International Journal of Diabetes in Developing Countries (April–June 2025) 45(2):288–293
https://doi.org/10.1007/s13410-024-01348-y

ORIGINAL ARTICLE

Associations between triglyceride-glucose index and risk of diabetic kidney disease progression in type 2 diabetes mellitus

Jiadian Huang[1] · Dengke Liu[3] · Haixia Zeng[1] · Jianping Liu[1,2]

Received: 19 November 2023 / Accepted: 1 May 2024 / Published online: 23 May 2024

Abstract

Objective Pending connections exist between the TyG index and the risk assessment of diabetic kidney disease (DKD), which includes glomerular filtration rate and urine albumin to creatinine ratio. DKD progression risk and the TyG index were examined in this study.

Methods Following the Kidney Disease: Improving Global Outcomes guidelines, combined with ACR and eGFR, the risk of DKD progression was divided into three groups: low risk (group 1), moderately increased risk (group 2), and high to very high risk (group 3) (group 3, which combined the high and very high risk in the guidelines). Groups' TyG index differences were compared. The association between the TyG index of patients and the risk of developing type 2 diabetic nephropathy was analyzed via linear and logistic regression.

Results The TyG index varied tremendously between risk groups ($p < 0.001$). In both sexes, multivariate analysis revealed that the TyG index was significantly associated with the moderately increased risk (male: $\beta = 0.186$, $p < 0.001$; female: $\beta = 0.339$, $p < 0.001$) and high to very high risk (male: $\beta = 0.186$, $p < 0.001$; female: $\beta = 0.181$, $p = 0.009$) of DKD progression. Logistic regression analysis showed a higher risk of increased TyG index in men compared to group 1.

Conclusions In patients with type 2 diabetes, the TyG index was associated with the risk of DKD progression, which increased by an elevated TyG index in male patients—supporting the clinical significance of the TyG index for assessing the risk of DKD progression.

Keywords Triglyceride-glucose index · Diabetic kidney disease · Insulin resistance. Albumin to creatinine ratio · Estimated glomerular filtration

Introduction

From 2015 to 2017, the Endocrinology Branch of the Chinese Medical Association conducted an epidemiological survey on diabetes in 31 provinces in China, revealing a prevalence of 11.2% among Chinese adults aged 18 and older [1]. Diabetic kidney disease (DKD) is one of the most prevalent chronic microvascular complications of diabetes and a leading cause of end-stage renal disease (ESRD) [2]. DKD's prevalence in China is 26–41%, rising proportionally with diabetes [3]. Blood sugar management, lipid disorders treatment, and high blood pressure management, especially RAAS inhibition, slowed DKD progression but did not reduce the annual incidence of ESRD from DKD [4].

TyG index was first proposed by Simental-Mendia et al. [5]. The index can be calculated easily and has good sensitivity and specificity for IR evaluation, making it useful for large-scale clinical and epidemiological studies. Guerrero

Jiadian Huang and Dengke Liu contributed equally to this work and shared first authorship.

✉ Jianping Liu
ndefy14105@ncu.edu.cn

[1] Department of Endocrinology and Metabolism, The 2nd Affiliated Hospital, Jiangxi Medical College, Nanchang University, Nanchang City 330006, Jiangxi Province, China

[2] Institute for the Study of Endocrinology and Metabolism in Jiangxi Province, Nanchang City 330006, Jiangxi Province, China

[3] Department of Endocrinology and Metabolism, The 1st Affiliated Hospital, Gannan Medical University, Ganzhou City 341000, Jiangxi Province, China

utilized the TyG index to assess IR in healthy, obese, and prediabetic patients, and it was found that the TyG index had a higher diagnostic sensitivity (96.5%) and specificity (85.0%) than the "gold standard" hyperinsulinemic-euglycemic clamp (HEC) test for assessing IR. It also has a good correlation with the homeostasis model of insulin resistance (HOMA-IR), which is widely used in clinical practice. Therefore, it can be used as a reliable surrogate marker for IR [6].

