Lipids in Health and Disease

RESEARCH

Open Access

Associations between different insulin resistance indices and the risk of all-cause mortality in peritoneal dialysis patients

Guowen Zhao[1†], Sijia Shang[1†], Na Tian[2], Xiaojiang Zhan[3], Fenfen Peng[4], Xiaoyang Wang[5], Yueqiang Wen[6], Qingdong Xu[7], Xiaoran Feng[8], Xingming Tang[9], Xianfeng Wu[10,11], Qian Zhou[12], Yuanyuan Yang[1], Xing Zhang[1*] and Ning Su[1*]

Abstract

Background Insulin resistance (IR) is prevalent in individuals undergoing peritoneal dialysis (PD) and is related to increased susceptibility to coronary artery disease and initial peritonitis. In recent investigations, correlations have been found between indices of IR and the incidence of all-cause mortality in various populations. However, such correlations have not been detected among individuals undergoing PD. Hence, the present study's aim was to explore the connections between IR indices and the incidence of all-cause mortality in PD patients.

Methods Peritoneal dialysis patients ($n=1736$) were recruited from multiple PD centres between January 2010 and December 2021. Cox proportional hazards and restricted cubic spline regression models were used to evaluate the connections between the triglyceride–glucose (TyG) index, triglyceride–glucose/body mass index (TyG–BMI), and triglyceride/high-density lipoprotein cholesterol (TG/HDL-C) ratio and the occurrence of all-cause mortality. All three IR indices were integrated into the same model to assess the predictive stability. Furthermore, a forest plot was employed to display the findings of the subgroup analysis of PD patients.

Results Overall, 378 mortality events were recorded during a median follow-up time of 2098 days. Among PD patients, a higher TyG index, TyG–BMI, and TG/HDL-C ratio were identified as independent risk factors for all-cause mortality according to Cox proportional hazards analyses (hazard ratio (HR) 1.588, 95% confidence interval (CI) 1.261–2.000; HR 1.428, 95% CI 1.067–1.910; HR 1.431, 95% CI 1.105–1.853, respectively). In a model integrating the three IR indices, the TyG index showed the highest predictive stability. According to the forest plot for the TyG index, no significant interactions were observed among the subgroups.

Conclusion Significant associations were found between the TyG index, TyG–BMI, and TG/HDL-C ratio and the incidence of all-cause mortality among PD patients. The TyG index may be the most stable of the three surrogate IR markers. Finally, a correlation was identified between IR and the risk of all-cause mortality in patients undergoing PD.

†Guowen Zhao and Sijia Shang both authors contributed equally to this work.

*Correspondence:
Xing Zhang
Zhangx325@mail.sysu.edu.cn
Ning Su
Suning5@mail.sysu.edu.cn
Full list of author information is available at the end of the article

Introduction

The prevalence of chronic kidney disease (CKD) has reached 8–16% globally [1]. There are approximately 759 people worldwide being treated for end-stage kidney disease (ESKD), and 11% of those individuals are undergoing peritoneal dialysis (PD) [2, 3]. Although some classic factors (diabetes, cardiovascular disease and malnutrition) are correlated with the incidence of all-cause mortality in PD patients, specific PD-related factors (exposure of glucose to the peritoneum, PD-related peritonitis and encapsulating peritoneal sclerosis) also contribute significantly to the increased mortality of these patients [4–6]. Although progress in dialysis technology has increased the potential for prolonged survival among PD patients [7], compared with that in the age-matched general population, the mortality rate is 6.1 to 7.8 times greater [8]. Thus, it is crucial for PD patients to undergo further research on prognostic factors and identify potential treatment targets.

Insulin resistance (IR) is considered a decrease in sensitivity or responsiveness to the metabolic actions of insulin, including insulin-mediated glucose disposal [9]. Along with exposure to a high glucose load from dialysis fluid and abnormalities in glucose and lipid metabolism, IR is frequently observed in PD patients and is related to adverse clinical outcomes [10–12]. The hyperinsulinaemic-euglycaemic clamp (HEC) represents the most reliable method for evaluating IR. The quantitative insulin sensitivity check index (QUICKI) and homeostasis model assessment of IR are among the other surrogate markers utilized to assess the levels of IR. Nevertheless, owing to the expense and complex calculations, their clinical implementation is limited [13]. Researchers have confirmed that the triglyceride (TG)–glucose (TyG) index, TG–glucose/body mass index (TyG–BMI), and TG/high-density lipoprotein cholesterol (TG/HDL-C) ratio serve as reliable surrogate markers for IR. [14–16]. Numerous studies have shown highly consistent associations between these indicators and adverse clinical outcomes among different populations [17–21]. However, these IR surrogates have not been studied previously in relation to all-cause mortality in PD patients. Therefore, the purpose of this study was to examine how these different indices are related to the risk of all-cause mortality in patients with PD and to identify the most stable predictors.

Methods

Study Design and Participants

From January 2010 to December 2021, 1746 patients with PD were recruited from four PD centres in this retrospective multicentre study. The inclusion criterion was patients who received continuous ambulatory peritoneal dialysis as their first form of renal replacement therapy. The exclusion criteria were as follows: (1) PD duration < 3 months; (2) age < 18 years; (3) lack of significant baseline data for calculating the TyG index, TyG–BMI and TG/HDL-C ratio; (4) the use of icodextrin as a PD fluid.

Data Collection

Clinical data were obtained via an electronic medical records system, which included demographic information (sex, age, weight and height), comorbidities (history of cardiovascular disease (CVD), diabetes and stroke), and the administration of medications (insulin and statins). Biochemical data, including leukocyte, haemoglobin (HGB), fasting blood glucose (FBG), TG, total cholesterol (TC), HDL-C, low-density lipoprotein cholesterol (LDL-C), albumin (Alb), uric acid (UA), calcium and phosphorus, were measured according to each PD centre's standard laboratory techniques. To estimate residual kidney function (RKF), the following formula, which was corrected by the area of the body, was used. The body surface area was calculated via the Gehan and George equations: $RKF = \frac{1}{2}\left\{\left[\frac{UrineCreatinine(\mu mmol/L)}{SerumCreatinine(\mu mmol/L)}\right] + \left[\frac{UrineUrea(mmol/L)}{SerumUrea(mmol/L)}\right]\right\} \times \frac{UrineVolum(mL)}{1440}$ [22]. The total Kt/V was calculated using PD Adequest software 2.0 (Baxter, Deerfield, IL). Continuous variables were standardized by the Z scores, which was calculated using the following equation: $Z = \frac{origindata - \text{mean}}{standarddeviation}$. Every quarter, patients were required to return to each centre for a comprehensive medical assessment, and to assess their general conditions, trained nurses followed-up with the patients monthly by telephone.

