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ORIGINAL ARTICLE

Study on risk factors of carotid atherosclerosis in type 2 diabetes mellitus and development of prediction model

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Abstract

Background Diabetes mellitus is a metabolic disease, characterized by chronic hyperglycemia that increases the risk of cardiovascular and cerebrovascular diseases.

Objective The aim of this study was to investigate the risk factors of carotid atherosclerosis in patients with type 2 diabetes mellitus (T2DM), and establish an accurate and simple prediction model for its development.

Methods The data of 435 patients with T2DM were collected from September 2021 to March 2022 at the First People's Hospital of Linping District. The least absolute shrinkage and selection operator regression and stepwise backward regression were used to screen variables, and multivariate logistic regression analysis was performed to establish a nomogram prediction model.

Results The results showed that the risk factors of T2DM with carotid atherosclerosis included male sex, elderly age, long course of disease, hypertension, cerebral infarction, alcohol drinking, and high level of low-density lipoprotein cholesterol. The models showed good discrimination with an area under the receiver operating characteristic curve of 0.862 (95%CI: 0.827–0.898) and 0.871 (95%CI: 0.837–0.905) and a good calibration. The cutoff value of the net reclassification improvement was − 0.0134 (95%CI: − 0.0897 to 0.0496, $p = 0.703$), and the integrated discrimination improvement was − 0.0163 (95%CI: − 0.0291 to − 0.0036, $p = 0.012$), indicating that there is no significant difference in the accuracy of the two prediction models, but the prediction probability of model A is slightly worse than that of model B.

Conclusion Two prediction models were developed to assist with the early screening of carotid atherosclerosis in T2DM patients.

Keywords Type 2 diabetes mellitus · Carotid atherosclerosis · Prediction model · LASSO regression · Stepwise backward regression

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Introduction

Diabetes mellitus (DM) is a group of metabolic diseases caused by a variety of etiologies and mainly characterized by chronic hyperglycemia and insufficient insulin secretion or defective insulin action. Chronic carbohydrate, fat, and protein metabolic disorders can cause multi-system damage, leading to chronic progressive lesions, functional decline, and failure of tissues and organs, such as eyes, kidneys, nerves, heart, and blood vessels. Acute and severe metabolic disorders may occur when the disease is serious or stressful. In recent years, with the changes in lifestyle and diet, the number of patients with type 2 diabetes mellitus (T2DM) is increasing yearly, and China ranks first in the world in the number of T2DM patients [1]. Therefore, the health management of patients with T2DM and the early

treatment of diabetic complications are crucial to prevent permanent end-organ damage.

The ultimate outcome of T2DM is atherosclerotic cardiovascular and cerebrovascular diseases, including cardiovascular, cerebrovascular, and peripheral arterial lesions, which are the main cause of death in diabetic patients [2]. Both men and women with T2DM are two to four times more likely to develop cardiovascular and cerebrovascular diseases than non-T2DM patients [3–5]. The purpose of treating patients with T2DM is to reduce mortality and improve their quality of life. To reduce the mortality and disability rate of patients with T2DM, the prevention of atherosclerotic cardiovascular and cerebrovascular diseases should be addressed first. Atherosclerosis is the main cause of cardiovascular and cerebrovascular diseases. In addition, studies have shown that T2DM patients with carotid atherosclerosis may develop more severe atherosclerotic disease [6]. Therefore, it is of great significance to examine the risk factors of carotid atherosclerosis in patients with T2DM and to intervene in advance to reduce the incidence of cardiovascular and cerebrovascular diseases. Conducted on T2DM patients admitted to a Chinese district hospital, this study aims to explore the risk factors of carotid atherosclerosis in T2DM patients and establish prediction models.

