Association of Triglyceride-glucose Index and the Risk of Incident Diabetes: a Secondary Analysis Based on a Chinese Cohort Study

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Research

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Abstract

Background

Triglyceride-glucose index (TyG index) has been regarded as a reliable alternative marker of insulin resistance. However, study on the relationship between TyG index and incident diabetes remains limited. This study aimed to investigate the association between TyG index and incident diabetes in a large cohort of Chinese population.

Methods

The present study was a retrospective cohort study using healthy screening programme data in China. A total of 201,298 subjects free of baseline diabetes were included who received a health check with all medical records from 2010 to 2016. TyG index was calculated as Ln[fasting triglyceride level (mg/dl) x fasting plasma glucose (mg/dl)/2]. Diagnosis of diabetes was based on fasting plasma glucose ≥ 7.00 mmol/L and/or self-reported diabetes. Cox proportion-hazard model was used to assess the relationship between TyG index at baseline and the risk of incident diabetes. It should be noted that the data was uploaded to the DATADRYAD website, and we only used this data for secondary analysis.

Results

During a mean follow-up of 3.12 years of 201,298 individuals aged ≥ 20 years old, 3389 subjects developed diabetes. After adjusting for age, sex, body mass index, systolic blood pressure, diastolic blood pressure, total cholesterol, low density lipoprotein cholesterol, alanine aminotransferase, aspartate aminotransferase, serum creatinine, smoking, drinking and family history of diabetes, multivariate cox hazards regression analysis indicated that TyG index was positive correlation with the risk of developing diabetes in Chinese population (HR, 3.34; 95% CI, 3.11 to 3.60). The risk of incident diabetes increased with increasing TyG index. Subjects with TyG index in the fourth quartile were 6.26 times more likely to develop diabetes than the lowest quartile (P trend < 0.001). Subgroup analysis showed the stronger association was observed in the population with age < 40, BMI (≥ 18.5, < 24 kg/m²), SBP < 140 mmHg or females (all P for interaction < 0.0001).

Conclusions TyG index was independently correlated with the increased risk of diabetes in Chinese adults, suggesting that TyG index may be a useful marker for identifying individuals at high risk of developing diabetes.

Background

Diabetes is one of the most common global epidemics, and it is expected to affect 439 million adults by 2030, which has become a growing global health problem with heavy financial burden on individuals and society [1–4]. To conquer the burden of this epidemic, public health strategies should focus on screening high-risk subjects of developing diabetes with the goal of early prevention and appropriate intervention.
Therefore, it is of great practical significance to find a predictor that is easy to measure, widely applicable and highly predictable.

Prospective studies on the natural history of type 2 diabetes (T2DM) have shown that insulin resistance is (IR) the main pathophysiological mechanism and has been present many years before diagnosis \[5, 6\]. Therefore, accurate measurement of IR will be the key factor to improve prediction of incident diabetes. The hyperinsulinemic -euglycemic clamp technique (HIEC) remains the current gold standard to quantify the degree of IR \[7\], however, it is difficult to be applied in clinical practice due to its time-consuming and expensive cost. Triglyceride-glucose index (TyG index), derived from fasting plasma glucose (FPG) and triglyceride (TG), has been suggested as a surrogate of IR in healthy subjects \[8, 9\]. Several studies have confirmed the diagnostic accuracy of TyG index in identifying IR with HIEC and homeostasis model assessment -IR (HOMA-IR) as reference standards \[9–12\]. As TyG index is a non-insulin-based index, it has the characteristics of easy access and low cost compared with other insulin- based indexes, which is its advantage in clinical and epidemiological research. Indeed, a few studies have shown that TyG index independently related to increase the risk of T2DM \[13–16\]. However, only one study \[13\] was conducted in China, with a relatively small sample size and normal BMI of the population, thus, its applicable population was relatively limited. Therefore, this study, based on a large cohort including 201,298 participants at 32 locations of 11 cities in China, aimed to further explore the relationship between TyG index and the risk of incident diabetes.

It should be noted that this study was a second analysis based on published data \[17\]. The whole study was completed by Chen et al, and the data was uploaded to the DATADRYAD website. In the original paper, the authors have studied the relationship between body mass index (BMI) and the risk of incident diabetes \[17\]. In this secondary analysis, TyG index was used as an independent variable, and outcome variable and other covariates were consistent with the original data.

