyses

Continuous variables (age, years of formal education, BMI, SBP, DBP, heart rate, WBC counts, and levels of FPG, 2-h PG, hs-CRP, SUA, TC, TG, HDL-C, LDL-C, ALT, AST, and TBIL) are presented as means with standard deviations; between-group comparisons were made using Student's *t*-tests. Categorical variables (age group, education group, income group, smoking status, alcohol consumption status, number of participants engaged in physical activity, and hypertensive status) are presented as numbers with frequencies, and between-group comparisons were made using chi-squared tests. Binary logistic regression analyses were used to evaluate the associated factors in the univariate and multivariate analyses. The relationships are presented as unadjusted odds ratios (ORs) and 95% confidence intervals (CIs) in the univariate analysis and adjusted OR (95% CI) in the multivariate analysis. Two-tailed P-values <0.05 were considered statistically significant. SPSS for Windows (version 22.0; IBM, Armonk, NY, USA) was used for all statistical analyses.

Results

A total of 3130 individuals were recruited into the study. Four hundred eighty-three did not receive OGTTs due to a history of diabetes or other health reasons, and 472 had FPG levels >6.1 mmol/L. Thus, 2175 individuals were included in the final analysis.

Demographic and Clinical Characteristics

The 2175 included participants [1172 (53.9%) females] had a mean age of 64.46 years and a mean of 5.53 years of formal education; more than half of the participants had annual incomes of <2000 yuan. The mean BMI (25.45 kg/m^2), SBP (149.03 mmHg), DBP (84.66 mmHg), and heart rate (72.81 bpm) were determined. Further, 74.6% of the participants had hypertension, and 64.6% were overweight or obese. The mean FPG and 2-h PG levels were 5.26 mmol/L and 6.75 mmol/L, respectively; SUA, ALT, and AST levels were 298.08 μmmol/L, 18.08 U/L, and 20.83 U/L, respectively (Table 1).

I-IGT Prevalence by Demographic Characteristics

Table 2 shows the prevalence of i–IGT by demographic characteristics of the participants in this study. The overall prevalence of i–IGT was 22.9%, although it was significantly higher in females (24.7%) than in males (20.8%; P=0.034). The prevalence of i–IGT increased with increasing participant age (P<0.001), and there was a higher prevalence of i–IGT among the less-educated (P<0.001) and lower-income (P=0.026) participants.

Factors Associated with I-IGT in the Univariate Analysis

Female sex, old age, low education level, and low income were associated with i–IGT development (all, P<0.05; Table 3). Participants with hypertension and obesity were

Table 1 Demographic and Clinical Characteristics of All Participants

Category	Men	Women	Total
Participants, n, (%)	1003 (46.1)	1172 (53.9)	2175 (100)
Age, means (SD), years	65.65 (7.59)	63.44 (7.61)	64.46 (7.68)
Age groups, n (%)			
50~ years	198 (19.7)	394 (33.6)	592 (27.2)
60~years	299 (29.8)	296 (25.3)	595 (27.4)
65~years	251 (25.0)	268 (22.9)	519 (23.9)
≥70 years	255 (25.4)	214 (18.3)	469 (21.6)
Education, means (SD), years	6.64 (2.90)	4.58 (3.72)	5.53 (3.55)
Education, n (%),			
≤6 years	495 (49.4)	782 (66.7)	1277 (58.7)
> 6 years	508 (50.6)	390 (33.3)	898 (41.3)
Income, n, (%)			
< 2000 yuan	677 (67.5)	767 (65.4)	1444 (66.4)
2000~6000 yuan	300 (29.9)	370 (31.6)	670 (30.8)
>6000 yuan	26 (2.6)	35 (3.4)	61 (2.8)
Smoking status, n (%)			
Never smoking	242 (24.5)	1108 (95.3)	1350 (62.7)
Ever smoking	248 (25.1)	11 (0.9)	259 (12.0)
Current smoking	499 (50.5)	44 (3.8)	543 (25.2)
Alcohol consumption, n, (%)			
Never drinking	454 (28.4)	1143 (97.9)	1597 (74.0)
Ever drinking	124 (5.7)	7 (0.6)	131 (6.1)
Current drinking	414 (41.7)	17 (1.5)	431 (20.0)
Sleep duration, n, (%)			
<5 hours	111 (11.2)	297 (25.5)	408 (19.0)
5~ hours	285 (28.8)	354 (30.4)	639 (29.7)
7~ hours	518 (52.4)	454 (39.0)	972 (45.1)
>9 hours	74 (7.5)	60 (5.2)	134 (6.2)
Physical exercise, n, (%)			
No	399 (39.8)	445 (38.0)	844 (38.8)
Yes	604 (60.2)	727 (62.0)	1331 (61.2)
Hypertension, n, (%)			
No	239 (23.9)	313 (26.8)	552 (25.4)
Yes	760 (76.1)	857 (73.2)	1617 (74.6)
BMI, means (SD), Kg/m2	24.88 (3.34)	25.94 (3.80)	25.45 (3.63)
BMI, n, (%)			
Normal	411 (41.0)	357 (30.5)	768 (35.4)
Over weight	428 (42.7)	504 (43.1)	932 (42.9)
Obesity	164 (16.4)	308 (26.3)	472 (21.7)
Central obesity, n, (%)			
No	658 (65.6)	587 (50.2)	1245 (57.3)
Yes	345 (34.4)	582 (49.8)	927 (42.7)

