Original Article

SAGE Open Medicine

SAGE Open Medicine
Volume 12: 1–9

DOI: 10.1177/20503121241265066
journals.sagepub.com/home/smo
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Effects of a combination of dyslipidemia and hypertension on the glycemic control of patients with type 2 diabetes mellitus: a cross-sectional study

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Abstract

Objectives: Both dyslipidemia and hypertension contribute to poor glycemic control in patients with type 2 diabetes mellitus, but the combined effect of dyslipidemia and hypertension on glycemic control in patients with type 2 diabetes mellitus has not been evaluated. The aim of this study was to analyze the interaction effect between dyslipidemia and hypertension on glycemic control in patients with type 2 diabetes mellitus.

Methods: A total of 2485 patients with type 2 diabetes mellitus were selected from the Xuzhou community of China by multi-stage cluster random sampling for a cross-sectional survey. Their glycated hemoglobin, dyslipidemia, and hypertension were assessed, and the interaction effects between dyslipidemia and hypertension on glycemic control were analyzed using relative excess risk due to the interaction, the synergy index, and the attributable proportion of the additive interaction.

Results: Of the participants, 62.13% (1544/2485) had dyslipidemia and 55.01% (1367/2485) had hypertension. Of the participants, 76.66% (1905/2485) who had both dyslipidemia and hypertension also had poor glycemic control. The prevalence of poor glycemic control was higher in those with both dyslipidemia and hypertension (odds ratio 2.735, 95% confidence interval 2.117–3.532; $p < 0.001$) compared with those who had normal blood lipids and without hypertension, after adjustment for confounders. The relative excess risk due to the interaction, the attributable proportion, and the synergy index were 1.077 (95% confidence interval 0.558–1.596), 2.637 (95% confidence interval 1.268–4.006), and 0.394 (95% confidence interval 0.230–0.558), respectively, for the interaction between dyslipidemia and hypertension.

Conclusions: Dyslipidemia and hypertension have an additive interaction on poor glycemic control in patients with type 2 diabetes mellitus.

Keywords

Dyslipidemia, hypertension, type 2 diabetes mellitus, glycemic control, interaction

Date received: 15 February 2024; accepted: 12 June 2024

Introduction

Type 2 diabetes mellitus (T2DM) represents a huge health challenge worldwide. Global data displays that 20–79-year-olds with diabetes were estimated to be 536.6 million in 2021, and this is predicted to rise to 783.2 million by 2045. Global diabetes-related health expenditure was estimated to be USD 966 billion in 2021 and is projected to reach 1054 billion by 2045.[1] The prevalence of T2DM increased from 0.9% in 1980 to 10.9% in 2013 in China, which reflects a higher prevalence than the global average of 8.8%,[2] and it

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estimated that 114 million people were living with diabetes and 61 million people with undiagnosed diabetes at this time.[3] Therefore, T2DM has become one of the most important public health problems in China.

Chronic hyperglycemia causes many of the complications of diabetes mellitus (DM), such as diabetic retinopathy and diabetic nephropathy, which can lead to blindness and kidney failure, respectively.[4,5] In addition, DM increases the risks of cardiovascular diseases (CVDs) and the associated mortality.[6,7] Previous studies have shown that adequate glycemic control significantly reduces the risk of diabetes-related complications and slows the progression of the disease.[8] However only 44.04% (95% confidence interval (CI) 46.9%–51.5%) of patients under treatment had adequate glycemic control, with glycated hemoglobin (HbA1c) $<$7.0% (53 mmol/mol), in China.[9] A series of studies have shown that many factors affect the glycemic control of patients with T2DM, including age, sex, obesity, smoking,[10,11] blood pressure (BP), dyslipidemia,[12] diet,[13] physical activity,[14] sleep disorders,[15] psychological disorders,[16] and environmental factors.[17]

Dyslipidemia is highly prevalent in patients with DM and particularly in those with poorly controlled diabetes.[18] Diabetes is usually accompanied by hypertension.[19] However, whether there is an additive effect of dyslipidemia and hypertension on the glycemic control of patients with T2DM is unclear. Therefore, we performed a cross-sectional study to evaluate the effect of a combination of dyslipidemia and hypertension on the glycemic control of patients with T2DM in a primary care setting in China.