**Methods**

**Data source**

The date was obtained from ‘DATADRYAD’ database (www.Datadryad.org). This website allows users to download raw data freely. According to Dryad Terms of Service, we have cited the Dryad data package in this study. (Dryad data package: Ying Chen, Xiao-Ping Zhang, Jie Yuan, Bo Cai, Xiao-Li Wang, Xiao-Li Wu, Yue-Hua Zhang, Xiao-Yi Zhang, Tong Yin, Xiao-Hui Zhu, Yun-Juan Gu, Shi-Wei Cui, Zhi-Qiang Lu, Xiao-Ying Li (2018) Data from: Association of body mass index and age with incident diabetes in Chinese adults: a population based cohort study. Dryad Digital Repository. https://doi.org/10.1136/bmjopen-2018-021768). Variables included in the database file were as follows: age, gender, height, weight, BMI, diastolic blood pressure (DBP), systolic blood pressure (SBP), FPG, TG, total cholesterol (TC), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C), Alanine aminotransferase (ALT), Aspartate aminotransferase (AST), Serum urea nitrogen (BUN), Serum creatinine (Scr), FPG of final visit, censor of diabetes at follow up, year of follow up, smoking status, drinking status and family history
of diabetes. The authors of the original study [17] declared that they have waived all copyright and relevant ownership of these data. Therefore, we could use these data for secondary analysis without violating the author's rights.

**Study population**

Ying Chen and her colleagues completed the entire study [17]. In order to understand the entire research process more clearly, we outlined the steps of the study here. The specific details were described in the original study. They conducted a retrospective cohort study using healthy screening programme data established by the Rich Healthcare Group at 32 sites of 11 cities in China. The study enrolled 685,277 participants who received a health check and were at least two visits between 2010 and 2016. Finally, in the original study [17], a total of 211,833 participants were recruited and selected according to exclusion standard. The exclusion standards were as follows: (1) no available weight, height, gender, fasting plasma glucose value at baseline. (2) extreme BMI values (< 15 kg/m$^2$ or > 55 kg/m$^2$). (3) visit intervals less than 2 years. (4) participants diagnosed with diabetes at baseline and participants with undefined diabetes status at follow-up. Details about the measurement of variables and outcome were described in that retrospective cohort study [17]. For further research, we excluded missing values of baseline TG (n = 5747) and outliers of TG and FPG values (< means minus three standard deviation (SD) or > means plus three SD) (n = 4789) [18]. Finally, 201,298 subjects (109236 males and 92062 females) were included for data analysis in our study. This study was a retrospective cohort study using healthy screening programme data established by the Rich Healthcare Group. In the original article [17], Ying Chen, et, al. has clearly stated that: this study was approved by the Rich Healthcare Group Review Board, and the information was retrieved retrospectively.

**Measurement of TyG index and other covariants**

Participants were requested to complete a detailed questionnaire to assess demographics, lifestyle, medical history and family history of chronic diseases. Height, weight and blood pressure were measured by well-trained staff. Weight measurement was required to wear light clothes and no shoes, with an accuracy of 0.1 kg. The height measurement was accurate to 0.1 cm. BMI was calculated by dividing weight (kg) by height (meter squared). Blood pressure was measured by standard mercury sphygmomanometers. Fasting venous blood samples were collected after fasting for at least 10 hours at each visit. TC, TG, LDL-C, HDL-C and FPG were measured on an autoanalyzer (Beckman 5800). TyG index was calculated as \( \text{Ln} \left[ \frac{\text{fasting triglyceride level (mg/dl)} \times \text{fasting plasma glucose (mg/dl)}}{2} \right] \) [8]. The dependent variable was incident diabetes during follow-up period. As this was a retrospective cohort study, it potentially reduced selection bias and observational bias.

**Ascertainment of incident diabetes**

Diagnosis of diabetes was based on fasting plasma glucose \( \geq 7.00 \text{ mmol/L} \) and/or self-reported diabetes during the follow-up period. Patients were confirmed at the date of diagnosis of diabetes or the final visit, whichever came first.

**Statistical analysis**
We first dealt with the missing values of other variables. If the missing data was a continuous variable, the mean or median was used to supplement it. While the missing data was a categorical variable, it was treated as a set of categorical variables [19].

Data were expressed as mean ± standard deviations (normal distribution) or median (quartile) (skewed distribution) for continuous variables and number (percentage) for categorical variables, respectively. The one-way ANOVA (normal distribution), Kruskal Wallis H (skewed distribution) test and chi-square test (categorical variables) were used to test the differences in mean, median and percentage among groups. Cox proportional hazard model was used to evaluate the independent effect of TyG index on the risk of incident diabetes. According to the recommendation of the STROBE statement [20], besides the unadjusted model, the results for mildly adjusted model (model 1) and fully adjusted model (model 2) were presented: model 1, adjusting for gender, age and BMI; model 2, additionally adjusted for SBP, DBP, TC, LDL-C, ALT, AST, Scr, smoking status, drinking status and family history of diabetes. To ensure the robustness of data analysis, TyG index was treated as a categorical variable. Taking the lowest quartile of TyG index as reference, hazard ratios (HRs) with 95% confidence intervals (CIs) of the upper three quartiles were calculated. Meanwhile, the linear trends across TyG index quartiles were assessed by a median value within each quartile as a continuous variable. In addition, a generalized additive model (GAM) was used to identify the non-linear relationship. In order to test the robustness of the results, the subgroup analyses were performed using cox proportional hazard models. The modification and interaction of subgroups were evaluated by the likelihood ration test. The Kaplan–Meier method was used to compare cumulative event rates by using the time-to-first event for each endpoint. The log-rank test was used to compare the Kaplan–Meier HRs with corresponding 95% CI for outcome events.

