Diabetes, Metabolic Syndrome and Obesity

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ORIGINAL RESEARCH

Development and Validation of a Nomogram for Predicting Carotid Atherosclerosis in Non-Obese Patients with Type 2 Diabetes

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Purpose: To develop and validate an individualized risk prediction model for carotid atherosclerosis (CAS) in non-obese patients with type 2 diabetes mellitus (T2DM), addressing the need for a non-invasive and practical screening tool.

Patients and Methods: This retrospective study analyzed data from a cohort of 1014 non-obese T2DM patients (mean age: 58.65±11.95 years; 691 males and 323 females) enrolled between 2016 and 2025. We collected a comprehensive set of clinical variables, including demographics, body mass index (BMI), blood pressure, lipid profile, hepatic and renal function, and glycemic indicators. The population was randomly divided into a training set and an internal validation set. Feature selection was performed using univariate and multivariate logistic analysis to identify significant predictors. A nomogram was subsequently constructed based on these independent risk factors. The model's performance was rigorously evaluated by assessing its discriminative ability with the area under the receiver operating characteristic curve (AUC), its calibration with calibration plots, and its potential clinical net benefit with decision curve analysis (DCA).

Results: The final prediction model incorporated five key clinical variables: age, gender, systolic blood pressure, low-density lipoprotein cholesterol, and fasting blood glucose. The nomogram demonstrated strong and consistent performance, achieving AUC values of 0.828 in the training set and 0.824 in the validation set, indicating high discriminatory power. Calibration curves showed excellent agreement between predicted probabilities and actual observed outcomes. Furthermore, decision curve analysis confirmed the clinical utility of the model for a wide range of risk thresholds.

Conclusion: The validated nomogram provides a reliable and easily applicable tool for the early identification of CAS risk in non-obese individuals with T2DM. This model facilitates personalized risk assessment and supports clinical decision-making for targeted preventive strategies, potentially reducing the incidence of associated cardiovascular and cerebrovascular events.

Keywords: type 2 diabetes mellitus, carotid atherosclerosis, non-obese, nomogram

Introduction

As an escalating public health crisis, type 2 diabetes (T2DM) imposes a substantial and growing burden on healthcare systems worldwide. This trend is particularly evident in China, where rapid socioeconomic development and lifestyle changes have driven a dramatic increase in its prevalence.[1] By 2019, an estimated 116.4 million Chinese adults had diabetes, a number projected to reach 147.2 million by 2045. T2DM accounts for approximately 95% of these cases, a proportion significantly higher than the global average.[1] Although overweight and obesity are primary pathogenic factors for T2DM, a substantial proportion of individuals develop the disease without being overweight or obese, particularly in Asian populations, where this figure can reach up to 50%.[2] Non-obese individuals often develop T2DM through distinct pathophysiological mechanisms,

Received: 10 October 2025
Accepted: 28 November 2025
Published: 16 December 2025

including earlier and more severe impairment of insulin secretion.[3] Atherosclerotic cardiovascular disease (ASCVD) remains the leading cause of mortality and morbidity in T2DM patients.[4] It underlies various cardiovascular and cerebrovascular disorders, such as coronary heart disease and stroke.[5] In T2DM, chronic hyperglycemia promotes ASCVD through multiple mechanisms, including the formation of advanced glycation end products, oxidative stress, protein kinase C activation, and chronic vascular inflammation.[6] Consequently, individuals with T2DM face a 2- to 3-fold higher risk of cardiovascular disease and related mortality compared to non-diabetics,[7] leading specialists to regard T2DM as an ASCVD risk equivalent. Early identification and prevention of ASCVD in T2DM patients are therefore crucial for improving quality of life, reducing premature mortality, and alleviating healthcare costs.[8]

Carotid atherosclerosis (CAS), as one of the earliest detectable manifestations of systemic atherosclerosis, provides a critical window into overall vascular health.[9] The assessment of carotid atherosclerosis presence and extent, which involves identifying arterial plaque, predicts and classifies an individual's cardiovascular risk, even in apparently healthy individuals.[10,11] In T2DM patients, CAS has also been shown to be an independent predictor of cardiovascular disease risk.[12] However, the majority of studies on the development and progression of diabetic vascular complications have been conducted in obese patients with T2DM. Although obesity is a well-established risk factor for atherosclerosis, CAS is also common in non-obese individuals with T2DM. In a Korean cohort of adults with T2DM, approximately 50% of non-obese patients had carotid plaque, and their mean and maximum carotid intima-media thickness (cIMT) values were comparable to those of obese participants.[13] These findings indicate that the risk of CAS remains substantial in diabetic populations even in the absence of obesity. Notably, CAS often begins early in life and can remain asymptomatic for decades, underscoring the importance of early risk factor identification for timely diagnosis and intervention.[14] Besides hyperglycemia, factors significantly associated with CAS include age, male sex, smoking history, hyperhomocysteinemia, dyslipidemia, hyperuricemia, hypertension, and metabolic syndrome.[9,15] While several clinical models have been developed to predict CAS risk based on these factors,[14,16] the complex formulas hindered their practical application and ease of use in clinical settings. Moreover, there is a lack of models tailored specifically to T2DM patients, particularly those who are non-obese. In clinical practice, CAS risk in non-obese T2DM patients is frequently underestimated, resulting in missed early interventions. To date, no study has focused specifically on building a CAS risk prediction model for non-obese T2DM patients.