(*Continued*)

Table 1 (Continued).

Category	Men	Women	Total
SBP, means (SD), mmHg	150.38 (20.64)	147.88 (19.38)	149.03 (20.00)
DBP, means (SD), mmHg	87.04 (11.40)	82.64 (10.06)	84.66 (10.92)
HR, means (SD), beats/min	70.49 (11.62)	72.94 (10.62)	71.81 (11.15)
FPG, means (SD), mmol/L	5.27 (0.45)	5.26 (0.43)	5.26 (0.44)
2-h PG, means (SD), mmol/L	6.49 (2.16)	6.97 (1.83)	6.75 (2.00)
WBC, means (SD), $\times 10^9$/L	6.20 (1.66)	5.93 (1.54)	6.05 (1.60)
hs-CRP, means (SD), mg/L	2.20 (3.94)	2.20 (4.13)	2.20 (4.04)
SUA, means (SD), μmmol/L	330.01 (86.70)	270.75 (72.90)	298.08 (84.85)
TC, means (SD), mmol/L	4.90 (0.81)	5.29 (0.89)	5.11 (0.88)
TG, means (SD), mmol/L	1.33 (1.03)	1.60 (0.99)	1.47 (1.02)
HDL-C, means (SD), mmol/L	1.42 (0.47)	1.43 (0.41)	1.43 (0.44)
LDL-C, means (SD), mmol/L	2.95 (0.79)	3.24 (0.88)	3.10 (0.86)
ALT, means (SD), U/L	18.64 (15.21)	17.61 (10.12)	18.08 (12.73)
AST, means (SD), U/L	21.42 (12.96)	20.33 (7.32)	20.83 (10.32)
TBIL, means (SD), μmmol/L	11.10 (5.04)	9.01 (4.07)	9.98 (4.66)

Abbreviations: SD, standard deviation; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; FPG, fasting plasma glucose; 2-h PG, two-hour plasma glucose; WBC, white blood cell; hs-CRP, high-sensitivity C-reactive protein; SUA, serum uric acid; TC, total cholesterol; TG, triglycerides; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; CIMT, carotid intima-media thickness.

Table 2 The Prevalence of Isolated Impaired Glucose by Demographic Characteristics

Groups	Non-i-IGT	i–IGT	P
Participants n (%)	1677 (77.1)	498 (22.9)	—
Sex, n (%)			0.034
Men	794 (79.2)	209 (20.8)	
Women	883 (75.3)	289 (24.7)	
Age groups, n (%)			<0.001
50~years	483 (81.6)	109 (18.4)	
60~years	475 (79.8)	120 (20.2)	
65~years	392 (75.5)	127 (24.5)	
≥70 years	327 (69.7)	1472 (30.3)	
Education, n (%),			<0.001
≤6 years	945 (74.0)	332 (26.0)	
> 6 years	732 (81.5)	166 (18.5)	
Income, n, (%)			0.026
<2000 yuan	1090 (75.5))	354 (24.5)	
2000~6000 yuan	535 (79.9)	135 (20.1)	
>6000 yuan	52 (85.2)	9 (14.8)	

Abbreviation: i–IGT, isolated impaired glucose tolerance.

also more likely to develop i–IGT (both, P<0.001). Further, individuals were more likely to develop i–IGT if they were current drinkers and underwent physical exercise (both, P<0.05).