All of the analyses were conducted using the statistical software packages R (http://www.R-project.org, The R Foundation) and EmpowerStats (http://www.Empowerstats.com, X&Y Solutions, Inc., Boston, MA). P values less than 0.05 (two-sided) were considered statistically significant.

Results:

The selection of participants

Of the 211,833 participants, 5746 subjects were excluded for lack of baseline TG values, and 4789 participants were removed due to outliers of TG and FPG, leaving 201,298 subjects for final data analysis.

Baseline characteristics of the study participants

A total of 201,298 participants (54.3% men and 45.7% women) were included in the analysis. The mean age and BMI of the population were 42.08 ± 12.67 years old and 23.19 ± 3.32 kg/m², respectively. The mean year of follow up was 3.12 ± 0.94 years, and 3389 people developed diabetes during follow-up. The mean TyG index was 8.35 ± 0.57, and TyG index was significantly higher in subjects who developed diabetes compared with those who did not (8.90 ± 0.52 vs 8.34 ± 0.57; P < 0.001). Table 1 described the
baseline characteristics of the population by TyG index quartiles (< 7.93, 7.93–8.31, 8.31–8.73, ≥ 8.73). There was no statistically significant difference in HDL-C among different TyG index groups. In contrast, in the highest TyG group, participants generally had higher age, BMI, SBP, DBP, TC, LDL-C, ALT, AST, Scr and higher rates of current smoker, drinker and family history of diabetes.

**Univariate analysis**

The results of univariate analysis revealed that age, gender, BMI, SBP, DBP, FPG, TC, TG, LDL-C, TyG, ALT, AST, Scr, smoking, drinking and family history of diabetes were positively associated with incident diabetes, whereas, HDL-C was not correlated with incident diabetes. Compared with males, females had a lower risk of developing diabetes. The results of univariate analysis were shown in Table 2.

The Kaplan–Meier curves showed significant differences of the cumulative hazards of incident diabetes among TyG index quartiles (log-rank test, p < 0.0001) (Fig. 1). With the increase of TyG index, the cumulative risk of diabetes gradually increased, and the highest quartile group showed the maximum risk of incident diabetes.
Table 1
Baseline Characteristics of participants (N = 201298)

| TyG index | Q1 (≤7.93) | Q2 (≥ 7.93 to ≤8.31) | Q3 (≥ 8.31 to ≤8.73) | Q4 (≥ 8.73) | P-value |
|-----------|-------------|------------------------|------------------------|-------------|---------|
| Participants | 49413       | 50766                  | 49852                  | 51267       | < 0.001 |
| Age (years, mean ± SD) | 37.32 ± 9.93 | 40.48 ± 12.00 | 43.76 ± 13.26 | 46.61 ± 13.20 | < 0.001 |
| Gender, n (%) | < 0.001 | < 0.001 | < 0.001 | < 0.001 | < 0.001 |
| Male | 16016 (32.41) | 24391 (48.05) | 30683 (61.55) | 38146 (74.41) | < 0.001 |
| Female | 33397 (67.59) | 26375 (51.95) | 19169 (38.45) | 13121 (25.59) | < 0.001 |
| BMI (kg/m^2, mean ± SD) | 21.26 ± 2.59 | 22.40 ± 2.95 | 23.71 ± 3.13 | 25.31 ± 3.11 | < 0.001 |
| SBP (mmHg, mean ± SD) | 112.37 ± 14.02 | 116.50 ± 15.29 | 120.82 ± 16.07 | 125.62 ± 16.64 | < 0.001 |
| DBP (mmHg, mean ± SD) | 69.98 ± 9.53 | 72.45 ± 10.09 | 75.10 ± 10.51 | 78.47 ± 10.92 | < 0.001 |
| FPG (mg/dL, mean ± SD) | 83.49 ± 9.29 | 86.88 ± 9.40 | 89.61 ± 9.75 | 93.58 ± 10.48 | < 0.001 |
| TC (mg/dL, mean ± SD) | 165.41 ± 28.64 | 175.71 ± 30.75 | 185.95 ± 32.89 | 198.45 ± 34.94 | < 0.001 |
| TG (mg/dL, mean ± SD) | 51.00 ± 11.26 | 78.87 ± 12.03 | 113.51 ± 18.14 | 199.82 ± 58.97 | < 0.001 |
| LDL-C (mg/dL, mean ± SD) | 50.27 ± 50.02 | 57.99 ± 54.48 | 65.55 ± 58.26 | 71.42 ± 60.79 | < 0.001 |
| HDL-C (mg/dL, mean ± SD) | 53.17 ± 11.91 | 53.09 ± 11.82 | 53.08 ± 11.90 | 53.07 ± 11.79 | 0.769 |
| ALT (IU/L, median (Q1-Q3)) | 13.90 (10.90–18.60) | 16.00 (12.00–22.80) | 19.05 (14.00–28.00) | 25.40 (18.00–38.30) | < 0.001 |
| AST (IU/L, mean ± SD) | 21.74 ± 6.05 | 22.25 ± 6.41 | 22.95 ± 6.75 | 24.25 ± 8.22 | < 0.001 |
| Scr (umol/L, mean ± SD) | 64.70 ± 13.37 | 68.27 ± 14.45 | 71.31 ± 14.57 | 74.29 ± 14.19 | < 0.001 |