Kidney Disease: Improving Global Outcomes (KDIGO) suggests combining the chronic kidney disease (CKD) stage and proteinuria category to evaluate the risk of diabetic kidney disease progression. Previous research has demonstrated that patients with diabetes or microalbuminuria tend to exhibit a higher degree of insulin resistance [7], indicating that IR might hasten the progression of DKD. The contribution of insulin resistance to the advancement of proteinuria in type 2 diabetes mellitus (T2DM) patients remains debatable. Studies have demonstrated that patients with IR and T2DM who suffer from proteinuria also have lower eGFR [8]. However, contrary findings have been reached by other researchers [9]. These negative conclusions may be attributable to using various study groups or IR markers in the studies. Identifying significant markers will aid in elucidating the potential relationship between IR and DKD progression. Finding meaningful markers helps us clarify the potential linkages between IR and DKD progression, improving risk stratification, targeting treatments, and potentially identifying new intervention points to improve prognosis. In this study, we aimed to explore the relationship between the TyG index and DKD risk progression in T2DM patients.

Materials and methods

Study design

The study subjects were adults with type 2 diabetes who were admitted to the Second Affiliated Hospital of Nanchang University Department of Endocrinology between December 2021 and December 2022, regardless of insulin or oral hypoglycemic drug use. Exclusion criteria: (1) T1DM, gestational diabetes, and other specific kinds of diabetes; (2) Primary glomerular, tubular, renal interstitial, and renovascular kidney disorders; hypertensive nephropathy. (3) Diabetes patients with acute consequences such as diabetic ketoacidosis, hyperosmolar hyperglycemic syndrome, and proliferative retinopathy; (4) T2DM complicated by severe cardiac, hepatic, or stress state, malignant tumor, pancreatitis; (5) Suspected familial hypertriglyceridemia [serum triglycerides (TG) > 500 mg/dl (5.65 mmol/L)] or lipid-lowering drug use in the past three months. Finally, 64.50% (269/420) of 420 T2DM patients aged 18–70 with complete clinical data were diagnosed with DKD. The big data center of the Second Affiliated Hospital of Nanchang University's management system/electronic medical record cohort database provides relevant data.

Definition

Diabetes is diagnosed according to the diagnostic criteria for type 2 diabetes developed by the World Health Organization (WHO) in 1999. DKD was diagnosed according to the 2017 American Diabetes Association (ADA) criteria [10]: Chronic kidney disease caused by diabetes, including GFR lower than 60 m1/min/1.73m^2 and (or) urinary albumin-creatinine ratio(UACR) higher than 30 mg/g, lasting for more than three months, two test results on different days meet the above standards, and excluding other reasons cause renal insufficiency. Stratification: Based on the KDIGO guidelines, according to the UACR and eGFR levels of the research subjects, as shown in Supplementary Fig. 1 [11]. The risk of DKD progression was stratified into low risk, moderately increased risk, high risk, and very high risk. The high and very high risk were pooled in this study. Patients were divided into low risk (group 1) group ($n = 150$), moderately increased risk (group 2) group ($n = 156$), high to very high risk (group 3) group ($n = 114$).

Clinical data and biochemical parameters

After fasting for at least 8 h, venous blood was taken the next morning to detect relevant study indicators. Detecting HbA1c with HPLC (4500MD, AB SCIEX, USA), FPG was detected by Bcekman coulter5800 automatic chemical analyzer, and four blood lipid levels [TG, high-density lipoprotein cholesterol (HDL-C), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C)], serum creatinine (SCr), and serum uric acid (SUA) were detected by the automated biochemical analyzer (Beckman Coulter AU5831, USA). Urinary albumin was measured using laser immunonephelometry (Siemens BN ProSpec), and urinary creatinine was measured using chromatographic stable isotope dilution electrospray mass spectrometry. Calculation indicators: (1) estimated glomerular filtration rate by simplified MDRD formula: eGFR (ml/min/1.73m2) = 186 × (SCr/88.41)-1.154 × age-0.203 × 0.742(female); (2) TyG index = Ln[fasting triacylglycerol (mg/dL) × FPG (mg/dL)/2]; (3) TG/HDL-C = TG (mmol/L)/HDL-C (mmol/L); (4) HOMA2-IR: Assessment of insulin resistance models based on fasting C-peptide. It was calculated using the HOMA calculator downloaded

from the official website of the University of Oxford Endocrinology (http://www.dtu.ox.ac.uk).