Definitions

Patients aged ≥ 65 years were considered elderly [23]. Body mass index was calculated using the following formula: $BMI(kg/m^2) = [\frac{Weight(kg)}{Height^2(m^2)}]$. A BMI > 24.9 kg/m^2 was considered overweight or obese [24]. In accordance with the recommendations of the Kidney Disease: Improving Global Outcomes (KDIGO), participants were diagnosed with anaemia by HGB concentration < 130 g/L in males and < 120 g/L in females [25]. Cardiovascular disease was defined as a history of conditions including coronary heart disease, myocardial infarction, heart failure, vascular intervention procedures or coronary artery bypass surgery [26]. The following criteria were used to define diabetes: (1) treatment with insulin and antidiabetic drugs; (2) glycated HGB A1c (HbA1c) levels ≥ 6.5%; (3) FBG levels ≥ 7.0 $mmol/L$; or (4) a history of diabetes. The International Classification of Diseases, Ninth Revision (ICD-9) was used to define the other comorbidities [27]. Individuals were divided into lower and higher IR

index groups according to the optimal cut-off values for the TyG index, TyG–BMI, and TG/HDL-C ratio. The following formulas were used to calculate the TyG index, TyG–BMI, and TG/HDL-C ratio:

$$TyG = ln\left[\frac{(TG(mg/dL) \times FBG(mg/dL)}{2}\right],$$

$$TyG - BMI = ln\left[\frac{(TG(mg/dL) \times FBG(mg/dL)}{2}\right] \times BMI\left(\frac{Kg}{m^2}\right),$$

$$\frac{TG}{HDL - C} = \frac{TG\left(\frac{mg}{dL}\right)}{HDL - C\left(\frac{mg}{dL}\right)}.$$

Study Outcomes

All-cause mortality during the PD period was the primary endpoint. The numbers of patients who were transferred to haemodialysis (HD), underwent kidney transplantation, transferred to other centres and lost to follow-up were also recorded. The end of the follow-up period for this study was 31 December 2021.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA), R programming language (R Project for Statistical Computing; R Foundation) and GraphPad Prism 8 (GraphPad Software, Inc.). The receiver operating characteristic (ROC) curve was used to determine the optimal cut-off value for dividing individuals into high- and low-index groups. Missing data were imputed via multiple imputation. Statistical significance was determined by $P < 0.05$. The Kolmogorov–Smirnov normality test was used to determine whether the data were normal. Continuous variables without a normal distribution are expressed as medians (25th–75th percentiles), whereas categorical variables are expressed as numbers (%). The chi-square test or nonparametric Mann–Whitney test was used to assess differences between two groups. Univariable Cox proportional hazards regression was used to examine the associations between significant risk factors and the risk of all-cause mortality, and multivariable Cox proportional hazards regression was used to assess the associations between diverse levels of IR indices and the risk of all-cause mortality. Model 1 was unadjusted, Model 2 was adjusted for laboratory indices, and Model 3 was adjusted for laboratory indices, elderly status, sex, BMI, comorbid conditions and medication use. To eliminate the potential impact of statins on the TyG index and TG/HDL-C ratio, sensitivity analyses were conducted in PD patients who were not taking statins. Spearman's correlation analysis was conducted to explore the correlations between the IR indices and other significant mortality risk factors. The adjusted Kaplan–Meier survival curve was used to show differences in survival outcomes between the high- and low-IR index groups. A forest plot was used to present the outcomes of the subgroup analysis. Additionally, the relationship between the TyG index and the risk of all-cause mortality was explored in PD patients without elderly status, diabetes and CVD. Furthermore, restricted cubic splines (RCSs) were used to elucidate the relationships between various IR indices and the risk of all-cause mortality.

Results

Baseline characteristics of the participants

The study ultimately enrolled 1242 PD patients. At the end of follow-up, 378 participants had died, 111 participants were transferred to HD, 61 participants had undergone kidney transplantation, and 18 participants had been transferred to another centre. A total of 18 participants were lost to follow-up, and 656 reached the final follow-up date (Fig. 1).

No significant differences were observed in the data before and after missing value imputation (Table S5).

The baseline features of the nonsurviving and surviving groups are shown in Table 1. Compared with individuals in the surviving group, nonsurviving individuals were more likely to be older; have a history of CVD, stroke or diabetes; and receiving insulin therapy. In addition, patients in the nonsurviving group had higher FBG, TG, TC, LDL-C, and calcium levels; lower HGB and leukocyte levels; and a higher TyG index, TyG–BMI, and TG/HDL-C ratio. Furthermore, participants who died had lower levels of UA and worse RKF.

Correlations between IR indices and traditional all mortality risk factors

The relationships of the TyG index, TyG–BMI and TG/HDL-C ratio with other risk factors and with the risk of all-cause mortality in PD patients are presented in Table S1 Age, BMI, TC, LDL-C, HGB, and Kt/V were positively correlated with the TyG index, and HDL-C and RKF were negatively linked. Moreover, similar to the TyG index, the TyG–BMI was also positively correlated with age, TC, and LDL-C and negatively correlated with HDL-C. There was a negative correlation between the TyG–BMI and Alb and Kt/V. The TG/HDL-C ratio was positively correlated with age, BMI, FBG, and TC, while there was no significant correlation between the TG/HDL-C ratio and LDL-C, Alb Kt/V or RKF.

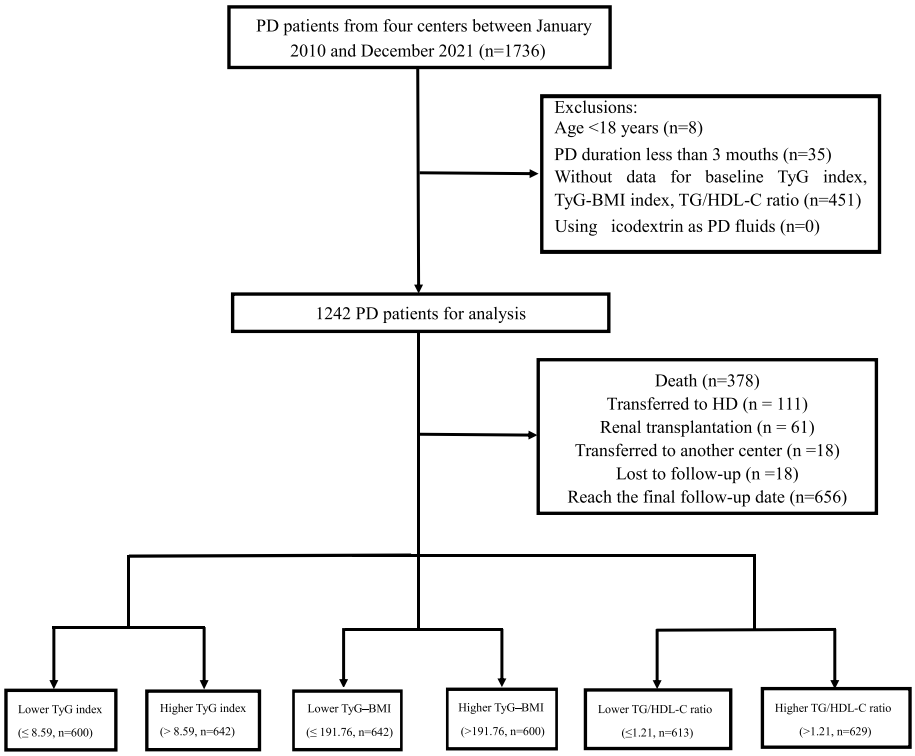


Fig. 1 The flow chart shows the exclusion and selection of patients. PD, peritoneal dialysis; HD, haemodialysis;TyG index, triglycerideglucose index; TyG–BMI, triglyceride–glucose/body mass index; TG/HDL-C ratio,triglyceride/high-density lipoprotein cholesterol

Relationships between IR Indices and all-cause mortality

All-cause mortality was linearly associated with the TyG index and TyG–BMI according to RCS analysis (*P* values for nonlinearity of 0.566 and 0.716, respectively). However, a nonlinear relationship was observed between the TG/HDL-C ratio and the risk of all-cause mortality (Fig. 2a, b and c).