Materials and methods

Study design

This cross-sectional study included 441 patients with T2DM who were admitted in the Department of Endocrinology at the First People's Hospital of Linping District (Hangzhou, China) between September 2021 and March 2022 and met the American Diabetes Association's diagnostic criteria for diabetes [7]. All patients underwent basic clinical examination, physical examination, laboratory examination, and carotid ultrasound examination. The exclusion criteria were as follows: age < 18 years; type 1 diabetes, gestational diabetes and other special types of diabetes; complicated with severe renal insufficiency (eGFR < 15 ml/min/1.73 m^2) or liver failure, history of malignant tumor, and history of mental disorder. Laboratory indicators of total bilirubin (TB), blood urea nitrogen (BUN), estimated glomerular filtration rate (eGFR), uric acid (UA), triglycerides (TGs), cholesterol (CHO), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and glycosylated hemoglobin (HbA1c) were measured for all patients during treatment in our hospital. Patients lacking data on any of these laboratory indicators were excluded. This study was reviewed and approved by the Ethics Committee of the First People's Hospital of Linping District, and all participants gave informed consent.

Data selection and measurements

We used a questionnaire survey method to collect the general information and clinical data of the research population, including (1) basic information of patients (sex, age, and course of diabetes); (2) previous medical history (hypertension, cerebral infarction, coronary heart disease, malignant tumor, chronic renal failure, chronic liver failure and mental disorder); (3) the history of smoking (defined as at least one cigarette a day or seven cigarettes a week in the past 6 months [8]) and the history of alcohol drinking (defined as at least 100 g alcohol consumption a week in the past 6 months [9]); (4) pregnancy history. The patient's height and weight were measured at admission, and the body mass index (BMI) was measured as follows: BMI = weight (kg)/height^2 (m^2). Laboratory indicators included TB, BUN, eGFR, UA, TG, CHO, HDL-C, LDL-C, and HbA1c. Venous blood was drawn from patients, after fasting for 8 h. Measurements of all laboratory indicators were performed in the Laboratory Department of the First People's Hospital of Linping District. All diabetic inpatients underwent carotid ultrasound examination at the Ultrasound Department of the First People's Hospital of Linping District. According to the classification of carotid arteries in the 2018 ESC/ESH Guidelines for Arterial Hypertension Management [10], the diagnosis was designated as normal, intima-media thickening, plaque, and lumen stenosis. High resolution B-mode ultrasound was used to measure the carotid intimal medial thickness (CIMT) at the bilateral common carotid arteries, the bifurcation of the carotid arteries and the beginning of the internal carotid arteries. The average values of a single point or multiple points were used. A CIMT > 0.9 mm was defined as intima-media thickening; A CIMT ≥ 1.5 mm, a local thickening of 0.5 mm, a thickening of 50% over the surrounding CIMT value were defined as plaque formation. Carotid intima-media thickening and/or plaque formation were defined as carotid atherosclerosis.

Statistical analysis

The SPSS 27.0 software (IBM Corporation, Armonk, NY, USA) and R software version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria) were used for statistical analysis and processing the data. The measured data conforming to normal distribution are represented as the mean ± standard deviation $\bar{x} \pm SD$, and the *t*-test was used for comparison between groups. The measured data of non-normal distribution are represented as M_d (P_{25}, P_{75}), and a non-parametric rank sum Mann–Whitney *U* test was used for comparison between groups. The recorded data

are represented as *n* (%), and the chi-square test was used for comparison between groups.

Two nomogram prediction models are established using least absolute shrinkage and selection operator (LASSO) regression analysis and backward stepwise regression analysis to screen variables, and evaluate their performance, respectively. First, both LASSO regression analysis [11] and backward stepwise regression analysis [12] were used to screen all independent variables. Multivariate logistic regression analysis was performed on the selected variables and after establishing the prediction models, the *P*-value, odds ratio (OR), and 95% confidence interval (CI) of the variables were analyzed. Then, the nomogram was drawn to visually display the model. The prediction models were evaluated mainly by three aspects: differentiation, calibration, and clinical net benefit. The receiver operating characteristic (ROC) curve and the area under the curve (AUC) were used to evaluate differentiation ability; the calibration curve, Hosmer–Lemeshow goodness of fit test, and Brier score test were used to evaluate the calibration ability; decision curve analysis (DCA) was used to evaluate the clinical effectiveness. The net reclassification improvement (NRI) and integrated discrimination improvement (IDI) were used to compare the two models. The NRI can be used to assess the accuracy of the prediction models, while the IDI reflects the change in the prediction probability gap between the two models. Ultimately, the models were evaluated by cross validation and bootstrap internal validation to ensure the stability of the models and make high-quality predictions for the population providing data sources, which could be applied to different populations. For all statistical tests, $p < 0.05$ was considered to be statistically significant.