Methods

Study design

We performed a cross-sectional study of the glycemic control of patients with T2DM in Xuzhou City in 2021. Approximately 240,000 patients with T2DM were registered in 3980 villages/communities of 10 administrative districts of Xuzhou City, a moderately-developed city located in the north of Jiangsu Province, eastern China, by December 2020, and the study was conducted between March and December 2021. The participants were selected using multi-stage cluster random sampling from the 10 regions. First, two sub-districts/townships were selected from each region, then two communities/villages were selected from each sub-district/township, and finally, the patients who had registered in each of these communities/villages were included in the study. All the eligible patients were invited by community general practitioners to undergo face-to-face interviews with the study staff at community health stations. The participants also underwent a physical examination and blood sampling for laboratory testing, completed questionnaires, and were provided with breakfast and a small gift.

Ethics approval statement

The study was approved by the Xuzhou Center for Disease Control and Prevention and the Xuzhou Medical Sciences Ethics Committee (approval no. 20151210).

Sample size

The prevalence of adequate glycemic control in patients with T2DM was 44.04% in China,[9] but when dyslipidemia and hypertension were both present, the prevalence was only 23.5%.[20] Therefore, in the present study, in the presence of both dyslipidemia and hypertension in the participants, we expected a prevalence of glycemic control of 20%; and with a statistical power of 80%, a two-sided type I error of 5%, a predicted effect size of 1.3, and a 15% refusal rate, we calculated that 2298 patients with T2DM would be needed to detect a 10% relative error in the prevalence of glycemic control.[21] Ultimately, we recruited 2501 patients with T2DM from 40 communities.

Participants

Patients with a diagnosis of diabetes and diagnosised according to the recommendations of the American Diabetes Association[21] were recruited from community health stations. The inclusion criteria were as follows: (1) T2DM and (2) a normal ability to communicate. The exclusion criteria were as follows: (1) treatment of T2DM for $<$3 months; (2) type 1 diabetes; (3) concurrent secondary hypertension; (4) presence of an acute complication of diabetes, such as diabetes ketoacidosis, (5) serious mental or psychological disease; (6) concurrent serious disease, such as heart, liver, or lung insufficiency, or malignant tumor; (7) infectious disease, such as hepatitis or tuberculosis; and (8) lack of willingness to participate. The guidelines of the Consolidated Standards of Reporting Trials Statement for cross-sectional studies were followed.[22]

Physical examination

The physical examination included the measurement of body mass, height, and BP by experienced and uniformly trained staff in a warm room. Body mass was measured using a portable digital scale with a precision of 0.1 kg, with the participant wearing light clothes. Height was measured using an instrument with an accuracy of 0.1 cm, whereas the participants were standing still and not wearing shoes or socks. The body mass index (BMI) of each participant was calculated by dividing their body mass (kg) by the square of their height (m^2). After a 10-min rest, BP was measured by experienced staff using an upper arm electronic sphygmomanometer (Hoofddorp, Netherlands) in a room at 25°. The participants were seated, with their right upper arm at heart level, and their BP was measured twice, with a 5-min interval between

measurements. Mean systolic and diastolic BP (SBP and DBP, respectively) values were calculated, but if the two values obtained differed by >10 mmHg, they would be determined a third time, and the second and third values were used to compute the mean values for SBP and DBP.

Laboratory testing

Fingertip venous blood samples were collected, and the HbA1c level was measured using a NycoCard Reader II (Axis-Shield, Oslo, Norway). This instrument is a convenient, rapid, and accurate (coefficient of variation <5%) means of measuring HbA1c. The serum concentrations of triglycerides, low-density lipoprotein-cholesterol (LDL-C), high-density lipoprotein-cholesterol (HDL-C), and total cholesterol were measured enzymatically using quality-controlled kits (Pars Azmun, Karaj, Iran) that were distributed by the central reference laboratory of Tehran, Iran. Random samples were sent to the central laboratory to be verified, and the results were discarded if a significant difference was identified.

Other demographic and clinical parameters

A locally developed questionnaire was used to collect information regarding the following demographic and clinical parameters: sex; age; marital status; duration of education; lifestyle; duration of diabetes; family history of diabetes; medication; comorbidities; and smoking, drinking, and exercise habits. The medication and complications of the participants were checked on the electronic medical record system. The reliability and validity of the questionnaire were tested on 944 patients with T2DM. The validity of the questionnaire content is 0.852, and the validity of the item content is between 0.8 and 1.0). The coefficients of Cronbach's α of the total questionnaire was 0.911, and the retest reliability was 0.866.