Data were expressed as mean ± SD, median (Q1–Q3) or n (%).

Abbreviations: ALT Alanine aminotransferase, AST Aspartate transaminase, BMI Body mass index, DBP Diastolic blood pressure, DM Diabetes Mellitus, FPG Fasting plasma glucose, HDL-C High-density lipoprotein cholesterol, LDL-C Low-density lipoprotein cholesterol, SBP Systolic blood pressure, Scr Serum creatinine, TC Total cholesterol, TG Triglyceride, TyG index Triglyceride-glucose index
| TyG index          | Q1 (≤7.93) | Q2 (≥ 7.93 to ≤8.31) | Q3 (≥ 8.31 to ≤8.73) | Q4 (≥ 8.73) | P-value |
|-------------------|------------|----------------------|----------------------|------------|---------|
| Smoking status, n (%) |            |                      |                      |            | < 0.001 |
| current smoker    | 1011 (2.05)| 2096 (4.13)          | 3140 (6.30)          | 4824 (9.41)|         |
| ever smoker       | 304 (0.62 )| 536 (1.06)           | 732 (1.47)           | 847 (1.65 )|         |
| never smoker      | 10591 (21.43)| 11372 (22.40)    | 10978 (22.02)        | 10556 (20.59)|         |
| not recorded      | 37507 (75.91)| 36762 (72.41)     | 35002 (70.21)        | 35040 (68.35)|         |
| Drinking status, n (%) |            |                      |                      |            | < 0.001 |
| current drinker   | 108 (0.22 )| 225 (0.44)           | 329 (0.66)           | 581 (1.13 )|         |
| ever drinker      | 1180 (2.39)| 1831 (3.61)         | 2357 (4.73)          | 3128 (6.10)|         |
| never drinker     | 10618 (21.49)| 11948 (23.54)   | 12164 (24.40)        | 12518 (24.42)|         |
| not recorded      | 37507 (75.91)| 36762 (72.41)     | 35002 (70.21)        | 35040 (68.35)|         |
| Family history of DM, n (%) |            |                      |                      |            | < 0.001 |
| No                | 48526 (98.20)| 49708 (97.92)    | 48804 (97.90)        | 50158 (97.84)|         |
| Yes               | 887 (1.80 )| 1058 (2.08)         | 1048 (2.10)          | 1109 (2.16 )|         |

Data were expressed as mean ± SD, median (Q1–Q3) or n (%).

Abbreviations: ALT Alanine aminotransferase, AST Aspartate transaminase, BMI Body mass index, DBP Diastolic blood pressure, DM Diabetes Mellitus, FPG Fasting plasma glucose, HDL-C High-density lipoprotein cholesterol, LDL-C Low-density lipoprotein cholesterol, SBP Systolic blood pressure, Scr Serum creatinine, TC Total cholesterol, TG Triglyceride, TyG index Triglyceride-glucose index
Table 2
The results of univariate analysis