Participants with i–IGT had higher heart rates, WBC counts, and levels of hs-CRP, SUA, and ALT than those without i–IGT (all, P<0.05). Furthermore, the levels of TC, TG, and LDL-C were significantly higher among participants with i–IGT than among those without i–IGT, but there was an inverse trend for HDL-C levels (all, P<0.05).

Multivariate Analysis of the Factors Associated with I-IGT

In the multivariate analysis, older age, hypertension, central obesity, high WBC counts, and elevated levels of hs-CRP, SUA, TG, and ALT were independent factors associated with i–IGT among adults ≥50 years old. When using the ≤60-year-old age group as a reference group, the prevalence of i–IGT was 60.6% higher among individuals who were ≥70 years old (OR, 1.606; 95% CI, 1.101–2.342; P=0.014).

Table 3 The Associated Factors of I–IGT for All Participants in the Univariate Analysis

Groups	NGT	i–IGT	P
Sex, n (%)			0.038
Men	762 (78.5)	209 (21.5)	
Women	850 (74.6)	289 (25.4)	
Age groups, n (%)			<0.001
50~years	477 (81.4)	109 (18.6)	
60~years	456 (79.2)	120 (20.8)	
65~years	376 (74.8)	127 (25.2)	
≥70 years	303 (68.1)	1472 (31.9)	
Education, n (%),			<0.001
≤6 years	901 (73.1)	332 (26.9)	
> 6 years	711 (81.1)	166 (18.9)	
Income, n, (%)			0.023
< 2000 yuan	1047 (74.7)	354 (25.3)	
2000~6000 yuan	513 (79.2)	135 (20.8)	
>6000 yuan	52 (85.2)	9 (14.8)	
Smoking status, n (%)			0.004
Never smoking	978 (74.4)	336 (25.6)	
Ever smoking	189 (75.9)	60 (24.1)	
Current smoking	428 (81.7)	96 (18.3)	
Alcohol consumption, n, (%)			0.142
Never drinking	1177 (75.6)	380 (24.4)	
Ever drinking	94 (74.0)	33 (26.0)	
Current drinking	328 (80.0)	82 (20.0)	
sleep duration, n, (%)			0.426
<5 hours	287 (73.4)	104 (26.6)	
5~ hours	481 (77.7)	138 (22.3)	
7~ hours	729 (76.7)	222 (23.3)	
>9 hours	100 (78.1)	28 (21.9)	
Physical exercise, n, (%)			0.029
No	648 (78.9)	173 (21.1)	
Yes	964 (74.8)	325 (25.2)	
Hypertension, n, (%)			<0.001
No	461 (84.7)	83 (15.3)	
Yes	1147 (73.5)	414 (26.5)	
BMI, n, (%)			<0.001
Normal	613 (82.1)	134 (17.9)	
Over weight	680 (75.1)	225 (24.9)	
Obesity	317 (69.7)	138 (30.3)	
Central obesity, n, (%)			<0.001
No	988 (81.2)	229 (18.8)	
Yes	622 (69.9)	268 (30.1)	

(*Continued*)

Table 3 (Continued).

Groups	NGT	i–IGT	P
Heart rate, means (SD), beats/min	71.37 (11.05)	73.36 (11.52)	0.001
WBC, means (SD), $\times10^9$/L	5.94 (1.48)	6.39 (1.90)	<0.001
hs-CRP, means (SD), mg/L	1.91 (3.29)	3.04 (5.73)	<0.001
SUA, means (SD), μmmol/L	290.65 (79.58)	320.16 (95.70)	<0.001
TC, means (SD), mmol/L	5.08 (0.86)	5.21 (0.94)	0.004
TG, means (SD), mmol/L	1.40 (0.90)	1.69 (1.33)	<0.001
HDL-C, means (SD), mmol/L	1.44 (0.44)	1.37 (0.41)	0.001
LDL-C, means (SD), mmol/L	3.08 (0.84)	3.18 (0.90)	0.025
ALT, means (SD), U/L	17.54 (12.30)	19.83 (14.21)	0.001
AST, means (SD), U/L	20.55 (10.25)	21.58 (10.86)	0.054
TBIL, means (SD), μmmol/L	9.91 (4.59)	10.10 (4.73)	0.422