Definitions of terms

HbA1c values ⩾7.0% (53 mmol/mol) were taken to indicate poor control of glycemia, except for participants who were >65 years old or had CVD, in whom an HbA1c threshold of 8.0% was used.[23] Dyslipidemia was defined using a triglyceride concentration ⩾150 mg/dL (1.7 mmol/L), a total cholesterol concentration ⩾200 mg/dL (5.2 mmol/L), an LDL-C concentration ⩾100 mg/dL (2.6 mmol/L) for participants without a history of CVD or nephropathy and ⩾70 mg/dL (1.8 mmol/L) for those with a history of CVD or nephropathy, and an HDL-C concentration ⩽50 mg/dL (1.3 mmol/L) or 40 mg/dL (1.0 mmol/L) for women and men, respectively; or a self-reported history of dyslipidemia or the use of lipid-lowering drugs during the preceding 2 weeks.[23] Hypertension was defined based on a mean SBP ⩾130 mmHg and/or a mean DBP ⩾80 mmHg, or a previous diagnosis of hypertension and treatment.

The participants were categorized as being underweight (⩽18.5 kg/m^2), normal weight (18.5–23.9 kg/m^2), overweight (24.0–27.9 kg/m^2), or obesity (⩾28.0 kg/m^2) using their BMI values. Abdominal obesity was defined using a waist circumference ⩾85 cm for men and ⩾80 cm for women.[24] A smoking habit was recorded if the participant had smoked at least 100 cigarettes in their lifetime. Information regarding the amount and type of alcohol consumed during the previous year was obtained, and participants were recorded as alcohol consumers if they consumed at least 30 g every week over a period of at least 1 year. Regular leisure time physical activity was defined as participating in moderate or vigorous activity for no less than 30 min per day and on at least 3 days per week.[25]

Statistical analysis

Continuous data are presented as mean ± standard deviation and were analyzed using Student's *t*-test or a non-parametric test (χ^2 test), depending on whether the data were normally distributed. Categorical data are presented as proportions and were compared using the chi-square test.

The relationships of the glycemic control of the participants with the presence of hypertension or dyslipidemia were characterized using binary logistic regression. During this, the participants were stratified according to their glycemic control (poor versus good), hypertension (present versus absent), and dyslipidemia (present versus absent); and the data were adjusted for age (continuous), sex (male or female), educational level (less than high school versus high school or further), marital status (married versus unmarried), comorbidities (present versus absent), smoking habit (yes versus no), alcohol consumer (yes versus no), exercise habit (regular or not), duration of diabetes (continuous), BMI (continuous), and medication (hypoglycemic drugs alone, insulin alone, or both). An interaction item was included in the logistic regression model to identify additive or multiplicative interactions. Odds ratios (ORs) and 95% CIs were calculated using a contrast statement.

Biological interactions should be based on the sum of the model rather than multiplying the model.[26,27] Therefore, the relative excess risk owing to an interaction (RERI), the attributable proportion (AP) owing to an interaction, and the synergy index (S) were used to evaluate the biological interaction between dyslipidemia and hypertension with respect to an effect on the glycemic control of the participants. By calculating the parameter estimates and covariance matrix of the logistic regression model, the Excel table developed was used to calculate the additive interaction indicators. Compared to the risk of not being exposed to dyslipidemia and hypertension, RERI quantified the excessive risk attributable to interactions.

AP quantifies the AP of the disease, which relates to an interaction in individuals who have been exposed to both risk factors. S refers to the excess risk associated with exposure to both factors when there is a biological interaction, relative to the risk associated with exposed to both factors, but in the absence of an interaction. In the absence of an additive interaction, the values for RERI and AP are zero.[28]

$$\text{Relative excess risk (RERI)} = RR11 - RR10 - RR01 + 1;$$

$$\text{Attributable proportion (AP)} = RERI / RR11;$$

$$\text{Synergy index (S)} = \left[RR11 - 1\right] / \left[RR01 - 1\right]$$

RR11 represents the RR (Risk Ratio) value in the presence of both A and B.

RR10 and RR01 indicate the RR value in the presence of one factor.

In the present study, we refined the criteria such that a statistically significant RERI >0 or AP >0 would be taken to indicate a biological interaction.

All the analyses were performed using SPSS v.17.0 (SPSS, Chicago, IL, USA), and a $p \leqslant 0.05$ (two-tailed) was considered to represent statistical significance.