| Statistics          | HR (95% CI)         | P value |
|---------------------|---------------------|---------|
| Age (y)             | 42.08 ± 12.67       | 1.07 (1.06, 1.07) | < 0.0001 |
| Gender              | 0.75 (0.70, 0.81)   | 0.0003  |
| Male                | 109236 (54.27%)     | Ref     |
| Female              | 92062 (45.73%)      | 0.51 (0.47, 0.55) | < 0.0001 |
| BMI (kg/m^2)        | 23.19 ± 3.32        | 1.24 (1.23, 1.25) | < 0.0001 |
| SBP (mmHg)          | 118.88 ± 16.31      | 1.04 (1.04, 1.04) | < 0.0001 |
| DBP (mmHg)          | 74.03 ± 10.76       | 1.05 (1.04, 1.05) | < 0.0001 |
| FPG (mg/dl)         | 88.43 ± 10.43       | 1.15 (1.14, 1.15) | < 0.0001 |
| TC (mg/dl)          | 181.51 ± 34.19      | 1.01 (1.01, 1.01) | < 0.0001 |
| TG (mg/dl)          | 111.41 ± 64.72      | 1.01 (1.01, 1.01) | < 0.0001 |
| LDL-C (mg/dL)       | 61.39 ± 56.64       | 1.01 (1.00, 1.02) | < 0.0001 |
| HDL-C (mg/dL)       | 53.10 ± 11.85       | 1.00 (1.00, 1.01) | 0.4881  |
| TyG index           | 8.35 ± 0.57         | 5.78 (5.44, 6.14) | < 0.0001 |
| ALT (U/L)           | 23.52 ± 19.95       | 1.01 (1.01, 1.01) | < 0.0001 |
| AST (U/L)           | 22.81 ± 6.98        | 1.01 (1.01, 1.02) | < 0.0001 |
| Scr (umol/L)        | 69.68 ± 14.60       | 1.01 (1.01, 1.01) | < 0.0001 |
| Smoking status      | 0.75 (0.70, 0.81)   | 0.0003  |
| current smoker      | 11071 (5.50%)       | Ref     |
| ever smoker         | 2219 (1.20%)        | 0.75 (0.56, 1.00) | 0.0506  |
| never smoker        | 43497 (21.61%)      | 0.46 (0.40, 0.53) | < 0.0001 |
| not recorded        | 144311 (71.69%)     | 0.63 (0.56, 0.71) | < 0.0001 |
| Drinking status     | 0.48 (0.33, 0.70)   | 0.0001  |
| current drinker     | 1243 (0.62%)        | Ref     |
| ever drinker        | 8496 (4.22%)        | 0.48 (0.33, 0.70) | 0.0001  |
| never drinker       | 47248 (23.47%)      | 0.50 (0.35, 0.70) | < 0.0001 |
| not recorded        | 144311 (71.69%)     | 0.54 (0.39, 0.76) | 0.0003  |
| Statistics                  | HR (95% CI)      | P value |
|-----------------------------|------------------|---------|
| Family history of DM        |                  |         |
| No                          | 197196 (97.96%)  | Ref     |
| Yes                         | 4102 (2.04%)     | 1.74 (1.47, 2.06) | < 0.0001 |

Data were expressed as mean ± SD or n (%).

**Abbreviations:** ALT Alanine aminotransferase, AST Aspartate transaminase, BMI Body mass index, CI Confidence Interval, DBP Diastolic blood pressure, DM Diabetes Mellitus, FPG Fasting plasma glucose, HDL-C High-density lipoprotein cholesterol, HR hazard ratio, LDL-C Low-density lipoprotein cholesterol, Ref Reference, SBP Systolic blood pressure, Scr Serum creatinine, TC Total cholesterol, TG Triglyceride, TyG index Triglyceride-glucose index

**The results of relationship between TyG index and incident diabetes**

Cox proportional hazard model was used to evaluate the relationship between TyG index and incident diabetes. As shown in Table 3, in crude model, a positive association between TyG index and incident diabetes was found (HR, 5.78; 95% CI, 5.44–6.14). In minor adjusted model (adjusted age, gender and BMI), the positive correlation became relatively weaker (HR, 3.31; 95% CI, 3.09–3.55). While after adjusting for the full adjusted model (adjusted age, gender, BMI, SBP, DBP, TC, LDL-C, ALT, AST, Scr, smoking status, drinking status and family history of diabetes), the correlation did not change significantly compared with minor adjusted model (HR, 3.34; 95% CI, 3.11–3.60). For the purpose of sensitivity analysis, we further treated TyG index as a categorical variable (quartile). There was a graded, positive association between TyG index and the future risk of diabetes (p for trend < 0.001) (Table 3). Subjects with TyG index in the fourth quartile were 6.26 times more likely to develop diabetes than the lowest quartile (Table 3).

**The analyses of non-linear relationship**

In view of the fact that TyG index was a continuous variable, a generalized additive model was used to find the non-linear relationship between TyG index and incident diabetes. As shown in Fig. 2, after adjusting age, gender, BMI, SBP, DBP, TC, LDL-C, ALT, AST, Scr, smoking status, drinking status and family history of diabetes, there was a significant non-linear relationship between TyG index and the risk of diabetes (P < 0.001), and the slope increased with the increase of TyG index.
Table 3
Relationship between TyG index and the incident of diabetes in different models

| Outcomes          | Crude model | Model I | Model II |
|-------------------|-------------|---------|----------|
|                   | HR (95% CI) | P       | HR (95% CI) | P  | HR (95% CI) | P  |
| TyG index         | 5.78 (5.44, 6.14) | < 0.0001 | 3.31 (3.09, 3.55) | < 0.0001 | 3.34 (3.11, 3.60) | < 0.0001 |
| TyG (quartile)    |             |         |           |      |             |    |
| Q 1               | Ref         |         | Ref       |     | Ref         |   |
| Q 2               | 2.88 (2.34, 3.53) | < 0.0001 | 1.84 (1.50, 2.27) | < 0.0001 | 1.83 (1.49, 2.26) | 0.0293 |
| Q 3               | 7.45 (6.17, 9.00) | < 0.0001 | 3.29 (2.70, 3.99) | < 0.0001 | 3.29 (2.70, 4.01) | 0.0004 |
| Q 4               | 19.94 (16.64, 23.88) | < 0.0001 | 6.36 (5.26, 7.70) | < 0.0001 | 6.26 (5.15, 7.60) | < 0.0001 |
| P for trend       | < 0.0001    |         | < 0.0001  |     | < 0.0001    |   |