Abbreviations: NGT, normal glucose tolerance; i–IGT, isolated impaired glucose tolerance; DM, diabetes mellitus; SD, standard deviation; BMI, body mass index; FPG, fasting plasma glucose; 2-h PG, two-hour plasma glucose; HR, heart rate; WBC, white blood cell; hs-CRP, high-sensitivity C-reactive protein; SUA, serum uric acid; TC, total cholesterol; TG, triglycerides; HDL-C, high density lipoprotein cholesterol; LDL-C, low density lipoprotein cholesterol; CIMT, carotid intima-media thickness.

Participants with hypertension had 55.4% higher prevalence of i–IGT than those with normal BP (OR, 1.554; 95% CI, 1.152–2.095; P=0.004). The prevalence of i–IGT was also 39.5% higher among individuals with central obesity compared to individuals without central obesity (OR, 1.395; 95% CI, 1.099–1.771; P=0.006). The prevalence of i–IGT increased with each 1 unit increase in the WBC count (8.9%; OR, 1.089; 95% CI, 1.009–1.175; P=0.029), hs-CRP level (4.9%; OR, 1.049; 95% CI, 1.020–1.078; P=0.001), SUA level (0.3%; OR, 1.0003; 95% CI, 1.001–1.004; P=0.001), TG level (54%; OR, 1.540; 95% CI, 1.105–2.147; P=0.011), and ALT level (1.2%; OR, 1.012; 95% CI, 1.004–1.021; P=0.004) (Table 4).

Discussion

In this population-based, cross-sectional study, we explored the i–IGT prevalence and associated factors among adults ≥50 years old in a low-income population in rural China. The overall prevalence of i–IGT was 22.9%, and it was significantly higher among females than males and in low-income, poorly educated individuals. Old age, hypertension, central obesity, and elevated levels of WBCs, hs-CRP, SUA, TG, and ALT were associated with i–IGT.

Due to population growth, ageing, and dietary transitions, China has witnessed a sharp increase in the prevalence of abnormal glucose regulation.[21,22] In the current study population, the overall prevalence of i–IGT was 22.9% and much higher than that reported in other studies. For example, in southern Germany, 35–59-year-old individuals were reported to have an i–IGT prevalence of 6.3%.[9] Further, a national, cross-sectional survey conducted in Spain demonstrated an i–IGT prevalence of 9.2% for individuals ≥18 years old.[7] Consistent with this, a cross-sectional study performed in Shanghai Pudong New District showed that the i–IGT prevalence was 9.2% for urban residents of China.[14] In Hubei Province, central China, the prevalence of i–IGT was estimated to be 13.9% among Han ≥40 years old.[23] Thus, in this low-income, low education level population, the i–IGT prevalence was much higher than that in urban China. Differences in age, income, and education level of the present study's target population, as well as study design differences, may partly explain the high prevalence of i–IGT in our study population compared with the other study populations. However, the high i–IGT prevalence also indicates that OGTTs are essential for the early identification of individuals with abnormal glucose regulation in the target population.

Previous studies have revealed that older age is associated with an increased risk of diabetes.[7,11,24] For example, a 12-year, prospective study with participants aged 40–69 years showed that older age was independently associated with progression to diabetes (hazard ratio, 1.02; 95% CI, 1.02–1.03).[25] Furthermore, the Tehran Lipid and Glucose