Results

Characteristics of patients

This study included 441 patients with T2DM who were treated at our hospital from September 2021 to March 2022. Since one patient was younger than 18 years of age and three patients had severe renal insufficiency, 4 patients were eventually excluded from the study. In addition, since one patient lacked blood lipid data and one patient lacked glycosylated hemoglobin data, ultimately 435 patients were included in this study, consisting of 291 males and 144 females. The patients were divided into the T2DM with atherosclerosis group (261 patients) and T2DM without atherosclerosis group (174 patients) according to whether there was carotid atherosclerosis. All data of the two groups are shown in Table 1, including basic information, past history, and laboratory test indicators.

Establishment and illustration of the nomogram model

According to the demographic data, past history, and test indicators of the patients, 4 predictive variables with nonzero coefficients were screened from 18 variables using LASSO regression analysis, including age, course of disease, hypertension, and LDL-C (supplementary Fig. 1). Seven predictive variables, including sex, age, course of disease, hypertension, cerebral infarction, history of alcohol drinking, and LDL-C, were ultimately screened by backward stepwise regression analysis.

The variables screened by LASSO regression analysis and backward stepwise regression analysis were used to construct the logistic regression prediction models (model A and model B), respectively, and the results are shown in Table 2. Through the prediction model analysis, age (OR = 1.09), course of disease (OR = 1.01), and LDL-C (≥ 1.8, OR = 4.55) can be obtained in model A, and sex (male, OR = 1.87), age (OR = 1.10), course of disease (OR = 1.01), and LDL-C (≥ 1.8, OR = 4.99) can be obtained in model B, all of which were statistically significant. Although the *p* values of hypertension (model A: yes, OR = 1.69; model B: yes, OR = 1.62), cerebral infarction (yes, OR = 2.67), and the history of alcohol drinking (yes, OR = 1.75) in the multivariate logistic regression prediction model were higher than 0.05, considering their important clinical significance, these variables were still included in the model. Therefore, model A including 4 independent predictive variables (age, course of disease, hypertension, and LDL-C) and Model B including 7 independent predictive variables (sex, age, course of disease, hypertension, cerebral infarction, the history of alcohol drinking, and LDL-C) were ultimately developed, and nomograms were respectively drawn (Fig. 1).

Evaluation and validation of the models

The evaluation of the prediction models was mainly based on three aspects, namely discrimination, calibration, and clinical net income. By drawing a ROC curve to evaluate the discrimination of the models (supplementary Fig. 2), the AUC value of model A was 0.862 (95% CI: 0.827–0.898), and the AUC value of Model B was 0.871 (95% CI: 0.837–0.905), indicating that these two prediction models have good discrimination ability. The prediction models were evaluated for the Hosmer–Lemeshow goodness of fit, and the results showed that the *p* values of model A and model B were 0.110 and 0.233, respectively, and both *p* values were greater than 0.05, indicating that the prediction models had good fit and were effective. In addition, the Brier scores of model A and model B were 0.143 and 0.140, respectively (the lower the score, the better the calibration). Additionally, the calibration

Table 1 Demographic and clinical characteristics of the participants in the study