To explore the associations between baseline characteristics and the incidence of all-cause mortality in patients with PD, a univariate Cox proportional hazards regression model was constructed. All-cause mortality was associated with advanced age; history of diabetes, stroke and CVD; use of insulin; and levels of leukocytes, UA, FBG, TC, TG, Ca, Alb, Kt/V and RKF. Except for UA, Alb and RKF, which were negatively linked to the incidence of all-cause mortality, the other baseline characteristics were positively correlated with the incidence of all-cause mortality. After standardization by the Z scores, the FBG level was more significantly associated with the risk of all-cause mortality in PD patients than other continuous variables (Table S2). According to the ROC curve, the optimal cut-off values for the TyG index, TyG–BMI, and TG/HDL-C ratio were 8.59, 191.76, and 1.21, respectively (Table S3). The results of the multivariable Cox proportional hazards regression can be found in Table 2. As shown in Table 2, an elevated TyG index and TyG–BMI were related to a greater incidence of mortality for patients with PD, regardless of whether the models were unadjusted or adjusted for potential confounders (HR 1.254, 95% CI 1.082–1.452, *P* 0.003; HR 1.009, 95% CI 1.003–1.016, *P* 0.004, respectively). After standardization by the Z scores, the TyG–BMI was more significantly associated with the risk of all-cause mortality in PD patients than TyG index (Table 2). Additionally, compared with those in the lower TyG index category, patients in the higher TyG index category had a 1.588-fold greater incidence of mortality (95% CI 1.261–2.000, *P* value < 0.001), which resembled the results of the comparisons between the lower and higher TyG–BMI (HR 1.428, 95% CI 1.067–1.910, *P* value 0.017) and TG/HDL-C ratio (HR 1.431, 95% CI 1.105–1.853, *P* value 0.007) groups. After exclusion of patients taking statins, the higher IR index group remained an independent risk factor for all-cause mortality in PD patients, which was consistent with the results of Cox regression models in the general population (Table S6). Additionally, adjusted Kaplan–Meier survival curves were plotted to depict the risk of all-cause mortality associated with different IR index groups. Compared with the patients

Table 1 Baseline clinical characteristics of peritoneal dialysis patients

	Total ($n=1242$)	Non-death ($n=864$)	Death ($n=378$)	*P* value
Demographics				
Male (%)	686 (55.2)	482 (55.8)	204 (54.0)	0.553
Elderly status (%)	239 (19.2)	112 (13.0)	127 (33.6)	< 0.001
Age (years)	53.50 (42.00–63.00)	50.00 (38.00–60.00)	60.50 (51.00–68.00)	< 0.001
BMI (kg/m^2)	21.91 (20.04–24.44)	21.98 (19.92–24.43)	21.77 (20.28–24.50)	0.830
Comorbid				
Diabetes (%)	468 (37.7)	264 (30.6)	204 (54.0)	< 0.001
CVD (%)	220 (17.7)	101 (11.7)	119 (31.5)	< 0.001
Stroke (%)	61 (4.9)	28 (3.2)	33 (8.7)	< 0.001
Medication use				
Use of insulin (%)	190 (15.3)	117 (13.5)	73 (19.3)	0.009
Use of statins (%)	193 (15.5)	135 (15.6)	58 (15.3)	0.900
Laboratory variables				
Leukocyte (10^9/L)	6.71 (5.43–8.31)	6.59 (5.35–8.19)	6.98 (5.70–8.60)	0.010
HGB (g/L)	101.00 (87.00–116.00)	100.00 (86.00–115.00)	104.00 (90.00–118.00)	0.011
Anaemia (%)	1059 (85.3)	746 (86.3)	313 (82.0)	0.105
FBG (mmol/L)	4.81 (4.20–6.00)	4.70 (4.12–5.47)	5.30 (4.36–7.49)	< 0.001
TG (mmol/L)	1.41 (0.97–2.13)	1.35 (0.93–2.02)	1.49 (1.04–2.34)	0.001
TC (mmol/L)	4.75 (4.00–5.61)	4.61 (3.90–5.50)	5.01 (4.32–6.00)	< 0.001
HDL-C (mmol/L)	1.11 (0.91–1.38)	1.11 (0.90–1.36)	1.12 (0.92–1.40)	0.580
LDL-C (mmol/L)	2.78 (2.21–3.42)	2.72 (2.17–3.33)	2.92 (2.27–3.57)	0.003
Alb (g/L)	35.50 (31.70–39.30)	35.55 (31.93- 39.50)	35.20 (30.98–39.00)	0.262
UA (μmol/L)	408.50 (353.00–472.00)	413.00 (356.00–481.00)	399.50 (346.75–454.00)	0.002
Ca (mmol/L)	2.20 (2.04–2.37)	2.19 (2.03–2.35)	2.24 (2.08- 2.39)	0.001
P (mmol/L)	1.48 (1.20–1.83)	1.51 (1.22–1.84)	1.44 (1.18–1.78)	0.050
Kt/V	2.31 (1.95–2.79)	2.30 (1.93–2.78)	2.34 (1.96–2.80)	0.298
RKF (mL/min/1.73m^2)	3.81 (2.04–8.62)	4.04 (2.09–11.27)	3.31 (1.93–5.62)	< 0.001
TyG–BMI	190.59 (168.37–215.91)	188.87 (167.13–213.25)	194.28 (172.17–220.84)	0.008
TyG index	8.63 (8.19–9.16)	8.53 (8.14–9.08)	8.81 (8.36–9.37)	< 0.001
TG/HDL-C ratio	1.22 (0.75–2.18)	1.16 (0.72–2.13)	1.37 (0.80–2.32)	0.014
PD vintage (days)	1733.50 (1025.00–2449.00)	1960.50 (1420.75–2688.50)	1106.00 (619.75–2310.70)	< 0.001
Cause of death				
Cardiovascular-related		-	137 (36.2)	
Cerebrovascular-related		-	61 (16.1)	
Pneumonia		-	41 (10.8)	
PD-related peritonitis		-	18 (4.8)	
Other infection		-	15 (4.0)	
GIB		-	11 (3.0)	
Cancer-related		-	11 (3.0)	
Unknown		-	84 (22.2)	

Data are shown as medians (25th-75th percentile) or n (%). Age ≥ 65 was considered as the elderly. Anaemia: haemoglobin concentration is < 130 g/L in males and < 120 g/L in females

Abbreviations: BMI Body mass index, *CVD* Cardiovascular disease, *HGB* Haemoglobin, *FBG* Fasting blood glucose, *TG* Triglyceride, *TC* Total cholesterol, *HDL-C* High-density lipoprotein cholesterol, *LDL-C* Low-density lipoprotein cholesterol, *Alb* Albumin, *UA* Uric acid, *Ca* Calcium, *P* Phosphorus, *RKF* Residual kidney function, *TyG* index Triglyceride–glucose index, *TyG–BMI* Triglyceride–glucose/body mass index, *TG/HDL-C* ratio Triglyceride/high-density lipoprotein cholesterol ratio, *PD* Peritoneal dialysis, *GIB* Gastrointestinal bleeding

in the three higher-IR index groups, the patients in each of the three lower-IR index groups had markedly better survival rates (Fig. 3a, b and c).