Table 4 The Associated Factors of I–IGT in the Multivariate Analysis

Groups	Reference	OR	P
Sex	Women		
Men		0.911 (0.635, 1.308)	0.615
Age groups	50~years		
60~years		0.967 (0.685, 1.365)	0.847
65~years		1.344 (0.936, 1.930)	0.109
≥70 years		1.606 (1.101, 2.342)	0.014
Education	> 6 years		
≤6 years		1.195 (0.916, 1.560)	0.190
Income	<2000 yuan		
2000~6000 yuan		0.838 (0.643, 1.091)	0.189
>6000 yuan		0.676 (0.306, 1.493)	0.332
Smoking status	Never smoking		
Ever smoking		0.875 (0.566, 1.355)	0.550
Current smoking		0.723 (0.494, 1.059)	0.096
Physical exercise	No		
Yes		1.192 (0.938, 1.515)	0.152
Hypertension	No		
Yes		1.554 (1.152, 2.095)	0.004
Central obesity	No		
Yes		1.395 (1.099, 1.771)	0.006
Heart rate	—	1.009 (0.999, 1.019)	0.095
WBC	—	1.089 (1.009, 1.175)	0.029
hs-CRP	—	1.049 (1.020, 1.078)	0.001
SUA	—	1.003 (1.001, 1.004)	0.001
TC		0.523 (0.254, 1.079)	0.079
TG	—	1.540 (1.105, 2.147)	0.011
HDL-C	—	1.737 (0.834, 3.617)	0.140
LDL-C	—	1.961 (0.979, 3.930)	0.057
ALT		1.012 (1.004, 1.021)	0.004

Abbreviations: i–IGT, isolated impaired glucose tolerance; DM, diabetes mellitus; OR, odds ratio; BMI, body mass index; WBC, white blood cell; hs-CRP, high-sensitivity C-reactive protein; SUA, serum uric acid; TG, triglycerides; HDL-C, high density lipoprotein cholesterol; CIMT, carotid intima-media thickness.

Study indicated that advanced age (≥40 years old) was an important predictor of i–IGT in adults with normal FPG levels.[12] In the present low-income population, we concluded that older age was an independent risk factor of i–IGT among adults ≥50 years old. Insulin secretion decreases by approximately 0.7% per year as people age; however, this decline in β-cell function is accelerated approximately 2-fold in people with IGT,[26] partly explaining the effect of age on plasma glucose levels.

A positive association between hypertension and diabetes has also been reported in numerous studies.[27–29] In a meta-analysis of prospective studies involving 4.1 million adults, each 20 mmHg-elevation in SBP and 10 mmHg-elevation in DBP increased the risk of new-onset diabetes by 58% and 52%, respectively, when compared with normal BPs.[30] A population-based survey conducted in Beijing demonstrated that 14–28-year-old individuals with hypertension had a 368% higher risk of i–IGT than those with normal BP (<130/85 mmHg).[6] Similarly, hypertension was an independent risk factor of i–IGT in the target population of the present study. Diabetes and hypertension are closely related because of their similar risk factors, such as endothelial dysfunction, vascular inflammation, advanced glycation end-products, and oxidative stress.[31,32]

In the present survey, we concluded that central obesity was an independent risk factor of i–IGT in the target population. Many studies have shown that central obesity is positively associated with diabetes.[33–35] A rural cohort study conducted in the Henan Province of China indicated that central obesity increased the risk of diabetes by 138% (OR, 2.38; 95% CI, 2.11–2.70).[36] Further, a population-based, cross-sectional study of adults with normal BMIs in the Jilin Province of China showed a significant association between central obesity and diabetes.[37] Resistin is an adipocyte-derived cytokine that causes insulin resistance and glucose intolerance in mice.[38] Increased resistin expression in abdominal fat compared with thigh fat may explain the increased risk of i–IGT associated with central obesity.[39]

Type 2 diabetes presents as a form of inflammatory disease.[40] Previously, a prospective study in China revealed a U-shaped association between WBC counts and the incidence of diabetes in adults between 18 and 59 years old.[41] However, other studies indicated that WBC counts are an independent risk factor for the development of diabetes even when the counts are within the normal range.[42,43] Moreover, a 6-year follow-up study indicated that elevated WBC counts are associated with impaired fasting glycemia risk in Chinese adults.[44] The increase in WBC counts and the activation of WBCs play a key role in diabetes-induced organ damage and increase in free fatty acid levels caused by microcirculation dysfunction.[45,46] In addition, in patients with type 2 diabetes and coronary heart disease, higher WBC counts are predictors of atrial fibrillation, all-cause death, and hospitalization for acute myocardial infarction.[47] In the present study, we demonstrated that elevated WBC counts are an independent risk factor of i–IGT. The elevated WBC counts in patients with i–IGT further suggest a role for chronic inflammation in the progression of i–IGT.