Characteristics	DM with atherosclerosis group ($n=261$)	DM without atherosclerosis group ($n=174$)	Total ($n=435$)	p value
Gender				0.074
Male	166 (63.6)	125 (71.8)	291 (66.9)	
Female	95 (36.4)	49 (28.2)	144 (33.1)	
Age, years	63 (54.4, 71.5)	43 (32, 55)	56 (44, 66)	< 0.001
Course of disease, months	120 (36, 180)	11 (1, 60)	60 (6, 120)	< 0.001
BMI, kg/m^2	24.49 (22.22, 26.66)	26.1 (23.15, 28.45)	25 (22.57, 27.47)	< 0.001
Hypertension				< 0.001
Yes	154 (59)	43 (24.7)	197 (45.3)	
No	107 (41)	131 (75.3)	238 (54.7)	
Cerebral infarction				< 0.001
Yes	31 (11.9)	3 (1.7)	34 (7.8)	
No	230 (88.1)	171 (98.3)	401 (92.2)	
Coronary heart disease				0.016
Yes	27 (10.3)	7 (4)	34 (7.8)	
No	234 (89.7)	167 (96)	401 (92.2)	
The history of smoking				0.716
Yes	96 (36.8)	67 (38.5)	163 (37.5)	
No	165 (63.2)	107 (61.5)	272 (62.5)	
The history of drinking				0.036
Yes	46 (17.6)	18 (10.3)	64 (14.7)	
No	215 (82.4)	156 (89.7)	371 (85.3)	
Total bilirubin, μmol/L				0.408
< 21	236 (90.4)	153 (87.9)	389 (89.4)	
≥ 21	25 (9.6)	21 (12.1)	46 (10.6)	
Blood urea nitrogen, mmol/L				< 0.001
< 7.6	202 (77.4)	159 (91.4)	361 (83)	
≥ 7.6	59 (22.6)	15 (8.6)	74 (17)	
Estimated glomerular filtration rate, mL/min				< 0.001
< 90	118 (45.2)	23 (13.2)	141 (32.4)	
≥ 90	143 (54.8)	151 (86.8)	294 (67.6)	
Uric acid, μmol/L				0.029
< 420	225 (86.2)	136 (78.2)	361 (83)	
≥ 420	36 (13.8)	38 (21.8)	74 (17)	
Triglyceride, mmol/L				0.003
< 1.7	126 (48.3)	59 (33.9)	185 (42.5)	
≥ 1.7	135 (51.7)	115 (66.1)	250 (57.5)	
Cholesterol, mmol/L				0.366
< 5.7	189 (72.4)	119 (68.4)	308 (70.8)	
≥ 5.7	72 (27.6)	55 (31.6)	127 (29.2)	
High-density lipoprotein cholesterol, mmol/L				0.032
< 1	96 (36.8)	82 (47.1)	178 (40.9)	
≥ 1	165 (63.2)	92 (52.9)	257 (59.1)	
Low-density lipoprotein cholesterol, mmol/L				0.007
< 1.8	27 (10.3)	34 (19.5)	61 (14)	
≥ 1.8	234 (89.7)	140 (80.5)	374 (86)	
Glycosylated hemoglobin, %				0.353
< 7	28 (10.7)	14 (8)	42 (9.7)	
≥ 7	233 (89.3)	160 (92)	393 (90.3)	

Values are presented as median (range), number (%)

Table 2 Prediction models established by logistic regression analysis

Variable	Predication models		
	β-coefficient	Odds ratio (95%CI)	p value
Model A			
Age, years	0.089	1.094 (1.069–1.120)	< 0.001
Course of disease, months	0.005	1.005 (1.001–1.009)	0.007
Hypertension			
No			
Yes	0.525	1.691 (0.990–2.891)	0.054
Low-density lipoprotein cholesterol, mmol/L			
< 1.8			
≥ 1.8	1.515	4.551 (2.239–9.502)	< 0.001
Model B			
Sex			
Female			
Male	0.627	1.873 (1.026–3.480)	0.044
Age, years	0.096	1.100 (1.074–1.130)	< 0.001
Course of disease, months	0.005	1.005 (1.001–1.009)	0.008
Hypertension			
No			
Yes	0.484	1.622 (0.931–2.827)	0.087
Cerebral infarction			
No			
Yes	0.980	2.665 (0.777–12.639)	0.157
The history of drinking			
No			
Yes	0.557	1.746 (0.831–3.772)	0.147
Low density lipoprotein cholesterol, mmol/L			
< 1.8			
≥ 1.8	1.607	4.989 (2.378–10.858)	< 0.001