Statistical analysis

The statistical analysis was conducted using the SPSS 26.0 software. Quantitative data with normal distribution were presented as mean ± standard deviation ($'x \pm s$), while non-normal distribution was represented as median and interquartile range. Two normal-distributed continuous variables were compared using the independent sample *t*-test. Non-normal variables were compared using the Mann–Whitney *U* test. Multi-group data with a normal distribution and homogenous variance was analyzed using a one-way analysis of variance, while non-normal and categorical data were tested using a non-parametric test of K-independent samples. Correlation analysis uses Pearson, Spearman, and partial correlation analysis, depending on the normality of the two data groups. Logistic regression examined univariate analysis's significant indicators. Multiple linear and logistic models were used to examine the TyG index and DKD progression risk.

Results

There were no significant differences in sex and diastolic blood pressure (DBP) among the three groups. Except for TC, there were significant differences in TG, HDL-C, and LDL-C. Participants at higher risk of DKD progression also had significantly higher systolic blood pressure, serum creatinine ($p < 0.001$), and substantially lower serum HDL ($p < 0.001$). The TyG index of patients in group 3 and group 2 was significantly higher than that in group 1 ($p < 0.001$), but there was no statistical difference between groups 2 and 3 ($p = 0.202$) (Table 1 and Supplementary Fig. 2).

Correlation analysis showed that there was a significant positive correlation between the TyG index and BMI, SBP, DBP, HbA1C, TC, LDL-C, SUA, CIMT, UACR, eGFR($p < 0.05$), a negative correlation with HDL-C and age ($p < 0.05$). After adjustment of relevant factors, TyG index was positively correlated with HbA1c, TC, LDL-C, UACR, CIMT, SBP, DBP ($p < 0.01$), and lipid-related insulin resistance index such as TG/HDL-C and TC/HDL-C was

Table 1 Clinical characteristics of subjects divided by DKD progression risk

	Group 1	Group 2	Group 3	*p*
Sex (female, male)	150 (86/64)	156 (99/57)	114 (65/49)	0.449
Age (years)	54.90 ± 9.79	54.02 ± 10.08	57.82 ± 8.82[ab]	0.005
FPG	8.40 ± 3.52	10.85 ± 4.03[a]	10.31 ± 5.15[a]	< 0.001
FCP	1.89 (1.21–2.75)	2.13 (1.41–3.00)	2.46 (1.51–3.31)	0.005
BMI	24.12 ± 3.30[b]	25.20 ± 3.51[a]	24.53 ± 3.54	0.022
SBP	123.19 ± 15.74	129.04 ± 14.30[a]	135.68 ± 15.86[ab]	< 0.001
DBP	80.03 ± 9.70	82.60 ± 9.61[a]	81.93 ± 10.00	0.061
SCr	62.55(51.24–75.26)	73.47(58.67–86.29)	113.73(86.48–155.49)	< 0.001
LDL-C	2.78 ± 0.93	3.10 ± 0.89[a]	3.10 ± 1.39[a]	0.006
Course (years)	5 (1–10)	6 (1–10)	10 (5–15)	< 0.001
TyG index	7.38 ± 0.67[b]	8.10 ± 0.62[a]	7.99 ± 0.91[a]	< 0.001
TG	1.42 ± 0.76	2.24 ± 1.15	2.34 ± 1.35	< 0.001
HBA1c	8.38 ± 2.30[b]	9.25 ± 2.35[a]	8.87 ± 2.42	0.005
HDL-C	1.21 ± 0.36[b]	1.08 ± 0.34[a]	1.06 ± 0.33[a]	< 0.001
SUA	320.67 ± 98.69[b]	350.52 ± 89.01[a]	407.45 ± 121.67[ab]	< 0.001
UACR	12.10 (5.65–21.99)	143.50 (64.17–227.57)	425.68 (270.06–872.77)	< 0.001
TC	4.797 ± 1.16	5.03 ± 1.10	5.06 ± 1.77	0.126
eGFR	112.127 ± 27.75[b]	100.537 ± 29.82[a]	61.19 ± 29.38[ab]	< 0.001
DR	124 (82.67%)	137 (87.82%)	107 (93.86%)	0.024
CAS	42 (28.00%)	69 (44.23%)	51 (44.74%)	0.004
HOMA2IR	1.6 (0.96–2.29)	2.19 (1.39–2.96)	2.27 (1.33–3.72)	< 0.001