In conclusion, risk of mortality was increased among patients with a higher TyG index, TyG–BMI, and TG/HDL-C ratio. To determine the most stable index for

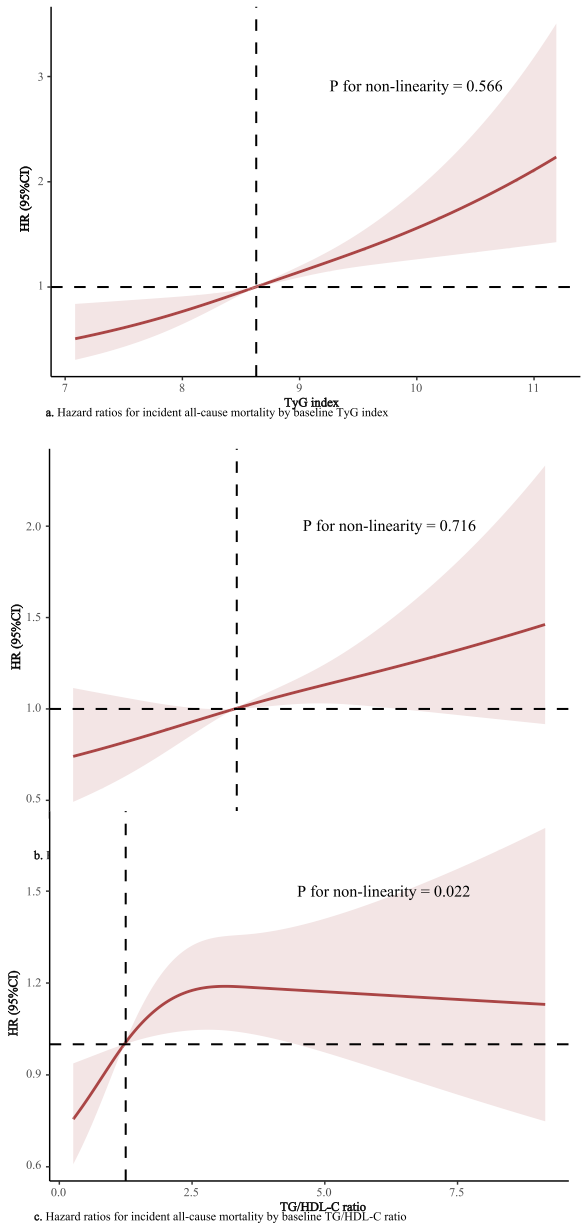


Fig. 2 Fig 2a. Hazard ratios for incident all-cause mortality by baseline TyG index. Fig 2b. Hazard ratios for incident all-cause mortality by baseline TyG–BMI. Fig 2c. Hazard ratios for incident all-cause mortality by baseline TG/HDL-C ratio

predicting all-cause mortality in PD patients, results were integrated for the three IR indices into Model 3 to construct Model 4. In Model 4, the TyG index was significantly positively correlated with the incidence of all-cause mortality (HR 1.489, 95% CI 1.102–2.012, *P* value 0.010), whereas no statistically significant relationship was found between a higher TyG–BMI or TG/HDL-C ratio and the risk of all-cause mortality (Table 3). Based on these results, it appears that the TyG index is the most stable predictor. Moreover, according to the area under the curve (AUC) results, the TyG index had the highest predictive ability among the three IR indices (Table S3).

Subgroup analyses

Subgroup analyses were performed for sex (male or female), elderly status (yes or no), diabetes status (yes or no), CVD status (yes or no), stroke status (yes or no), anaemia status (yes or no) and overweight or obesity status (yes or no) (Fig. 4). A significant interaction was not found in any of the subgroups, even after adjusting for confounders (all *P* values for interactions > 0.05). Furthermore, in PD patients without diabetes, CVD or elderly status, a higher TyG index was significantly associated with the risk of all-cause mortality (Table S4).

Discussion

This retrospective cohort study found that the studied IR indices were significantly positively associated with the incidence of all-cause mortality in patients with PD. After adjusting for potential confounders in Model 3, the risk of mortality was increased by 1.588-fold in the higher TyG index group, 1.428-fold in the higher TyG–BMI group, and 1.431-fold in the higher TG/HDL-C ratio group compared with that of the lower index groups. A high TyG index, TyG–BMI and TG/HDL-C ratio are independent risk factors for all-cause mortality in patients with PD and may be potential targets for improving the survival of patients undergoing PD.

Previous studies have indicated strong relationships between the TyG index, TyG–BMI, and TG/HDL-C ratio and the incidence of mortality in different populations. A large cross-sectional study from the National Health and Nutrition Examination Survey found that the TyG–BMI was associated with the risk of CVD mortality [28]. A prospective cohort study conducted by Lopez-Jaramillo et al. revealed that the TyG index was positively associated with the incidence of cardiovascular mortality [29]. Furthermore, in a cohort study targeting the acute ischaemic stroke population, according to Deng and his collaborators [30], the TG/HDL-C ratio was negatively related to 3-month survival. In a cohort study involving 6697 patients diagnosed with chronic heart failure, the incidence of all-cause mortality was higher among patients with a high TyG index [31]. Moreover, a consensus exists regarding the negative impact of elevated TG, FBG, and BMI on the prolonged survival of individuals with PD [32–34]. Additionally, a linear association was observed between the TG/HDL-C ratio and the risk of all-cause mortality in both early and advanced CKD patients [35]. However, to date, the relationships between

Table 2 Association between the IR index and all-cause mortality in the peritoneal dialysis patients

	Events/Total	Model 1		Model 2		Model 3	
		HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
Continuous TyG Index (per unit change)	378/1242 (30.4)	1.420 (1.259–1.600)	< 0.001	1.455 (1.276–1.660)	< 0.001	1.254 (1.082–1.452)	0.003
Standardized TyG Index (per SD change) [a]	378/1242 (30.4)	1.314 (1.197–1.442)	< 0.001	1.339 (1.209–1.484)	< 0.001	1.193 (1.064–1.337)	0.003
Lower TyG index	138/600 (23.0)	Reference	-	Reference	-	Reference	-
Higher TyG index	240/642 (37.4)	1.786 (1.448–2.202)	< 0.001	1.816 (1.458–2.262)	< 0.001	1.588 (1.261–2.000)	< 0.001
Continuous TyG–BMI (per unit change)	378/1242 (30.4)	1.004 (1.001–1.006)	0.005	1.004 (1.001–1.007)	0.006	1.009 (1.003–1.016)	0.004
Standardized TyG–BMI (per SD change) [a]	378/1242 (30.4)	1.149 (1.043–1.226)	0.005	1.154 (1.041–1.279)	0.006	1.420 (1.121–1.799)	0.004
Lower TyG–BMI	172/642 (26.8)	Reference	-	Reference	-	Reference	-
Higher TyG–BMI	206/600 (34.3)	1.393 (1.137–1.706)	0.001	1.356 (1.101–1.671)	0.004	1.428 (1.067–1.910)	0.017
Continuous TG/HDL-C ratio (per unit change) [b]	378/1242 (30.4)	-	-	-	-	-	-
Standardized TG/HDL-C ratio (per SD change) [b]	378/1242 (30.4)	-	-	-	-	-	-
Lower TG/HDL-C ratio	164/613 (26.8)	Reference	-	Reference	-	Reference	-
Higher TG/HDL-C ratio	214/629 (34.0)	1.350 (1.102–1.655)	0.004	1.566 (1.223–2.005)	< 0.001	1.431 (1.105–1.853)	0.007