Crude model adjust for: none.
Model I adjust for: age, sex and BMI
Model II adjust for: age, sex, BMI, SBP, DBP, AST, ALT, TC, LDL-C, Scr, smoking status, drinking status and family history of diabetes

Abbreviations: TyG index Triglyceride-glucose index, HR Hazard ratio, CI Confidence interval, Ref Reference

The results of subgroup analyses

To further explore the impact of other risk factors on the relationship between TyG index and the risk of developing diabetes, subgroup analyses were performed according to these stratification variables including age, gender, BMI, SBP, DBP, smoking status, drinking status and family history of diabetes. As was shown in Table 4, we noted that the interactions were observed between TyG index and age, gender, BMI, and SBP (all P values for interaction < 0.05). In this study, stronger associations were observed in the population with age < 40, BMI (≥ 18.5, < 24 kg/m²), SBP < 140 mmHg or females, while the test for interactions were not statistically significant for DBP, smoking status, drinking status and family history of diabetes (P for interaction = 0.99, 0.70, 0.22, 0.12, respectively).
Table 4
Effect size of TyG index on the incident of diabetes in prespecified and exploratory subgroup

| Characteristic      | No. of participants | HR (95% CI)   | P-value | P for interaction |
|---------------------|---------------------|---------------|---------|-------------------|
| Age (year)          |                     |               |         |                   |
| < 40                | 106447              | 4.53 (3.76, 5.45) | < 0.0001 |                   |
| >=40, < 60          | 71176               | 3.54 (3.19, 3.93) | < 0.0001 |                   |
| >=60                | 23675               | 2.67 (2.37, 3.00) | < 0.0001 |                   |
| Gender              |                     |               | 0.0150  |                   |
| Male                | 109236              | 3.16 (2.90, 3.45) | < 0.0001 |                   |
| Female              | 92062               | 3.84 (3.37, 4.37) | < 0.0001 |                   |
| BMI (kg/m$^2$)      |                     |               | < 0.0001 |                   |
| < 18.5              | 11593               | 3.64 (1.53, 8.64) | 0.0034  |                   |
| >=18.5, < 24        | 112241              | 4.13 (3.62, 4.71) | < 0.0001 |                   |
| >=24, < 28          | 60886               | 3.22 (2.90, 3.58) | < 0.0001 |                   |
| >=28                | 16578               | 3.07 (2.64, 3.56) | < 0.0001 |                   |
| SBP (mmHg)          |                     |               | < 0.0001 |                   |
| < 140               | 181383              | 3.48 (3.19, 3.79) | < 0.0001 |                   |
| >=140               | 19915               | 2.89 (2.53, 3.29) | < 0.0001 |                   |
| DBP (mmHg)          |                     |               | 0.9984  |                   |
| < 90                | 185636              | 3.29 (3.04, 3.56) | < 0.0001 |                   |
| >=90                | 15661               | 3.43 (2.90, 4.05) | < 0.0001 |                   |
| Smoking status      |                     |               | 0.6979  |                   |
| Current smoker      | 11071               | 3.03 (2.36, 3.90) | < 0.0001 |                   |
| Ever smoker         | 2419                | 4.27 (2.30, 7.91) | < 0.0001 |                   |
| Never smoker        | 43497               | 3.40 (2.84, 4.08) | < 0.0001 |                   |

**Note 1**: Above model adjusted for age, sex, BMI, SBP, DBP, AST, ALT, TC, LDL-C, Scr, smoking status, drinking status and family history of diabetes.

**Note 2**: In each case, the model was not adjusted for the stratification variable.

**Abbreviations**: BMI Body mass index, CI confidence interval, DBP Diastolic blood pressure, HR hazard ratio, SBP Systolic blood pressure.
| Characteristic                  | No. of participants | HR (95%CI)         | P-value | P for interaction |
|--------------------------------|---------------------|--------------------|---------|------------------|
| not recorded                   | 144311              | 3.39 (3.13, 3.69)  | < 0.0001|                  |
| Drinking status                |                     | 0.2174             |         |                  |
| current drinker                | 1243                | 5.31 (2.34, 12.05) | < 0.0001|                  |
| ever drinker                   | 8496                | 3.65 (2.52, 5.28)  | < 0.0001|                  |
| never drinker                  | 47248               | 3.33 (2.84, 3.90)  | < 0.0001|                  |
| not recorded                   | 144311              | 3.39 (3.13, 3.69)  | < 0.0001|                  |
| Family history of diabetes     |                     | 0.1175             |         |                  |
| No                             | 197196              | 3.39 (3.15, 3.65)  | <0.0001 |                  |
| Yes                            | 4102                | 3.07 (2.10, 4.50)  | <0.0001 |                  |

**Note 1:** Above model adjusted for age, sex, BMI, SBP, DBP, AST, ALT, TC, LDL-C, Scr, smoking status, drinking status and family history of diabetes.