Abbreviations: *FPG*, fasting plasma glucose; *FCP*, fasting C-peptide; *BMI*, body mass index; *SBP*, systolic blood pressure; *DBP*, diastolic blood pressure; *Scr*, serum creatinine; *LDL-C*, low-density lipoprotein cholesterol; *TyG index*, triglyceride glucose index; *TG*, triglyceride; *HBA1c*, glycosylated hemoglobinA1c; *eGFR*, estimated glomerular filtration rate; *HDL-C*, high-density lipoprotein cholesterol; *SUA*, serum uric acid; *TC*, total cholesterol; *UACR*, urinary albumin-to-creatinine ratio; DR, diabetes retinopathy; *CAS*, carotid atherosclerosis; *HOMA2IR*, homeostasis model 2 of insulin; [a,b]mean compared with group 1 and group 2; the differences were statistically significant ($p < 0.05$)

significantly positively correlated ($p < 0.001$), and negatively correlated with HDL-C ($r = -0.267$, $p < 0.01$). The natural logarithmic transformation of HOMA2-IR was carried out to make it approximately conform to the normal distribution, and the TyG index was significantly positively correlated with LnHOMA2-IR ($r = 0.555$, $p < 0.001$) (Supplementary Table 1).

With or without diabetic nephropathy as the dependent variable, meaningful variables in single-factor analysis are self-variables. Binary logistic regression analysis showed that increased TyG index (OR = 3.553, 95%CI 2.319–5.444, $p < 0.001$), increased systolic blood pressure, longer duration of diabetes, and increased SUA were independent risk factors for DKD in T2DM patients (Table 2).

The results showed that the risk of DKD progression was significantly associated with an increased TyG index. In both sexes, the TyG index was strongly associated with moderately increased, high to very high risks of DKD progression (male: $\beta = 0.186$, $p < 0.001$; $\beta = 0.186$, $p < 0.001$; female: $\beta = 0.339$, $p < 0.001$; $\beta = 0.181$, $p = 0.009$), and HDL (male: $\beta = -0.112$, $p < 0.001$; female: $\beta = -0.123$, $p = 0.002$), age (male: $\beta = -0.126$, $p < 0.002$, 0.001; female: $\beta = -0.172$, $p = 0.005$) are closely related (Table 3).

Multivariate logistic regression analysis after further adjustment of age, BMI, and other factors showed that compared with group 1, men had a higher risk of increased TyG index (OR, p value: group 2: 3.228, $p < 0.001$; group 3: 4.669, $p < 0.001$). Among women, the odds ratio of group 2 was 6.647 ($p < 0.001$), and that of group 3 was 4.580 ($p < 0.001$) (Table 4).

Discussion

In this study, patients at increased risk of DKD progression showed a more significant burden of metabolic syndrome-related clinical parameters, including higher blood pressure, HbAlc, TG, TC, SUA, and lower HDL-c. Importantly, patients at increased risk of DKD progression had more severe insulin resistance, and both TyG index and HOMA2-IR scores were higher than those at low risk ($p < 0.05$). This was also found in a cross-sectional study of 1432 patients with T2DM [12], the TyG index was an independent risk factor for DKD (OR = 2.342, 95% CI 1.744 ~ 3.144) ($p < 0.001$). In this study, multivariate analysis showed that, as a surrogate marker of IR, increased TyG index was an independent risk factor for DKD in T2DM patients (OR = 3.553, $p < 0.001$). Our results were consistent with the above studies.

A new significant finding of this study is a significant correlation between the TyG index and the risk of DKD progression. In male patients, as the TyG index increases, the risk of DKD progression also increases.

Previous studies have shown that tight blood sugar control can reduce estimated glomerular filtration rate of less than 60 mL/min/1.73 m2 [13] and proteinuria [14, 15]. However, renal composite outcomes such ESKD and doubling serum creatinine were not significantly different between intensive and general control [16]. Two areas require improvement in HbA1c, which is a typical blood sugar indicator. First, DKD increases the risk of severe hypoglycemia and death when renal function declines. Target HbA1c may need to be adjusted. Furthermore, HbA1c does not accurately reflect hypoglycemia or blood glucose fluctuation. We often need to consider FPG in real life. To determine optimal therapeutic blood glucose levels for delaying diabetic nephropathy, Hae Hyuk Jung et al. conducted a follow-up study using FBG levels during treatment as an exposure factor, and elevated FBG levels during treatment were associated with favorable renal and mortality outcomes compared with patients without CKD [17]. Contrary to common belief, the "J" curve between FBG and various