Model 1 Unadjusted

Model 2 Adjusted by leukocyte, haemoglobin, calcium, phosphorus, albumin, uric acid, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, Kt/V

Model 3 Adjusted by model 2 plus sex, elderly status, body mass index, diabetes, stroke, cardiovascular disease, use of insulin, use of statins

TyG index, triglyceride–glucose index; TyG-BMI, triglyceride–glucose/body mass index; TG/HDL-C ratio, triglyceride/high-density lipoprotein cholesterol ratio;

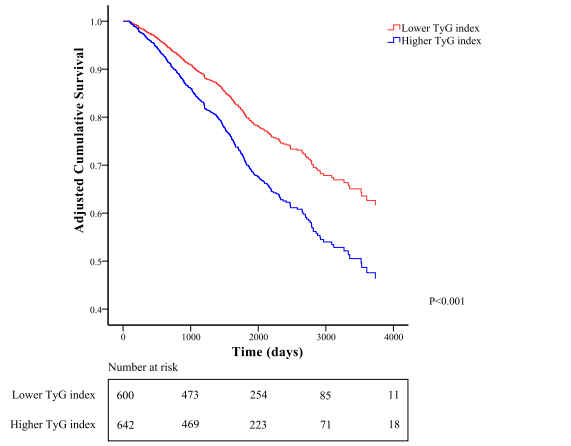
[a] Standardized using Z scores

[b] Since there was not a linear association between TG/HDL-C ratio and all-cause mortality, we didn't use Cox proportional hazards regression to assess the association between continuous and standardized TG/HDL-C ratio and all-cause mortality

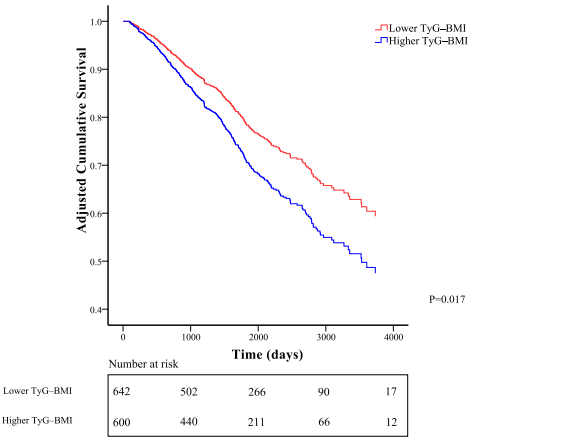
these composite indices and the risk of all-cause mortality have not been evaluated in the same PD patients, and linear or nonlinear associations have not been assessed.

Although the current study demonstrated that the TyG index, TyG–BMI, and TG/HDL-C ratio were positively associated with increased mortality risk in patients with PD, the specific biological mechanisms underlying these associations are unclear. The TyG index, TyG–BMI and TG/HDL-C ratio are derived from simple calculations based on TG, FBG, BMI and HDL-C data. The associations between these indices and IR have been demonstrated in earlier studies. According to Fernando et al., the TyG index has high sensitivity (96.5%) and specificity (85.0%) for diagnosing IR, with an area under the curve (AUC) of 0.858 [36]. A higher TyG–BMI and TG/HDL-C ratio were also related to greater morbidity in type 2 diabetic patients [37, 38]. Thus, the TyG index, TyG–BMI and TG-HDL-C ratio are considered simple and reliable markers for assessing IR. Current speculation is that IR may play a significant role in linking these indices with the risk of all-cause mortality.

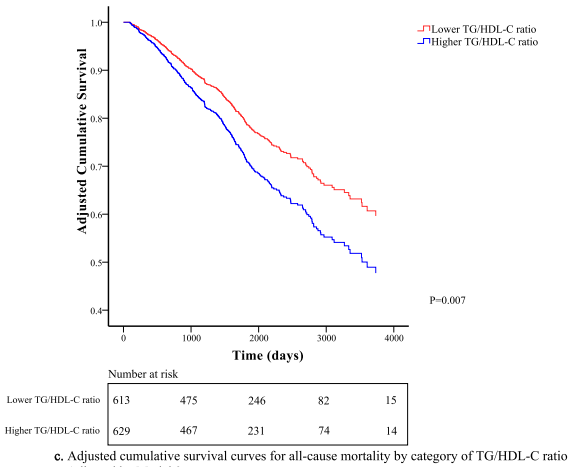
End-stage kidney disease and IR are closely related [39]. Recent studies have emphasized the association between IR severity and the clinical outcomes of PD patients [18, 40]. Based on the principles of technique, PD has specific problems, such as peritonitis and peritoneum damage, contributing to a high incidence of mortality. Compared with HD patients, PD patients are more likely to develop new-onset diabetes during the dialysis treatment period, implying a more severe IR [41]. Continuous contact with PD fluid containing high glucose concentrations may cause this clinical feature [10, 41]. Currently, although new PD fluids (such as icodextrin) have been used in clinical practice, conventional glucose-based solutions are utilized at a relatively high rate. Past publications have proposed that an increased peritoneal dialysate glucose concentration contributes to a greater risk of peritonitis and has adverse effects on the long-term survival of PD patients [6, 42]. Prolonged exposure of the peritoneum to high-glucose-concentration PD fluid continuously stimulates insulin secretion, leading to hyperinsulinaemia and increased IR, which aggravate glucose and lipid metabolic disorders, cause endothelial dysfunction and promote inflammation [43, 44], potentially resulting in an elevated incidence of cardiovascular morbidity and mortality among patients with PD [12]. Additionally, previous studies have shown that insulin is an anti-inflammatory hormone [11]. Insulin resistance status is positively correlated with infection-related mortality



a. Adjusted cumulative survival curves for all-cause mortality by category of TyG index Adjusted by Model 3
Lower TyG index: TyG index ≤ 8.59; Higher TyG index: TyG index > 8.59



b. Adjusted cumulative survival curves for all-cause mortality by category of TyG– BMI Adjusted by Model 3
Lower TyG–BMI: TyG–BMI ≤ 191.76; Higher TyG–BMI :TyG–BMI >191.76



c. Adjusted cumulative survival curves for all-cause mortality by category of TG/HDL-C ratio Adjusted by Model 3
Lower TG/HDL-C ratio: TG/HDL-C ratio ≤1.21; Higher TG/HDL-C ratio: TG/HDL-C ratio >1.21

◀ **Fig. 3** Fig 3a. Adjusted cumulative survival curves for all-cause mortality by category of TyG index. Adjusted by Model 3. Lower TyG index: TyG index ≤ 8.59; Higher TyG index: TyG index > 8.59. Fig 3b. Adjusted cumulative survival curves for all-cause mortality by category of TyG–BMI. Adjusted by Model 3. Lower TyG–BMI: TyG–BMI ≤ 191.76; Higher TyG–BMI :TyG–BMI >191.76. Fig 3c. Adjusted cumulative survival curves for all-cause mortality by category of TG/HDL-C ratio. Adjusted by Model 3. Lower TG/HDL-C ratio: TG/HDL-C ratio ≤1.21; Higher TG/HDL-C ratio: TG/HDL-C ratio >1.21