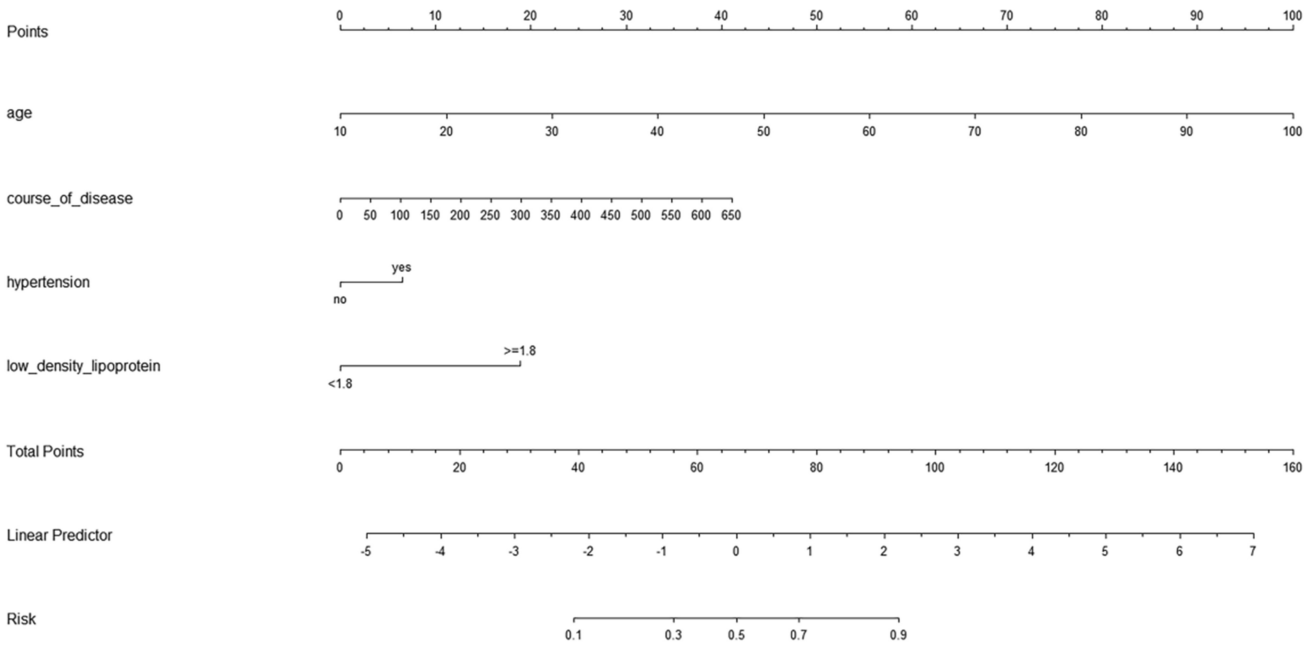
curves of the two models also indicated that the prediction models had good calibration ability (supplementary Fig. 3). Finally, the evaluation of the clinical effectiveness of the prediction models by DCA using the decision curve revealed that the net goodness of the two prediction models was significantly higher than that of the two extreme conditions, indicating good clinical feasibility (supplementary Fig. 4). The NRI and IDI of model A compared to model B were calculated, and the results showed that the cutoff value of the NRI was − 0.0134 (95%CI: − 0.0897 to 0.0496, $p = 0.703$), and the IDI was − 0.0163(95%CI: − 0.0291 to − 0.0036, $p = 0.012$), indicating that there was no significant difference in the accuracy of the two prediction models, but the prediction probability of model A was slightly worse than that of model B.

The verification of these prediction models was performed using two methods: cross verification and bootstrap internal verification. With 70% of the research objects as the training set and 30% as the verification set for cross-validation, the accuracy of Model A was 0.777 with a Kappa value of 0.525, and the accuracy of model B was 0.769 with a Kappa value of 0.512. In addition, the bootstrap internal verification method was used to verify the prediction model. The accuracy of model A and model B was 0.801 and 0.801, respectively, with Kappa values of 0.577 and 0.580, respectively. The results of the above two methods showed that model A and model B had good accuracy and moderate consistency.