**Note 2:** In each case, the model was not adjusted for the stratification variable.

**Abbreviations:** BMI Body mass index, CI confidence interval, DBP Diastolic blood pressure, HR hazard ratio, SBP Systolic blood pressure.

**Discussion**

This population-based retrospective cohort study indicated that TyG index was an independent predictor of diabetes (HR, 3.34; 95% CI, 3.11 to 3.60). The risk of incident diabetes increased with increasing TyG index among apparently healthy adults in China. Subjects with TyG index in the fourth quartile were 6.26 times more likely to develop diabetes than the lowest quartile (95% CI, 5.15–7.60; P trend < 0.001). The results of the subgroup analysis showed that this correlation still existed regardless of males or females, young or old, obese or non-obese subjects, which suggested that our results were robust and TyG index was suitable for a wide range of subjects. Furthermore, stronger associations were observed in the population with age < 40, BMI (≥ 18.5, < 24 kg/m²), SBP < 140 mmHg or females in this study.

TyG index, the combination of TG and FPG, has been proved to be a marker of IR in many epidemiological studies [8–12, 21]. Compared with HIEC of the gold standard for the diagnosis of IR, TyG index had high sensitivity (96.5%) and specificity (85.0%) for the diagnosis of IR in Mexicans [9], and TyG index was a better predictor than HOMA-IR in the Brazilian population [10]. As a marker for detecting the degree of IR, consistent with our results, several studies suggested that a high baseline TyG index was associated with the risk of developing T2DM in different races, such as Korea, Singapore and Europe [14–16, 22]. Furthermore, similar results were observed in another Chinese cohort study [13], which provide evidence that TyG index can be an important indicator for predicting T2DM among people with normal BMI (quartiles 4 versus quartile 1 of TyG index; aHR, 5.30; 95% CI, 2.21–12.71), and the general
trend of the non-linear relationship between TyG index and diabetes risk was similar to our study that the slope increased with the increase of TyG index. However, this study only included 5706 subjects with normal BMI and was conducted in rural areas, thus, its applicable population was relatively limited. While this present study was population-based cohort study including 201,298 apparently healthy adults from 32 sites of 11 cities, obviously, it was applicable to a relatively wide range of people and provided more basis for clinical promotion and application. Besides, in the Singaporean population [16], a progressively increased risk of diabetes was observed in subjects with Q1 to Q4 of TyG index Quartiles, and subjects with TyG index in quartile 4 were 4.68 times more likely to develop diabetes than quartile 1 of TyG index. However, the potential confounders were not adjusted sufficiently, such as smoking, drinking, family history of diabetes and blood lipid index (TC and LDL-C) were not adjusted, while these were closely related to the increased risk of diabetes [23, 24]. Fortunately, these confounding factors mentioned above were taken into account in our study to avoid the potential impact on the results.

- The exploration of subgroup analysis and interaction was crucial for clinical research, which could better understand the true relationship between independent variables and dependent variables [20]. Unfortunately, the above-mentioned similar studies only used gender, and/or age as stratification factors for subgroup analysis [13–15], and no interaction was detected, which hindered our understanding of true relationship between TyG index and the risk of diabetes. In this study, we used age, gender, BMI, hypertension, smoking status, drinking status and family history of diabetes as stratified variables, and stronger associations were observed in the population with age < 40, BMI (≥18.5, < 24 kg/m^2), SBP < 140 mmHg or females in this study. This association was particularly obvious in females, which agreed with another cohort study by Zhang et al. [13]. The possible reason was related to the higher lipid levels in female hepatocytes, both fasting and after glucose and lipid loading compared with males [25, 26]. In clinical practice, obese people and the elderly were generally considered to be the main targets for diabetes screening. However, from the results of subgroup analysis, TyG index seemed to be a more sensitive index to predicting the risk of diabetes in young people, females, people with normal BMI or normal SBP, suggesting that TyG index could be used as a promising index for screening the risk of future diabetes, especially in people without strong risk factors such as age, BMI and hypertension.

- Islet β-cell dysfunction and IR are considered to be the core pathological mechanisms of T2DM [27]. Interestingly, TyG index, besides as a surrogate of IR, is related to the susceptibility of β cells to glucotoxicity and lipotoxicity, which may be the underlying mechanism of TyG in the development of diabetes. On the one hand, evidence revealed that high levels of glucose increased the level of reactive oxygen species in β cells, which in turn had a toxic effect on pancreatic β cells, further leading to insulin resistance and T2DM [28]. On the one hand, the long-term high content of free fatty acids was related to the prolonged exposure time of TG in the pancreatic islets, which might damage the function of pancreatic β cells [29–31]. An intervention study confirmed that patients with impaired glucose metabolism improved their insulin secretion ability after being treated with n-3 fatty acids [32]. Moreover, skeletal muscle is the main target of insulin and the main part of glucose uptake. When TG levels in blood and skeletal muscle increase, it will interfere with glucose uptake.
metabolism in muscle [33], and thus TyG index reflects muscle insulin resistance to a certain extent [34].