Table 3 Integrating three IR indexes into Model 3

	Model 4	
	HR (95% CI)	**P value**
Lower TyG index	Reference	-
Higher TyG index	1.489 (1.102–2.012)	0.010
Lower TyG–BMI	Reference	-
Higher TyG–BMI	1.141 (0.829–1.570)	0.420
Lower TG/HDL-C ratio	Reference	-
Higher TG/HDL-C ratio	1.042 (0.751–1.446)	0.804

Model 4 Adjusted by Model 3 plus TyG index group, TyG–BMI index group, TG-HDL index group

TyG index, triglyceride–glucose index; TyG–BMI, triglyceride–glucose/body mass index; TG/HDL-C ratio, triglyceride/high-density lipoprotein cholesterol ratio

Abbreviations: HR Hazard ratio, *CI* Confidence interval

[45], and a link between the TyG index and initial peritonitis has also been reported [46]. On the basis of the reduced sensitivity to insulin and limited available evidence, it is tempting to speculate that greater IR severity contributes to greater peritonitis mortality in PD patients. However, in the future, further studies should be conducted to test this theory. Additionally, previous studies have shown that among patients undergoing dialysis, those diagnosed with bladder cancer often present with aggressive histological features [47]. A recent study suggested that IR may be related to the incidence of bladder cancer [48]. Therefore, for PD patients with high levels of insulin resistance, there is an increased risk of both morbidity and mortality from bladder cancer, which may further shorten their survival time.

Interestingly, the present study also indicated that among these three indices, the TyG index had the highest predictive ability and stability for all-cause mortality in patients undergoing PD. According to present hypothesis, this may be explained by the fact that among these indices, the TyG index demonstrated superior predictive ability for IR [49, 50]. However, the specific underlying mechanism remains to be

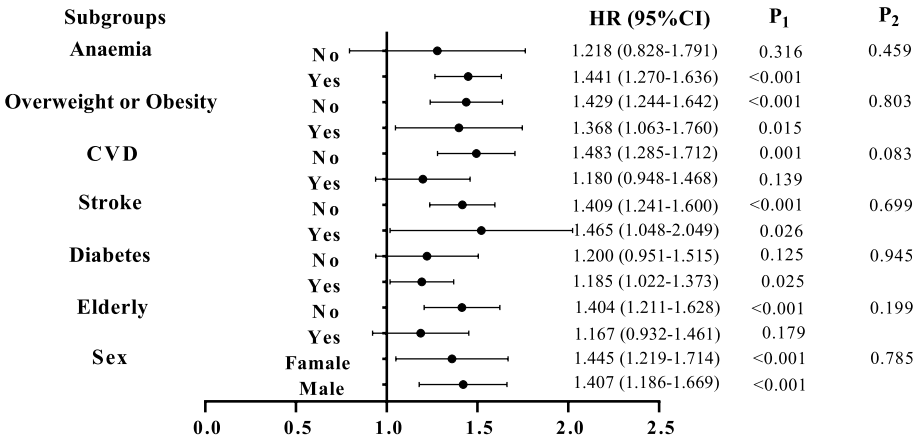


Fig. 4 Forest plot of relationship between TyG index and all-cause motality in different subgroup. Abbreviations: HR, hazard ratios; CI, confdence interval; P1, P value; P2, P for interaction; Elderly status: age ≥ 65; Anaemia: haemoglobin concentration is < 130 g/L in males and <120 g/L in females; Overweight or obesity: body mass index>24.9

elucidated. These findings suggest that clinicians can be encouraged to utilize the TyG index to evaluate and address all-cause mortality rates in patients undergoing PD.

Study strengths and limitations

There were several strengths in this study. Firstly, it was constructed in a multicenter, large-scale population, and found that different IR indices were identified as independent risk factors for all-cause mortality. Secondly, this study was the first to compare the predictive ability and stability of different IR indices for all-cause mortality risk in PD patients. Nevertheless, there were limitations to the current research. First, since this study was retrospective, the impact of various medications on the outcomes could not be completely eliminated. Second, since the present study was a retrospective cohort study, data on "C-reactive protein" "history of sarcopenia", "high peritoneal transport status", "fluid overload", "accumulating glucose exposure" and "occurrence of peritonitis" were not available. Therefore, in the future, more comprehensive data should be collected to explore the relationships between IR indices and the risk of all-cause mortality in PD patients. Third, although the present study hypothesized that the potential mechanism linking these indices and all-cause mortality rates may be related to IR, it did not conduct HEC. Thus, the predictive ability of these indicators in PD patients could not be evaluated. Therefore, there is a need for further research on the relationship between IR indices and HEC (the gold standard for IR assessment) in PD patients. Furthermore, this study analysed the TyG index, TyG–BMI and TG/HDL ratio at baseline only; dynamic changes in these indices were not included in the present study. Therefore, future studies are needed to explore the predictive power of changes in these indices for all-cause mortality in individuals undergoing PD. Additionally, the present study used the cut-off values recommended by the ROC curves to distinguish between the higher and lower TyG index, TyG–BMI, and TG/HDL-C ratio groups. This may impact the generalizability of the present study's conclusions.

Conclusion

The TyG index, TyG–BMI, and TG/HDL-C ratio have clinical significance for predicting all-cause mortality in PD patients. Based on the results of the present study, it is recommended that clinicians use the TyG index to evaluate and address all-cause mortality rates among individuals with PD, and reducing IR levels may improve the prognosis of PD patients.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12944-024-02275-x.

Supplementary Material 1.
Supplementary Material 2.
Supplementary Material 3.
Supplementary Material 4.
Supplementary Material 5.
Supplementary Material 6.

Acknowledgements
We would like to thank the Ever-green Tree Nephrology Group for data support. We thank all the doctors and nurses at the PD centres involved in this study.

Authors' contributions
All authors contributed to the study conception and design. Ning Su and Xing Zhang conceived the design of this manuscript. Guowen Zhao and Sijia Shang drafted the original manuscript. The data was provided by all authors. Qian Zhou and Xingming Tang checked the appraisals of risk of bias and applicability concerns. Data collection and analysis were performed by Tian Na, Xiaojiang Zhan and Yuanyuan Yang. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
This study was supported by the Wu Jieping Medical Foundation (No. 320.6750.2022–18-5), the Key Project of Social Science and Technology of Dongguan (No. 201950715046061) and the Guangzhou Science and Technology Program (No. 2023A04J2244).

Availability of data and materials
The datasets generated during or analysed during the current study are available from the corresponding author upon reasonable request.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Consent for participation was not required as the study was a retrospective review. All procedures in this study involving human participants were performed in accordance with the ethical standards of the institution. The study was performed in accordance with the 1975 Declaration of Helsinki and was approved by the Ethics Committee of the Sixth Affiliated Hospital of Sun Yet-Sen University (No. 2021SLYEC-177). Written informed consent was obtained from all the participants.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Haematology, The Sixth Affiliated Hospital, Sun Yat-Sen University, Guangzhou, China. [2]Department of Nephrology, General Hospital of Ningxia Medical University, Yinchuan, China. [3]Department of Nephrology, The First Affiliated Hospital of Nanchang University, Nanchang, Jiangxi, China. [4]Department of Nephrology, Zhujiang Hospital, Southern Medical University, Guangzhou, China. [5]Department of Nephrology, The First Affiliated Hospital of Zhengzhou University, Zhengzhou University, No. 1, Jianshe East Road, Zhengzhou, China. [6]Department of Nephrology, the Second Affiliated Hospital, Guangzhou Medical University, Guangzhou, China. [7]Department of Nephrology, Jiangmen Central Hospital, Jiangmen, China. [8]Department of Nephrology, Jiujiang NO.1 People's Hospital, Jiujiang, Jiangxi, China. [9]Department of Nephrology, Dongguan Songshan Lake Tungwah Hospital, No.7, Kefa Road, Dongguan 523000, China. [10]Department of Nephrology, Affiliated Sixth People's Hospital, Shanghai Jiao Tong University, Shanghai, China. [11]Department of Nephrology, Affiliated Eighth People's Hospital, Shanghai Jiao Tong University, Shanghai, China. [12]Department of Medical Statistics, Clinical Trials Unit, The First Affiliated Hospital, Sun Yat-Sen University, Guangzhou, China.