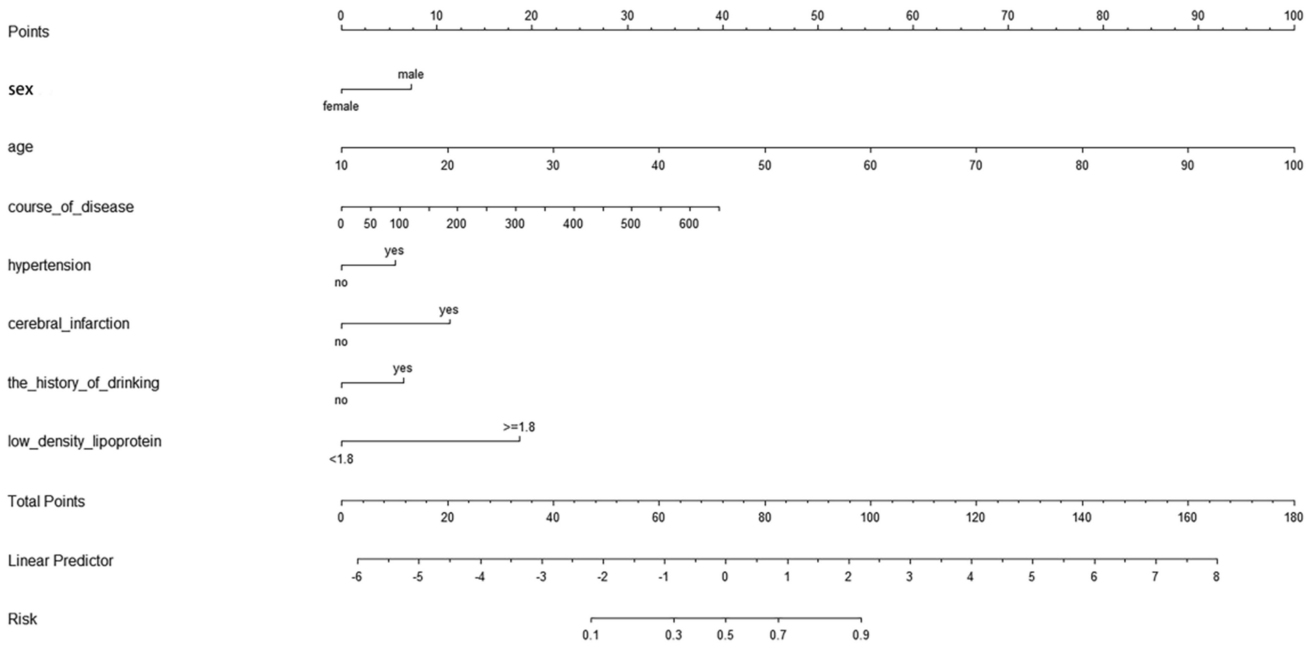
Discussion

At present, nomograms have been widely used in risk assessment of tumors and chronic diseases worldwide [13, 14]. The easy-to-understand image of the nomogram and the high accuracy of the prediction model allow clinicians to make better clinical decisions and facilitate the understanding of prognosis options. The traditional variable selection methods include forward stepwise regression and backward stepwise regression. The disadvantage of such traditional variable selection methods is that the variance of the model is generally relatively high and the flexibility is poor [12, 15]. The advantage of LASSO regression, which is the most related and widely used method, is that it makes the coefficient of the relatively unimportant independent variable become zero, thus excluding it from modeling. In addition, LASSO regression has the advantages of good stability, fast calculation speed, easy interpretation of the model, etc. [11, 15]. Therefore, in this study, the backward stepwise regression and LASSO regression were used to screen variables and establish prediction models, which were then implemented to compare the advantages and disadvantages of the two methods.

This study developed and validated the nomogram prediction models (model A and model B) to predict the risk of T2DM combined with carotid atherosclerosis. The predictive factors include sex, age, course of disease, hypertension, cerebral infarction, history of alcohol drinking, and LDL-C. Among them, age, course of disease, hypertension and LDL-C were all included in the two models. The results suggested that advanced age, male sex, long course of disease, history of hypertension, history of cerebral infarction, history of alcohol drinking, and high level of LDL-C were risk factors for T2DM patients with carotid atherosclerosis. The AUC values of the final nomogram for models A and B were 0.862 and 0.871, respectively, indicating a high prediction level. The calibration chart, Hosmer–Lemeshow goodness of fit, and Brier score showed good consistency between the actual diagnosis and predictive diagnosis, and the DCA showed good clinical effectiveness. There was no significant difference in the accuracy of the prediction model