Results

Characteristics of the participants

A total of 2485 participants with T2DM from 40 different communities, with a mean age of 67.73 ± 8.72 years, who met the eligibility criteria were studied. The participants consisted of 949 (38.2%) men and 1536 (61.8%) women. The prevalence of poor glycemic control among the participants with dyslipidemia was 62.13% (1544/2485), and that among participants with hypertension was 55.01% (1367/2485). Only 23.3% (580/2485) of the participants with both dyslipidemia and hypertension had adequate glycemic control. The characteristics of the study sample are presented in Table 1.

The prevalence of good glycemic control among the smokers was lower than that among the non-smokers ($\chi^2 = 38.87$, $p < 0.001$), and the prevalence in alcohol consumers was lower than in non-consumers ($\chi^2 = 18.88$, $p < 0.001$). In addition, participants with a waist circumference above the threshold value were less likely to have good glycemic control ($\chi^2 = 27.20$, $p < 0.001$). Overweight and obesity were associated with poor glycemic control, as was regular exercise ($\chi^2 = 32.20$, $p < 0.001$). A long duration of T2DM was associated with poorer glycemic control ($\chi^2 = 123.28$, $p < 0.001$). Finally, the prevalences of dyslipidemia, hypertension, a family history of diabetes, and co-morbidities in the poor glycemic control group were higher than those in the good glycemic control group ($p < 0.05$, see Table 1).

Relationship of glycemic control with dyslipidemia and hypertension in the participants

Glycemic control was used as the dependent variable, and in univariate analysis, dyslipidemia and hypertension were used as independent variables, which were analyzed using univariate logistic regression. The results showed that dyslipidemia and hypertension were associated with poor glycemic control in the participants (OR 1.618, 95% CI 1.326–1.910, $p < 0.01$ and OR 1.868, 95% CI 1.540–2.196, $p < 0.01$; respectively.).

Age, sex, marital status, educational level, employment status, smoking habits, alcohol consumption habits, waist circumference, BMI, physical activity habits, duration of disease, family history of diabetes, comorbidities, medication, dyslipidemia, and hypertension were used as independent variables, and in multivariate analysis using multivariate logistic regression models, glycemic control is used as the dependent variable. This analysis showed that dyslipidemia and hypertension were associated with poor glycemic control in the participants (OR 1.617, 95% CI 1.306–1.928, $p < 0.001$ and OR 1.808, 95% CI 1.471–2.145, $p < 0.001$; respectively). The results of the analysis are shown in Table 2.

Interaction of dyslipidemia and hypertension with respect to an effect on the glycemic control of the participants

Individuals with dyslipidemia or hypertension were at significantly higher risk of poor glycemic control than those with dyslipidemia but no hypertension (OR 1.275, 95% CI 1.004–1.546 and OR 1.383, 95% CI 1.054–1.712; respectively; $p < 0.001$ for both), after adjustment for confounders. Table 3 shows the results of the multiple logistic regression analysis. The prevalence of poor glycemic control was highest in participants with both dyslipidemia and hypertension (OR 2.858, 95% CI 2.082–3.634, $p < 0.001$), after adjustment for confounders. There was a strong additive interaction between dyslipidemia and hypertension (RERI 2.637, 95% CI 1.268–4.006), with 40% of the risk of poor glycemic control being attributable to an interaction between dyslipidemia and hypertension (Table 4).

Discussion

The main finding of the present study was that there is an interaction between dyslipidemia and hypertension with respect to their effect on the glycemic control of patients with T2DM. We found that dyslipidemia and hypertension increase the risk of poor glycemic control in Chinese patients with T2DM, independent of the potential confounders of

Table 1. Comparison of characteristics between individuals.