Received: 26 May 2024 Accepted: 28 August 2024
Published online: 07 September 2024

References

1. Ene-Iordache B, Perico N, Bikbov B, Carminati S, Remuzzi A, Perna A, Islam N, Bravo RF, Aleckovic-Halilovic M, Zou H, et al. Chronic kidney disease and cardiovascular risk in six regions of the world (ISN-KDDC): a cross-sectional study. Lancet Glob Health. 2016;4(5):e307-319.
2. Thurlow JS, Joshi M, Yan G, Norris KC, Agodoa LY, Yuan CM, Nee R. Global epidemiology of end-stage kidney disease and disparities in kidney replacement therapy. Am J Nephrol. 2021;52(2):98–107.
3. Cho Y, Bello AK, Levin A, Lunney M, Osman MA, Ye F, Ashuntantang GE, Bellorin-Font E, Gharbi MB, Davison SN, et al. Peritoneal dialysis use and practice patterns: an international survey study. Am J Kidney Dis. 2021;77(3):315–25.
4. Bieber S, Mehrotra R. Peritoneal dialysis access associated infections. Adv Chronic Kidney Dis. 2019;26(1):23–9.
5. Brown EA, Bargman J, van Biesen W, Chang MY, Finkelstein FO, Hurst H, Johnson DW, Kawanishi H, Lambie M, de Moraes TP, et al. Length of time on peritoneal dialysis and encapsulating peritoneal sclerosis - position paper for ISPD: 2017 update. Perit Dial Int. 2017;37(4):362–74.
6. Wen Y, Guo Q, Yang X, Wu X, Feng S, Tan J, Xu R, Yu X. High glucose concentrations in peritoneal dialysate are associated with all-cause and cardiovascular disease mortality in continuous ambulatory peritoneal dialysis patients. Perit Dial Int. 2015;35(1):70–7.
7. Li PK, Chow KM. Peritoneal dialysis-first policy made successful: perspectives and actions. Am J Kidney Dis. 2013;62(5):993–1005.
8. Saran R, Li Y, Robinson B, Ayanian J, Balkrishnan R, Bragg-Gresham J, Chen JT, Cope E, Gipson D, He K, et al. US renal data system 2014 annual data report: epidemiology of kidney disease in the United States 6.1-7.8. Am J Kidney Dis. 2015;66(1 Suppl 1):Svii, S1-305.
9. Hill MA, Yang Y, Zhang L, Sun Z, Jia G, Parrish AR, Sowers JR. Insulin resistance, cardiovascular stiffening and cardiovascular disease. Metabolism. 2021;119:154766.
10. Lambie M, Bonomini M, Davies SJ, Accili D, Arduini A, Zammit V. Insulin resistance in cardiovascular disease, uremia, and peritoneal dialysis. Trends Endocrinol Metab. 2021;32(9):721–30.
11. Fortes PC, de Moraes TP, Mendes JG, Stinghen AE, Ribeiro SC, Pecoits-Filho R. Insulin resistance and glucose homeostasis in peritoneal dialysis. Perit Dial Int. 2009;29 Suppl 2:S145-148.
12. Li Y, Zhang L, Gu Y, Hao C, Zhu T. Insulin resistance as a predictor of cardiovascular disease in patients on peritoneal dialysis. Perit Dial Int. 2013;33(4):411–8.
13. Gastaldelli A. Measuring and estimating insulin resistance in clinical and research settings. Obesity (Silver Spring). 2022;30(8):1549–63.
14. Du T, Yuan G, Zhang M, Zhou X, Sun X, Yu X. Clinical usefulness of lipid ratios, visceral adiposity indicators, and the triglycerides and glucose index as risk markers of insulin resistance. Cardiovasc Diabetol. 2014;13:146.
15. Kim JS, Kang HT, Shim JY, Lee HR. The association between the triglyceride to high-density lipoprotein cholesterol ratio with insulin resistance (HOMA-IR) in the general Korean population: based on the national health and nutrition examination survey in 2007–2009. Diabetes Res Clin Pract. 2012;97(1):132–8.
16. Er LK, Wu S, Chou HH, Hsu LA, Teng MS, Sun YC, Ko YL. Triglyceride glucose-body mass index is a simple and clinically useful surrogate marker for insulin resistance in nondiabetic individuals. PLoS One. 2016;11(3):e0149731.
17. Che B, Zhong C, Zhang R, Pu L, Zhao T, Zhang Y, Han L. Triglyceride-glucose index and triglyceride to high-density lipoprotein cholesterol ratio as potential cardiovascular disease risk factors: an analysis of UK biobank data. Cardiovasc Diabetol. 2023;22(1):34.
18. Zhan C, Peng Y, Ye H, Diao X, Yi C, Guo Q, Chen W, Yang X. Triglyceride glucose-body mass index and cardiovascular mortality in patients undergoing peritoneal dialysis: a retrospective cohort study. Lipids Health Dis. 2023;22(1):143.
19. Sato F, Nakamura Y, Kayaba K, Ishikawa S. TG/HDL-C ratio as a predictor of stroke in the population with healthy BMI: the jichi medical school cohort study. Nutr Metab Cardiovasc Dis. 2022;32(8):1872–9.
20. Huo RR, Zhai L, Liao Q, You XM. Changes in the triglyceride glucose-body mass index estimate the risk of stroke in middle-aged and older Chinese adults: a nationwide prospective cohort study. Cardiovasc Diabetol. 2023;22(1):254.
21. Yang Y, Huang X, Wang Y, Leng L, Xu J, Feng L, Jiang S, Wang J, Yang Y, Pan G, et al. The impact of triglyceride-glucose index on ischemic stroke: a systematic review and meta-analysis. Cardiovasc Diabetol. 2023;22(1):2.
22. Zhan X, Yang Y, Chen Y, Wei X, Xiao J, Zhang L, Yan C, Qiu P, Liu S, Hu Q, et al. Serum alkaline phosphatase levels correlate with long-term mortality solely in peritoneal dialysis patients with residual renal function. Ren Fail. 2019;41(1):718–25.
23. Tong T, Yang C, Tian W, Liu Z, Liu B, Cheng J, Cheng Q, Zhou B. Phenotypes and outcomes in middle-aged patients with diabetic foot ulcers: a retrospective cohort study. J Foot Ankle Res. 2020;13(1):24.