A



B

Fig. 1 The nomograms of type 2 diabetes mellitus (T2DM) with carotid atherosclerosis based on model A and model B. **A** Model A: The model was developed by the LASSO regression method. The nomogram for T2DM with carotid atherosclerosis was constructed in the cohort by incorporating age, course of disease, hypertension and low-density lipoprotein cholesterol (LDL-C) level. **B** Model B: The model was developed by the backward stepwise regression method. The nomogram for T2DM with carotid atherosclerosis was constructed in the cohort by incorporating sex, age, course of disease, hypertension, cerebral infarction, history of alcohol drinking, and LDL-C level

between model A using LASSO regression to filter variables and model B using backward stepwise regression to filter variables, although the prediction probability of model A is slightly lower than that of Model B. Therefore, it seems that LASSO regression should not be blindly chosen for the selection of variables, but should be selected [15].

This study revealed that older patients were more likely to develop carotid atherosclerosis. The median age of T2DM patients with atherosclerosis was 63 years old, while the median age of those without atherosclerosis was 43 years old, suggesting that older age is a risk factor for the occurrence of atherosclerosis, which is consistent with the previous finding of Guo et al. [16]. In addition, Kulkarni et al. [17] found that carotid artery and femoral artery atherosclerosis markers in T2DM patients over 60 years old were higher than those in patients under 60 years old ($p < 0.05$). With age, blood vessels gradually undergo physiological degeneration, thereby greatly increasing the risk of cardiovascular and cerebrovascular diseases [18]. In addition, this study also found that the number of male patients with T2DM in the hospital was significantly higher than that of female patients, and male patients had a higher risk of carotid atherosclerosis than female patients. Male patients are more prone to atherosclerosis, which is related to genetic and endocrine factors, and males are more likely to have unhealthy living habits, such as alcohol drinking and smoking [19, 20]. Furthermore, the social, work, group, and other aspects of pressure borne by males will also lead to more atherosclerotic lesions in blood vessels [21, 22]. Instead, females have the protective effect of ovarian hormones before menopause; as a result, the risk of carotid atherosclerosis is lower than that in male, but the risk of carotid atherosclerosis after menopause is still higher than before [23, 24]. Accordingly, the results of this study suggested that compared with females, elderly males should pay more attention to the occurrence of carotid atherosclerosis in advance, and try their best to quit smoking and alcohol and improve their lifestyle.

Hypertension and atherosclerosis have many common risk factors and pathogenesis, and the two promote and cause each other, forming a vicious circle [25–27]. In this study, both LASSO regression and stepwise backward regression analyses found that T2DM patients with a history of hypertension had an increased risk of carotid atherosclerosis. In addition, the occurrence of cerebral infarction in diabetic patients also often indicates the presence of vascular lesions. Tongtian et al. [28] found that the risk of moderate to severe cerebral infarction in patients with carotid atherosclerotic plaques was 2.11 times higher than that in patients without carotid atherosclerotic plaques. Therefore, T2DM patients with previous cerebral infarction and/or hypertension should pay more attention to their own vascular diseases and be alert to the emergence of other cardiovascular and cerebrovascular diseases.

Smoking and alcohol drinking are two major risk factors for cardiovascular and cerebrovascular diseases, which often occur at the same time. This study found that alcohol drinking is also one of the risk factors for carotid atherosclerosis in patients with T2DM, but smoking history did not show good predictability between the two groups. Kianoushi et al. [29] found in their Brazilian longitudinal study of adult health that the thickness of the carotid intima-media and the inflammatory index of hypersensitive C-reactive protein in smokers were higher than those in non-smokers, and the amount of smoking was positively related to the amount of hypersensitive C-reactive protein and coronary artery calcification. Stein et al. [30] found that quitting smoking can reduce the progress of carotid plaque. Therefore, the effect of smoking on vascular disease is obvious, but our study did not show a significant difference, which may be due to the common smoking of middle-aged and elderly men in China and the small sample size of this study. In addition, a study of Mahajan et al. [31] suggesting that heavy drinking may be an independent risk factor for atherosclerosis. The research by Kim et al. also showed that there was a linear harmful relationship between alcohol consumption and atherosclerosis in males [32]. The above results were consistent with the results of this study, suggesting that alcohol consumption may have a promoting effect on the formation of atherosclerosis. However, the present study did not conduct a detailed grouping of alcohol consumption among drinkers, and there may be some deficiencies. In addition, a cross-sectional study conducted by Yan et al. found that metabolites of alcohol are associated with inflammation and oxidation, causing the development of cardiovascular diseases [33]. Thus, neither smoking cessation nor alcohol abstinence should be underestimated for people with T2DM.