Reported variables	All	Glycemic control		*p*
		Poor	Well	
N	2485	1379	1106	
Age (years)	67.68 ± 8.71	67.69 ± 8.96	67.66 ± 8.39	0.942
Sex (% male)	949	526 (38.1%)	423 (38.2%)	0.958
Marred (living with partners; %)	2088	1168 (84.7%)	920 (83.2%)	0.762
Educational level				0.191
Below high school	1299	736 (53.4%)	563 (50.9)	
High school	709	391 (28.4%)	318 (28.8%)	
Above high school	477	252 (18.3%)	225 (20.3%)	
Occupation				0.062
Employed	339	182 (13.2%)	949 (85.8%)	
Retired	2146	1197 (86.8%)	648 (58.6%)	
Duration of diabetes, mean (SD)	9.34 ± 7.45	10.62 ± 7.79	7.75 ± 6.67	<0.001
Smoker	425 (17.1%)	294 (21.3%)	131 (11.8%)	<0.001
Drinker	384 (15.5%)	252 (18.3%)	132 (11.9%)	<0.001
Family history of diabetes	660 (26.6%)	391 (28.4%)	269 (24.3%)	0.024
Central obesity	1762 (70.9%)	1020 (74.0%)	742 (67.1%)	<0.001
BMI, mean (SD)	26.20 ± 6.66	26.68 ± 8.40	25.61 ± 3.35	<0.001
Regular exercise	941 (37.9%)	454 (32.9%)	487 (44.0%)	<0.001
Comorbidity	677 (27.2%)	422 (30.6%)	255 (23.1%)	<0.001
Hypertension	1367 (55.0%)	852 (61.8%)	515 (46.6%)	<0.001
Dyslipidemia	1544 (62.1%)	925 (67.1%)	619 (56.0%)	<0.001
Medication model				<0.001
Only take hypoglycemic drugs	2110 (84.9%)	1139 (82.6%)	971 (70.4%)	
Only inject insulin	162 (6.5%)	92 (6.7%)	70 (50.8%)	
Take hypoglycemic drugs and inject insulin	213 (8.6%)	148 (10.7%)	65 (4.7%)	

Values are numbers of subjects unless otherwise indicated.
BMI, body mass index; SD, standard deviation.

Table 2. Logistic analysis of association between glycemic control and dyslipidemia, hypertension in patients with T2DM.

Variable	Univariate analysis		Multivariate analysis[a]	
	OR (95% CI)	*p*	OR (95% CI)	*p*
Dyslipidemia				
No	1.000		1.000	
Yes	1.618 (1.326–1.910)	<0.001	1.617 (1.306–1.928)	<0.001
Hypertension				
No	1.000		1.000	
Yes	1.868 (1.540–2.196)	<0.001	1.808 (1.471–2.145)	<0.001

BMI, body mass index; CI, confidence interval; OR, odds ratio; T2DM, type 2 diabetes mellitus.
[a]Adjusted for a age, gender, marriage, education level, job, smoking, drinking, waist circumference, BMI, physical activity, disease duration, family history of diabetes, co-morbidity, medication model.

age, sex, marriage, educational level, employment status, smoking habits, alcohol consumption habits, waist circumference, BMI, physical activity habits, the duration of the disease, a family history of diabetes, comorbidities, and the medication used.

The prevalence of dyslipidemia in the patients with T2DM studied was 62.1%, which is similar to that recorded in Spain (60%), but lower than that recorded in the United States (77.2%).[29,30] The prevalence of hypertension in the present participants with T2DM was 55.0%, which is lower than that stated in national diabetes surveys performed in other countries. In the United States, the most common comorbidity in patients with T2DM was hypertension, and (82%),[29] and 74% (95% CI 62–86) of Canadian adults with

Table 3. Additive interaction between dyslipidemia and poor glycemic control by hypertension among participants.

Dyslipidemia	Hypertension	Glycemic control		Model 1	*p*	Model 2	*p*
		Good	Poor	OR (95% CI)		OR (95% CI)	
No	No	241	182	1.000		1.000	
Yes	No	350	345	1.324 (1.038–1.610)	0.024	1.275 (1.004–1.546)	0.010
No	Yes	244	272	1.488 (1.049–1.927)	0.003	1.383 (1.054–1.712)	0.019
Yes	Yes	271	580	2.858 (2.082–3.634)	0.001	2.735 (1.938–3.532)	<0.001

Mode 1: adjusted for a age; Model 2: adjusted for a age, gender, marriage, education level, job, smoking, drinking, waist circumference, BMI, physical activity, disease duration, family history of diabetes, co-morbidity, medication model.
BMI, body mass index; CI, confidence interval; OR, odds ratio.

Table 4. Measures for estimation of the biological interaction between dyslipidemia and hypertension for the prevalence of poor glycemic control in participants.