Table 2 Binary logistic regression analysis was used to analyze the influencing factors of DKD

Parameter	p	OR	95% CIs	
TyG index	< 0.001	3.553	2.319	5.444
DR (%)	0.055	0.506	0.253	1.014
CAS (%)	0.625	1.148	0.659	2.000
SBP (mmHg)	< 0.001	1.030	1.013	1.047
Course (years)	0.001	1. 072	1.030	1.115
HBAlc (%)	0.131	1.084	0.976	1.203
HDL-C (mmol/L)	0.150	0.589	0.287	1.210
LDL-C (mmol/L)	0.576	0.925	0.703	1.216
SUA (μmol/L)	0.001	1.004	1.002	1.006
HOMA2-IR	0.908	0.997	0.943	1.054

Table 3 Multivariable analysis of TyG index and risk of DKD progression

Factor	Men		Women	
	Standardized β (t)	p	Standardized β (t)	p
HOMA2IR	0.385	< 0.001	0.276	< 0.001
HDLC	−0.112	< 0.001	−0.123	0.002
LDLC	0.240	< 0.001	0.185	0.002
Age	−0.126	< 0.001	−0.172	0.005
BMI	0.156	< 0.001	0.136	0.023
CAS	0.229	< 0.001	0.214	< 0.001
HBAlc	0.150	0.003	0.108	0.070
Group 2 +	0.186	< 0.001	0.339	< 0.001
Group 3 +	0.186	< 0.001	0.181	0.009

UC, TC, DR, SBP, DBP, Course were adjusted

+ Reference group is low-risk group

Table 4 Multiple logistic regression analysis of correlation between TyG index and DKD progression risk

		Group 2		Group 3	
		ORs (95% CIs)	*p* value	ORs (95% CIs)	*p* value
Men	Model 1	3.721 (2.263–6.116)	< 0.001	4.689 (2.686–8.184)	< 0.001
	Model 2	3.228 (1.792–5.816)	< 0.001	4.669 (2.398–9.092)	< 0.001
Women	Model 1	6.647 (3.236–13.657)	< 0.001	4.580 (2.230–9.403)	< 0.001
	Model 2	7.499 (3.316–16.958)	< 0.001	4.134 (1.798–9.505)	< 0.001

Model 1: adjusted for age, BMI, and duration of DM

Model 2: model 1 adjustments + HbA1c, LDL-C, UA, TC, and DR

+ Group 1 was set as the reference group

outcomes in this study shows that good blood sugar control is not enough. Most DKD patients progress after regulating blood sugar and opposing the RAAS system. In their subsequent follow-up, Gong et al. found that a high level of TG was significantly correlated with the progression of DKD in new-onset DM patients [18]. Hyperglycemia and hyperlipidemia often cause renal injury synergistically, as a high-fat diet can worsen albumin and renal parenchymal lesions in diabetic animals. To conclude, DKD's metabolic abnormalities are hyperglycemia and dyslipidemia. DKD can be potentially predicted by combining the TyG index of FPG and TG.

In this paper, although the TyG index was significantly associated with the risk of DKD progression, the odds ratio showed a regular positive increase only in men. It has been reported that in the development of DKD, there are varying degrees of sex differences in incidence and prevalence, phenotype or clinical manifestations, and several risk factors [19]. Estrogen binds to bodily receptors to affect biology. In skeletal muscle, estrogen receptor-α and receptor-β expression promotes glucose homeostasis and decreases glucose transporter-4 expression [20]. Estrogen receptor-α knockout mice showed insulin resistance and changes in glucose levels, which also confirmed this view [21]. The ladies in this study averaged 57.5 years old, which was older than the typical Chinese women's menopausal age of 49. Female DM patients who lose estrogen protection after menopause may develop DKD more slowly. In a recent review, it was noted that there were no specific conclusions about gender differences in DKD due to different manifestations of DKD and potential unknowns about factors such as age and medication. However, combined with numerous epidemiological data, male patients with DM have a higher risk of DKD and a higher risk of DKD progression [19]. An analysis from the national Swedish Renal Registry-CKD (SRR-CKD) showed that among adults with CKD stages G3b-5, women were at a lower risk of CKD progression compared with men [sub-hazard ratio (SHR) 0.88 (0.85–0.92)] [22]. Another UK Prospective Diabetes Study (UKPDS) found a higher risk of microalbuminuria in men with T2DM [23]. This may explain the regular increase in males relative to females in the risk assessment combined with CKD stage and microalbumin. This gender difference may improve diagnosis and therapy.