In this study, LDL-C was a strong predictor of carotid atherosclerosis formation, which is consistent with findings in previous studies, and LDL-C has been considered a risk factor for cardiovascular and cerebrovascular diseases [34–36]. Thus, it is suggested that controlling the LDL level is an important factor in the prevention of carotid atherosclerosis. With either model A or model B, the probability of carotid atherosclerosis was significantly increased in T2DM patients with a long disease course. Hyperglycemia impairs endothelium-dependent vasodilation, leading to adverse changes in lipids and coagulation factors [37]. Also, chronic hyperglycemia can damage the kidneys. Persistent hyperglycemia can also cause irreversible adverse biological effects [38]. Therefore, for chronic T2DM patients, it is more important to pay attention to the vascular condition and advance the addition of pharmacological preventive treatment if necessary.

In addition, although the BMI is a parameter that affects CIMT, our study revealed that the BMI of T2DM patients with atherosclerosis was lower than that of T2DM patients without atherosclerosis. This may be due to several reasons:

(1) the metabolic disruption caused by the gradual onset of high blood sugar reduces the amount of fat stored for energy; (2) the patient took active weight loss measures in the early stage of T2DM and after being diagnosed with T2DM; (3) insulin is a hormone in the body that promotes anabolic metabolism and maintains weight. With the progression of the natural course of T2DM, the level of insulin secreted by beta cells decreases, leading to weight loss [39]. Therefore, the BMI was not included as a risk factor for T2DM patients with atherosclerosis in our prediction model when variables were screened by LASSO regression and backward stepwise regression.

Our study also had some additional limitations. Firstly, this study was a retrospective study that only included inpatients with T2DM as T2DM outpatients were not considered, and the sample size was small, so the cohort was not representative of all Chinese patients with T2DM. Secondly, the risk factors were not fully included, and other possible factors affecting the occurrence of carotid atherosclerosis in patients with T2DM were not considered, such as abdominal circumference, family history, etc. In addition, glucose-lowering regimens as well as other medications were not considered in patients with T2DM, which may have biased the results. T2DM patients with the same disease course were not compared, and there was a certain selection bias. Thirdly, although the nomogram constructed in this study had good accuracy and stability after internal verification by bootstrap, it has not been externally verified by other data, so it is impossible to determine whether this model is suitable for people in other regions and countries. In the future, our research group will further expand the sample size and include more comprehensive disease-related factors, and strive to establish a more comprehensive prediction model for the risk of carotid atherosclerosis in patients with T2DM.

Conclusion

In this study, two prediction models with relatively high accuracy were developed and validated using some simple and easily accessible indicators to help clinicians and patients understand the risk of carotid atherosclerosis in patients with T2DM in advance, so as to minimize the adverse health effects due to cardiovascular and cerebrovascular diseases in these patients and take early preventive measures when needed, such as smoking and alcohol drinking cessation, appropriate physical activity, and lipid control. However, there are still some additional disadvantages to this model, and it is necessary to expand the sample size and repeat external validation to demonstrate the value of this model. In the future, we plan to further refine this model to improve its accuracy and stability of prediction, so as to provide useful information for the prevention and control of cardiovascular and cerebrovascular diseases in patients with T2DM.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13410-024-01355-z.

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Author contribution XHC and JCS analyzed the data, drew the diagrams, and drafted the article. YLH and HHM performed data analysis and generated graphs. XHC and BL obtained the clinical data and revised the manuscript. XHC and ZHJ contributed to the design of the research and helped to write the manuscript. All authors read and approved the final manuscript.

Data availability The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

Declarations

Ethical approval This study was approved by Ethical Committee of The first People's Hospital of Linping District in Hangzhou, China. All research was performed in accordance with relevant guidelines. Informed consent was obtained from all participants and/or their legal guardians.

Conflict of interest The authors declare no conflicts of interest to disclose.

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