Model	RERI (95% CI)	AP (95% CI)	S (95% CI)
Model 1	1.046 (0.546–1.546)	0.366 (0.212–0.520)	2.288 (1.289–3.287)
Model 2	1.077 (0.558–1.596)	0.394 (0.230–0.558)	2.637 (1.268–4.006)

Model 1: adjusted for a age; Model 2: adjusted for a age, gender, marriage, education level, job, smoking, drinking, waist circumference, BMI, physical activity, disease duration, family history of diabetes, comorbidity, medication model.
AP, attributable proportion; BMI, body mass index; CI, confidence interval; RERI, relative excess risk due to the interaction; S, synergy index.

diabetes were also reported to have hypertension.[31] The most frequently recorded comorbidity in Belgian patients with T2DM was hypertension (85.5%).[32] These differences in prevalence might be related to the sampling method, the age of the participants, their diet, or their ethnicity.

Previous epidemiologic studies have shown that abnormal serum lipid concentrations are a risk factor for poor glycemic control in patients with T2DM.[12,18,20] Esteghamati et al. reported that poor glycemic control is associated with hyperlipidemia (OR 1.15, $p < 0.001$),[20] and each 1% increase in the HbA1c area under the curve was found to be associated with a 13% higher risk of the presence or progression of hypertriglyceridemia and a 20% higher risk of the presence or worsening of abnormal LDL-C concentrations.[33] The control of dyslipidemia in the present Chinese participants with T2DM was also rather poor. Previous studies have shown that dyslipidemia was closely related to poor glycemic control and that HbA1c could be used as a marker of serum lipid status in patients with T2DM.[34] Wang et al.[8] studied the circulating lipid status of older patients with T2DM in rural China and found that regardless of whether single-drug or multi-drug hypoglycemic treatment was used, the circulating concentrations of LDL, Total Cholesterol (TC), and Triglyceride (TG) positively correlated with blood glucose control, and negatively correlated with HDL concentration in such patients.[35] A previous prospective cohort study showed that abnormalities in LDL and TG are associated with high HbA1c in patients with T2DM who are not undergoing lipid-lowering therapy, both at baseline and after 7 years of follow-up.[33] However, after a period of lipid-lowering treatment in patients with T2DM, the prevalence of glycemic control increases.[36] In the present study, we also found that dyslipidemia is a risk factor for poor glycemic control in patients with T2DM. Therefore, for such patients, in addition to the primary management of their T2DM, attention should be paid to their lipid profiles, and appropriate treatment should be instituted to aid the attainment of adequate glycemic control.

Many previous studies have shown that hypertension is a risk factor for poor glycemic control in patients with T2DM.[12,20,36] A nationwide study conducted in the United States shows that the prevalence of glycemic control is the lowest in patients with both T2DM and hypertension.[37] Furthermore, patients with T2DM in combination with hypertension are at a 1.53-fold higher risk of poor glycemic control than those without hypertension.[20] Schmieder et al. conducted a 6-month follow-up study of patients with both T2DM and hypertension and found that their mean HbA1c at baseline was 7.8% ± 2.1%. However, after 6 months of antihypertensive and antihyperglycemic therapy, 64.8% of the patients had an HbA1c <7.0%.[38] Poor glycemic control (adjusted OR 5.39, 95% CI 2.07–13.99) has also been shown to be a predictor of poor BP control,[39] and the prevalence of glycemic control in patients with both T2DM and hypertension is much lower than in those without hypertension in China.[40] In the present study, we have found that, after adjustment for potential confounders, patients with both T2DM and hypertension are at a 1.387 times higher risk of poor glycemic control than those without hypertension. Therefore, patients with T2DM should control not only their glycemia but also their BP and lipid status.[41]

The mechanism of the interaction between dyslipidemia and hypertension with respect to poor glycemic control in patients with T2DM likely involves insulin resistance because circulating lipid concentrations positively correlate with the severity of insulin resistance.[42] Hypertension leads to insulin resistance because of the thinning of blood vessels and the decrease in capillary density, which affects the transmission process and diffusion ability of insulin and glucose in the target cells causes the unevenness of blood flow distribution, and impedes the uptake and utilization of glucose by myocytes.[43] Hypertension leads to the decrease in the sensitivity of adipose tissues to insulin, and insulin resistance.[44] High circulating free fatty acid concentrations in patients with T2DM and hyperlipidemia can cause lipid toxicity, interfere with the binding of insulin to its receptors on peripheral target organs, cause insulin resistance, and lead to disorders of glucose metabolism, thereby affecting glycemic control.[45,46]