This study has some limitations. First, our participants were hospitalized T2DM patients, there was a selection bias. Unfortunately, the cross-sectional study cannot determine a causal link between the TyG index and DKD progression. Secondly. TG and FPG measures showed biological variability in individuals. The model did not include nutrition or exercise, and urinary tract infection, exercise, etc., influenced UACR. This study measured ACR once. Due to the short sample size, most proteinuric individuals exhibited normal or microalbuminuria and a slightly higher eGFR. More extended sample-size studies are needed to better assess the TyG index and DKD progression risk through risk stratification. This may support the importance of TyG index in DM patients with varied DKD risk, as shown by our data. A large prospective multicenter cohort study is needed to evaluate the TyG index's DKD prediction potential in T2DM patients, especially the general population.

Conclusion

In this cross-sectional study, we found that an elevated TyG index was associated with an increased risk of DKD progression. For patients with a high TyG index, especially males, education and treatment interventions should be performed as early as possible.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s13410-024-01348-y.

Data availability The data are available from the corresponding authors.

Declarations

Ethics approval and consent to participate The Nanchang University Second Affiliated Hospital Ethics Review Committee approved this study. The Ethics Review Committee of Nanchang University's Second Affiliated Hospital exempted the study from informed consent. The Declaration of Helsinki was followed for all techniques.

Conflict of interests The authors declare no competing interests.