- This study has several advantages. Firstly, this study was based on a large cohort study, with a large sample size and a broad age spectrum. Thus, there were sufficient subjects for analysis to ensure the reliability and robustness of the results. Meanwhile, the results were applicable to a relatively wide range of people. While other similar cohort studies had relatively small sample sizes and tended to be older. Secondly, we treated the target independent variable TyG index as both continuous variable and categorical variable to analyze the relationship with the dependent variable, and conducted a trend test. This method could reduce the contingency of data analysis and enhance the robustness of the results. Thirdly, we also performed the effect modifier factor analysis to assess the robustness of the association between the TyG index and diabetes risk, and to discover possible interactions with other variables. Finally, we first discovered that TyG index seemed to be more sensitive to predicting the risk of diabetes in young people, females, normal BMI or normal SBP. This suggested that TyG index may be a reliable indicator for screening the risk of diabetes in people without high risk factors such as age, BMI and hypertension, and it certainly requires more research to further verify it.

- However, some limitations should be noted in this study. First, diagnosis of diabetes was based on fasting blood glucose > 7.00 mmol/L and/or self-reported diabetes, rather than a 2-hour oral glucose tolerance test or glycosylated hemoglobin, which might lead to an underestimation of the incidence of diabetes. Second, this study did not distinguish the types of diabetes. However, as T2DM accounts for approximately 95% of all diabetes cases, our findings may be more representative of T2DM. Thirdly, as this large cohort study was conducted in China, our findings may be not applicable to other races and some special groups, such as children and pregnant women. Finally, this study was based on a secondary analysis of published data, even though a lot of confounding factors have been adjusted, some variables not included in the database, such as physical activity, dietary factors and lipid-lowering agents, failed to be adjusted. Thus, the potential impact of these residual confounding factors on the results still could not be ignored.

**Conclusions**

In summary, our study demonstrated that TyG index was independent correlation with an increased risk of developing diabetes in Chinese adults. And the risk of incident diabetes increased with increasing TyG index. In addition, these findings extend our existing knowledge that TyG index seems to be more sensitive to predicting the risk of diabetes in young people, females, people with normal BMI or normal SBP. In other words, TyG index may be a useful marker for screening people at early risk of future diabetes without these strong risk factors such as age, BMI and hypertension.

**Abbreviations**
ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; BMI: Body mass index; BUN: Serum urea nitrogen; CI: Confidence interval; DBP: Diastolic blood pressure; FPG: Fasting plasma glucose; HDL-C: High density lipoprotein cholesterol; HR: Hazard ratios; IR: Insulin resistance; SBP: Systolic blood pressure; Scr: Serum creatinine; TC: total cholesterol; T2DM: Type 2 diabetes; TG: Triglyceride; TyG index: Triglyceride-glucose index.

Declarations

Ethics approval and consent to participate

In the previously published article [17], Ying Chen, et al. has clearly stated that this study was approved by the Rich Healthcare Group Review Board and complied with the declaration of Helsinki. Given the retrospective nature of the study, no patients were involved in any aspect of the study.

Consent for publication

Not applicable.

Availability of data and materials

Data can be downloaded from ‘DATADRYAD’ database (www.Datadryad.org).

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

XLL and HJM designed this study. XLL, GLL and TTC conducted data cleaning and statistical analysis. XLL and JL made the result interpretation. XLL, GYS and HJM participated in the discussion; XLL drafted the manuscript, and HJM revised the manuscript. All authors read and approved the final manuscript.

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Figures

Kaplan–Meier survival estimates

![Kaplan–Meier event-free survival curve. Kaplan–Meier analysis of incident of diabetes based on TyG index quartiles (logrank, P < 0.0001).](image)
Figure 1
Kaplan–Meier event-free survival curve. Kaplan–Meier analysis of incident of diabetes based on TyG index quartiles (logrank, P < 0.0001).
Figure 2

The relationship between TyG index and the incident of diabetes. A nonlinear relationship between TyG index and the incident of diabetes was found after adjusting for age, sex, BMI, SBP, DBP, AST, ALT, TC, LDL-C, Scr, smoking status, drinking status and family history of diabetes.
Figure 2

The relationship between TyG index and the incident of diabetes. A nonlinear relationship between TyG index and the incident of diabetes was found after adjusting for age, sex, BMI, SBP, DBP, AST, ALT, TC, LDL-C, Scr, smoking status, drinking status and family history of diabetes.