Hs-CRP, produced by the liver, is a nonspecific marker of acute phase, systemic inflammation, and previous studies have shown an association between hs-CRP levels and diabetes.[48,49] For example, in the Jackson Heart Study, participants with hs-CRP levels in the third tertile demonstrated a higher risk of type 2 diabetes when compared with those in the first tertile of hs-CRP levels (HR 2.07; 95% CI, 1.67–2.56).[50] The present study shows that an elevated hs-CRP level is an independent risk factor of i–IGT in the target population. Because hs-CRP levels predict changes in insulin secretion and insulin sensitivity,[51] hs-CRP levels may also predict i–IGT development.

SUA is a purine metabolite that can cause hyperuricemia, gout, and renal failure, and high levels of SUA are associated with an increased risk of IGT and diabetes.[52,53] A prospective study in Shanghai has revealed that SUA levels are strongly associated with the incidence of diabetes in middle-aged and elderly adults.[54] Moreover, the Beijing Health Management Cohort has shown that persistent hyperuricemia results in a 75% increase in the risk of diabetes (risk ratio, 1.75; 95% CI, 1.47–2.08).[55] Similarly, we found that SUA levels represent an independent i–IGT risk factor in our study population. High SUA levels can cause inflammation and oxidative stress,[56] which can partially mediate insulin resistance,[57] leading to i–IGT and diabetes.

Previous studies have shown that TG levels are also associated with a higher risk of diabetes in Chinese adults.[11,58,59] Furthermore, a study performed in Beijing demonstrated that hypertriglyceridemia increases the risk of i–IGT by 192% compared with normal TG levels (OR, 2.92; 95% CI, 1.27–6.73; P=0.012).[6] In the present study's target population, we found that the prevalence of i–IGT increased by 54% for each 1 mmol/L-increase in TG levels. Hence, strict lipid management appears to be essential for this population.

ALT, found in a variety of cells, is most abundant in hepatocytes. Previous studies have revealed that ALT levels are positively associated with diabetes risk.[60,61] Further, a prospective study in China showed that ALT levels are positively associated with the incidence of diabetes (hazard ratio, 1.12; 95% CI, 1.02–1.22) after adjusting for nonalcoholic fatty liver disease and other covariates.[62] In the present study, we concluded that high ALT levels are an independent risk factor of i–IGT. High ALT levels decrease hepatic insulin sensitivity and predict the incidence of type 2 diabetes,[63] possibly explaining the link between ALT levels and i–IGT development.

This study had several limitations. First, the nature of cross-sectional studies prevents the identification of causal relationships. Second, this study involved only people living in the rural areas of Tianjin, China; therefore, our findings cannot be generalized to other populations. Third, since we did not measure insulin levels, we could not evaluate insulin resistance or insulin secretion. Fourth, residents aged <50 years were excluded from this study because there were large proportions of them living outside the area due to work. This may impact the assessment of i–IGT status among younger individuals. Our future studies will evaluate this. Finally, our reliance on self-reported sleep durations may have influenced the accurate assessment of any association between sleep duration and i–IGT.

Conclusion

In this cross-sectional study conducted in rural China, the overall prevalence of i–IGT was 22.9% among adults ≥50 years old; the i–IGT prevalence was significantly higher among females and individuals with low incomes and low levels of education. The conventional risk factors, including older age, hypertension, central obesity, and elevated TG and SUA levels, were independently associated with a high risk of i–IGT development. The results suggest that promoting health education and standardizing the management of body weight, BP, lipid levels, and uric acid levels is essential for this low-income population in rural China.

Abbreviations

i-IGT, isolated impaired glucose tolerance; OR, odds ratio; CI, confidence interval; 2-h PG, 2-h plasma glucose; FPG, fasting plasma glucose; BPs, blood pressures; SBP, systolic blood pressure; DBP, diastolic blood pressure; OGTTs, oral glucose tolerance tests; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; hs-CRP, high-sensitivity C-reactive protein; SUA, serum uric acid; WBCs, white blood cells; ALT, alanine aminotransferase; AST, aspartate aminotransferase; TBIL, total bilirubin; BMI, body mass index.

Data Sharing Statement

The datasets generated during and/or analyzed during the current study are available from the corresponding authors on reasonable request.

Ethics Approval and Consent to Participate

The study was approved by the medical research ethics committee at Tianjin Medical University General Hospital; written informed consent was obtained from each participant during recruitment.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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