References

1. Li Y, Teng D, Shi X, Qin G, Qin Y, Quan H, et al. Prevalence of diabetes recorded in mainland China using 2018 diagnostic criteria from the American Diabetes Association: national cross sectional study. BMJ (Clin Res Ed). 2020;369:m997. https://doi.org/10.1136/bmj.m997.
2. Jia W, Gao X, Pang C, Hou X, Bao Y, Liu W, et al. Prevalence and risk factors of albuminuria and chronic kidney disease in Chinese population with type 2 diabetes and impaired glucose regulation: Shanghai diabetic complications study (SHDCS). Nephrol Dial Transplant. 2009;24(12):3724–31. https://doi.org/10.1093/ndt/gfp349.
3. Mendis S, Davis S, Norrving B. Organizational update: the world health organization global status report on noncommunicable diseases 2014; one more landmark step in the combat against stroke and vascular disease. Stroke. 2015;46(5):e121–2. https://doi.org/10.1161/strokeaha.115.008097.
4. Albvr VR, Tan SH, Candasamy M, Bhattamisra SK. Diabetic nephropathy: an update on pathogenesis and drug development. Diabetes Metab Syndr. 2019;13(1):754–62. https://doi.org/10.1016/j.dsx.2018.11.054.
5. Simental-Mendía LE, Rodríguez-Morán M, Guerrero-Romero F. The product of fasting glucose and triglycerides as surrogate for identifying insulin resistance in apparently healthy subjects. Metab Syndr Relat Disord. 2008;6(4):299–304. https://doi.org/10.1089/met.2008.0034.
6. Guerrero-Romero F, Simental-Mendía LE, González-Ortiz M, Martínez-Abundis E, Ramos-Zavala MG, Hernández-González SO, et al. 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. https://doi.org/10.1210/jc.2010-0288.
7. Pham H, Robinson-Cohen C, Biggs ML, Ix JH, Mukamal KJ, Fried LF, et al. Chronic kidney disease, insulin resistance, and incident diabetes in older adults. Clin J Amer Soc Nephrol: CJASN. 2012;7(4):588–94. https://doi.org/10.2215/cjn.11861111.
8. Bjornstad P, Maahs DM, Cherney DZ, Cree-Green M, West A, Pyle L, et al. Insulin sensitivity is an important determinant of renal health in adolescents with type 2 diabetes. Diabetes Care. 2014;37(11):3033–9. https://doi.org/10.2337/dc14-1331.
9. Jager A, Kostense PJ, Nijpels G, Heine RJ, Bouter LM, Stehouwer CD. Microalbuminuria is strongly associated with NIDDM and hypertension, but not with the insulin resistance syndrome: the Hoorn Study. Diabetologia. 1998;41(6):694–700. https://doi.org/10.1007/s001250050970.
10. American Diabetes Association. 10. Microvascular complications and foot care. Diabetes Care. 2017;40(Supplement_1):S88–98.
11. Navaneethan SD, Zoungas S, Caramori ML, Chan JCN, Heerspink HJL, Hurst C, et al. Diabetes management in chronic kidney disease: synopsis of the 2020 KDIGO clinical practice guideline. Ann Intern Med. 2021;174(3):385–94. https://doi.org/10.7326/M20-5938.
12. Lv L, Zhou Y, Chen X, Gong L, Wu J, Luo W, et al. Relationship between the TyG index and diabetic kidney disease in patients with type-2 diabetes mellitus. Diabetes Metab Syndr Obes: Targets Ther. 2021;14:3299–306. https://doi.org/10.2147/dmso.S318255.
13. de Boer IH, Sun W, Cleary PA, Lachin JM, Molitch ME, Steffes MW, et al. Intensive diabetes therapy and glomerular filtration rate in type 1 diabetes. N Engl J Med. 2011;365(25):2366–76. https://doi.org/10.1056/NEJMoa1111732.
14. Duckworth W, Abraira C, Moritz T, Reda D, Emanuele N, Reaven PD, et al. Glucose control and vascular complications in veterans with type 2 diabetes. N Engl J Med. 2009;360(2):129–39. https://doi.org/10.1056/NEJMoa0808431.
15. Ismail-Beigi F, Craven T, Banerji MA, Basile J, Calles J, Cohen RM, et al. Effect of intensive treatment of hyperglycaemia on microvascular outcomes in type 2 diabetes: an analysis of the ACCORD randomised trial. Lancet. 2010;376(9739):419–30. https://doi.org/10.1016/s0140-6736(10)60576-4.
16. Ruospo M, Saglimbene VM, Palmer SC, De Cosmo S, Pacilli A, Lamacchia O, et al. Glucose targets for preventing diabetic kidney disease and its progression. Cochrane Database Syst Rev. 2017;6(6):Cd010137. https://doi.org/10.1002/14651858.CD010137.pub2.
17. Jung HH. Evaluation of serum glucose and kidney disease progression among patients with diabetes. JAMA Netw Open. 2021;4(9):e2127387. https://doi.org/10.1001/jamanetworkopen.2021.27387.
18. Gong L, Wang C, Ning G, Wang W, Chen G, Wan Q, et al. High concentrations of triglycerides are associated with diabetic kidney disease in new-onset type 2 diabetes in China: findings from the China Cardiometabolic Disease and Cancer Cohort (4C) Study. Diabetes Obes Metab. 2021;23(11):2551–60. https://doi.org/10.1111/dom.14502.
19. Giandalia A, Giuffrida AE, Gembillo G, Cucinotta D, Squadrito G, Santoro D, et al. Gender differences in diabetic kidney disease: focus on hormonal, genetic and clinical factors. Int J Mol Sci. 2021;22(11):5808. https://doi.org/10.3390/ijms22115808.
20. Barros RP, Machado UF, Warner M, Gustafsson JA. Muscle GLUT4 regulation by estrogen receptors ERbeta and ERalpha. Proc Natl Acad Sci USA. 2006;103(5):1605–8. https://doi.org/10.1073/pnas.0510391103.
21. Heine PA, Taylor JA, Iwamoto GA, Lubahn DB, Cooke PS. Increased adipose tissue in male and female estrogen receptor-alpha knockout mice. Proc Natl Acad Sci USA. 2000;97(23):12729–34. https://doi.org/10.1073/pnas.97.23.12729.
22. Retnakaran R, Cull CA, Thorne KI, Adler AI, Holman RR. Risk factors for renal dysfunction in type 2 diabetes: U.K. Prospective Diabetes Study 74. Diabetes. 2006;55(6):1832–9. https://doi.org/10.2337/db05-1620
23. de Hauteclocque A, Ragot S, Slaoui Y, Gand E, Miot A, Sosner P, et al. The influence of sex on renal function decline in people with Type 2 diabetes. Diabet Med: J Br Diabet Assoc. 2014;31(9):1121–8. https://doi.org/10.1111/dme.12478.