The mechanism whereby hypertension affects glucose metabolism in patients with T2DM may involve atherosclerosis because this features endothelial dysfunction, which might cause or exacerbate insulin resistance by limiting glucose delivery to key target tissues.[47,48] Dyslipidemia, especially elevated levels of LDL-C, is considered a pathogenic risk factor for atherosclerosis.[49] In recent years, it has been found that elevated levels of lipoprotein a increase the risk of atherosclerosis.[50] In addition, when patients with diabetes have hypertension and dyslipidemia, the risks of cardiovascular and cerebrovascular complications are higher than if they do not have these comorbidities, which implies the presence of poor glycemic control.[51,52] These findings suggest that patients with T2DM should carefully monitor and control their BP and circulating lipid concentrations to better control their glycemia.

Limitations

The limitations include the reliance on self-reported measures of smoking habit and alcohol consumption in the first place. Second, owing to the cross-sectional nature of the study, definitive conclusions regarding causality cannot be drawn. Therefore, a large cohort study should be conducted to verify the interaction between dyslipidemia and hypertension with respect to an effect on blood glucose control in patients with T2DM. Third, we were unable to adjust for certain potential confounders, such as hypoglycemia. We also did not consider the effects of factors such as the dose, quantity, and type of hypoglycemic drugs used by the participants. Fourth, we only studied older Chinese patients in the Xuzhou area; therefore, similar investigations should be performed on participants of other ages and ethnicities. Fifth, there is no difference in glycemic control rates between men and women.[2] The control rate of dyslipidemia was significantly higher in women than men.[53] The control rate of hypertension is also higher in females than in males.[54] Our results may underestimate the interaction between hypertension and dyslipidemia on blood glucose control in diabetes patients due to the high proportion of women. Finally, this study does not consider that poor glycemic control in diabetes patients is caused by drug resistance because there is no report on anti-diabetic medications of diabetes in China.

Strengths

The strengths of the present study include the homogeneity of the random sample, the large sample size, and the community-based nature of the sample.

Conclusion

Despite these limitations, we believe that the present findings have great significance for the management of patients with T2DM. We identified a strong negative relationship between hypertension and glycemic control in patients with T2DM and also found that dyslipidemia is strongly associated with poor glycemic control. In fully adjusted models, we calculated that 40% of the risk of poor glycemic control in patients with T2DM could be explained by an interaction between dyslipidemia and hypertension. This implies that clinicians should monitor patients with T2DM for hypertension and dyslipidemia and treat these promptly when identified.

Acknowledgements

We thank all the participants involved in the study. We also thank Mark Cleasby, PhD from Liwen Bianji (Edanz) (https://www.liwenbianji.cn) for editing the language of a draft of this manuscript.

Author contributions

FC, HL, and YJ were involved in proposal writing and designing the study and participated in the analysis and interpretation of data. FC, HL, YJ, CX, ZD, DL, CQ, and PZ were involved in the data collection and drafting of the original article. FC, HL, YJ, and PZ finalized the write-up of the manuscript. All authors critically revised the manuscript and read and approved the final manuscript for publication.

Data availability statement

Data are available on motivated request from the corresponding author on reasonable request, if relevant legislation and required data protection measures are met.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work

was supported by the Xuzhou Medical Youth Innovation Project [grant numbers XWKYHT20200004 and XWKYHT20220126], the Xuzhou Science and Technology Project [Grant number KC22226], and the Young Medical Science and Technology Innovation Project of the Xuzhou Municipal Health Commission [Grant number XWKYHT20200030]. The funders had no involvement in the study design, data collection, analysis, interpretation of the data, writing of the report, or decision to submit the article for publication.

Ethics approval

The study was approved by the Xuzhou Center for Disease Control and Prevention and the Xuzhou Medical Sciences Ethics Committee (approval no. 20151210).

Written informed consent

The purpose and method of the study were clearly explained to the participants. Data were collected after each participant provided written informed consent. Illiterate participants provided written informed consent after the consent form was read to them, and they signed it with their fingers. They would have been assured of anonymity and confidentiality of personal information. Participants in the trial were given the option to decline or discontinue participation at any time, and they were also allowed to ask questions about the study. The study was conducted in accordance with the ethical principles in the Declaration of Helsinki.

Informed consent

Written informed consent was obtained from all subjects before the study.

Trial registration

Chinese Clinical Trials Registration (ChiCTR-IOP-16008045).

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Supplemental material

Supplemental material for this article is available online.

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