24. Blüher M. Obesity: global epidemiology and pathogenesis. Nat Rev Endocrinol. 2019;15(5):288–98.
25. Анемії К. KDIGO clinical practice guideline for anemia in chronic kidney disease. Kidney Int. 2012;2:279.
26. Zhang Y, Lai X, Chen Q, Zhan X, Long H, Peng F, Zhang F, Feng X, Zhou Q, Wu X, et al. The relationship between neutrophil-to-lymphocyte ratio and the first occurrence of pneumonia in peritoneal dialysis patients. Clin Exp Nephrol. 2020;24(9):770–8.
27. Classification and Diagnosis of Diabetes. Standards of medical care in diabetes-2020. Diabetes Care. 2020;43(Suppl 1):S14-s31.
28. Dang K, Wang X, Hu J, Zhang Y, Cheng L, Qi X, Liu L, Ming Z, Tao X, Li Y. The association between triglyceride-glucose index and its combination with obesity indicators and cardiovascular disease: NHANES 2003–2018. Cardiovasc Diabetol. 2024;23(1):8.
29. Lopez-Jaramillo P, Gomez-Arbelaez D, Martinez-Bello D, Abat MEM, Alhabib KF, Avezum Á, Barbarash O, Chifamba J, Diaz ML, Gulec S, et al. Association of the triglyceride glucose index as a measure of insulin resistance with mortality and cardiovascular disease in populations from five continents (PURE study): a prospective cohort study. Lancet Healthy Longev. 2023;4(1):e23–33.
30. Deng QW, Li S, Wang H, Lei L, Zhang HQ, Gu ZT, Xing FL, Yan FL. The short-term prognostic value of the triglyceride-to-high-density lipoprotein cholesterol ratio in acute ischemic stroke. Aging Dis. 2018;9(3):498–506.
31. Zhou Y, Wang C, Che H, Cheng L, Zhu D, Rao C, Zhong Q, Li Z, Wang X, Wu Z, et al. Association between the triglyceride-glucose index and the risk of mortality among patients with chronic heart failure: results from a retrospective cohort study in China. Cardiovasc Diabetol. 2023;22(1):171.
32. Habib AN, Baird BC, Leypoldt JK, Cheung AK, Goldfarb-Rumyantzev AS. The association of lipid levels with mortality in patients on chronic peritoneal dialysis. Nephrol Dial Transplant. 2006;21(10):2881–92.
33. Li X, Fan C, Wang C, Zhang Y, Niu L. Non-linear relationship between baseline fasting blood glucose and mortality in peritoneal dialysis patients, a retrospective cohort study. Front Med (Lausanne). 2024;11:1325914.
34. Ahmadi SF, Zahmatkesh G, Streja E, Mehrotra R, Rhee CM, Kovesdy CP, Gillen DL, Ahmadi E, Fonarow GC, Kalantar-Zadeh K. Association of body Mass Index with mortality in peritoneal dialysis patients: a systematic review and meta-analysis. Perit Dial Int. 2016;36(3):315–25.
35. Kim Y, Lee S, Lee Y, Kang MW, Park S, Park S, Han K, Paek JH, Park WY, Jin K, et al. Predictive value of triglyceride/high-density lipoprotein cholesterol for major clinical outcomes in advanced chronic kidney disease: a nationwide population-based study TG/HDL-C. Clin Kidney J. 2021;14(8):1961–8.
36. Guerrero-Romero F, Simental-Mendía LE, González-Ortiz M, Martínez-Abundis E, Ramos-Zavala MG, Hernández-González SO, Jacques-Camarena O, Rodríguez-Morán M. The product of triglycerides and glucose, a simple measure of insulin sensitivity. Comparison with the euglycemic-hyperinsulinemic clamp. J Clin Endocrinol Metab. 2010;95(7):3347–51.
37. Song B, Zhao X, Yao T, Lu W, Zhang H, Liu T, Liu C, Wang K. Triglyceride glucose-body mass index and risk of incident type 2 diabetes mellitus in Japanese people with normal glycemic level: a population-based longitudinal cohort study. Front Endocrinol (Lausanne). 2022;13:907973.
38. Yuge H, Okada H, Hamaguchi M, Kurogi K, Murata H, Ito M, Fukui M. Triglycerides/HDL cholesterol ratio and type 2 diabetes incidence: panasonic cohort study 10. Cardiovasc Diabetol. 2023;22(1):308.
39. DeFronzo RA, Alvestrand A, Smith D, Hendler R, Hendler E, Wahren J. Insulin resistance in uremia. J Clin Invest. 1981;67(2):563–8.
40. Yan Z, Yu D, Cai Y, Shang J, Qin R, Xiao J, Zhao B, Zhao Z, Simmons D. Triglyceride glucose index predicting cardiovascular mortality in chinese initiating peritoneal dialysis: a cohort study. Kidney Blood Press Res. 2019;44(4):669–78.
41. Wang IK, Lin CL, Chen HC, Lin SY, Chang CT, Yen TH, Sung FC. Risk of new-onset diabetes in end-stage renal disease patients undergoing dialysis: analysis from registry data of Taiwan. Nephrol Dial Transplant. 2018;33(4):670–5.
42. Jiang N, Zhang Z, Fang W, Qian J, Mou S, Ni Z. High peritoneal glucose exposure is associated with increased incidence of relapsing and recurrent bacterial peritonitis in patients undergoing peritoneal dialysis. Blood Purif. 2015;40(1):72–8.
43. Zhang AMY, Wellberg EA, Kopp JL, Johnson JD. Hyperinsulinemia in obesity, inflammation, and cancer. Diabetes Metab J. 2021;45(3):285–311.
44. Liu R, Guan S, Gao Z, Wang J, Xu J, Hao Z, Zhang Y, Yang S, Guo Z, Yang J, et al. Pathological hyperinsulinemia and hyperglycemia in the impaired glucose tolerance stage mediate endothelial dysfunction through miR-21, PTEN/AKT/eNOS, and MARK/ET-1 Pathways. Front Endocrinol (Lausanne). 2021;12:644159.
45. Cheong HS, Chang Y, Kim Y, Joo E-J, Kwon M-J, Wild SH, Byrne CD, Ryu S. Glycaemic status, insulin resistance, and risk of infection-related mortality: a cohort study. Eur J Endocrinol. 2023;188(2):197–205.
46. Liu G, Yan Q, Wang R, Li D, Cong J, Chen X. Elevated triglyceride-glucose index predisposes to the initial episode of peritonitis in chronic peritoneal dialysis patients. Ren Fail. 2023;45(2):2267127.
47. Yossepowitch O, Sagy I, Margel D, Baniel J. Urothelial carcinoma of the bladder in patients on hemodialysis: clinical characteristics and oncological outcomes. J Urol. 2012;187(4):1215–9.
48. Tarantino G, Crocetto F, Di Vito C, Creta M, Martino R, Pandolfo SD, Pesce S, Napolitano L, Capone D, Imbimbo C. Association of NAFLD and insulin resistance with non metastatic bladder cancer patients: a cross-sectional retrospective study. J Clin Med. 2021;10(2):346.
49. Du T, Yuan G, Zhang M, Zhou X, Sun X, Yu X. Clinical usefulness of lipid ratios, visceral adiposity indicators, and the triglycerides and glucose index as risk markers of insulin resistance. Cardiovasc Diabetol. 2014;13:146.
50. Mirr M, Skrypnik D, Bogdański P, Owecki M. Newly proposed insulin resistance indexes called TyG-NC and TyG-NHtR show efficacy in diagnosing the metabolic syndrome. J Endocrinol Invest. 2021;44(12):2831–43.

Publisher's Note