Nomograms are visual tools that integrate multiple predictors to simplify the estimation of clinical outcomes.[17] By translating specific variables into a graphical scoring system, a nomogram can offer an intuitive and efficient method for assessing the risk of CAS, while also illustrating how variations in risk factors influence disease probability.[18,19] Against this background, the current study seeks to construct a non-invasive, nomogram-based model for quantitatively predicting the risk of CAS in non-obese (BMI<25kg/m^2) individuals with T2DM. While BMI serves as a practical and widely adopted criterion in the assessment of obesity, it is recognized that it does not fully capture body fat distribution, a limitation we will address in the discussion.

Material and Methods

Research Design and Participants

This retrospective cross-sectional study enrolled non-obese adults with type 2 diabetes from the Department of Endocrinology at Qilu Hospital of Shandong University Dezhou Hospital between 2016 and 2025. The inclusion criteria were as follows: (1). Age ≥ 18 years; (2). Body mass index (BMI) < 25 kg/m^2; (3). A confirmed diagnosis of type 2 diabetes mellitus according to the American Diabetes Association (ADA) criteria;[20] (4). Availability of complete clinical and laboratory data required for the analysis. The exclusion criteria were as follows: (1) Acute diabetic complications, such as diabetic ketoacidosis or hyperosmolar hyperglycemic state; (2) Severe heart failure (NYHA class III or IV), severe hepatic impairment (Child-Pugh class C), or severe renal dysfunction (estimated glomerular filtration rate < 30 mL/min/1.73m^2); (3) Active infections, trauma, malignant tumors, or pregnancy; (4) Prior diagnosis of stroke, coronary heart disease, myocardial infarction, or arteritis. After screening, a total of 1,014 patients were included in the final analysis. The study protocol received approval from the Institutional Ethics Review Board of Qilu Hospital of Shandong University Dezhou Hospital (ethical approval number: 2025099), and was conducted in accordance with the principles of the Declaration of Helsinki. Informed consent was obtained from all participants.

Physical and Laboratory Examinations

Data on demographic, anthropometric, and laboratory parameters were systematically collected for all participants. Demographic information, including age and sex, was carefully documented. Following standardized protocols, height and weight were measured to calculate the body mass index (BMI, kg/m^2), and systolic and diastolic blood pressure (SBP/DBP) were recorded from the right arm after a 10-minute seated rest. After an overnight fast of at least 8 hours, venous blood samples were collected for biochemical analysis. A suite of serological parameters was quantified using a Hitachi 7600 automated biochemical analyzer (Tokyo, Japan), in accordance with methods endorsed by the International Federation of Clinical Chemistry and Laboratory Medicine (IFCC). The measured biomarkers included alanine aminotransferase (ALT), aspartate aminotransferase (AST), gamma-glutamyl transferase (GGT), total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides (TG), fasting blood glucose (FBG), creatinine (Cr), blood urea nitrogen (BUN), and serum uric acid (SUA). All clinical data were sourced from the hospital's electronic medical record system. The selection of these variables was based on their established clinical relevance. Rigorous quality control procedures were implemented throughout the data collection process to ensure accuracy and consistency.

Assessment of Carotid Atherosclerosis

Carotid ultrasonography was performed by trained sonographers using high-resolution ultrasound systems equipped with linear array transducers. The protocol involved a comprehensive scan of the near and far walls of the bilateral common carotid artery, bulb, and internal and external carotid arteries. According to the Mannheim Consensus,[21] carotid atherosclerosis was defined by the presence of either atherosclerotic plaque or a significantly increased intima-media thickness (cIMT). A plaque was identified as a focal structure encroaching into the arterial lumen by at least 0.5 mm, or 50% of the surrounding cIMT value, or having a thickness >1.5 mm measured from the media-adventitia interface to the intima-lumen interface. To ensure diagnostic consistency, all ultrasound images were independently interpreted by two physicians using a standardized protocol.

Statistical Analysis

All analyses were performed with SPSS (version 21.0; IBM Corp., USA) and R software (v. 4.3.2; R Foundation for Statistical Computing). The participants were randomly split into a training set (70%) and a validation set 30%) with the createDataPartition function (caret package). Normality of continuous variables was evaluated using the Kolmogorov–Smirnov test. The normally distributed variables were expressed as mean ± SD and non-normally distributed variables as median (IQR). The qualitative variables were presented by frequency and percentage. Group comparisons were made using independent samples *t*-tests (normal data), Man-Whitney *U*-tests (non-normal data), and chi-square tests (categorical data). Univariate and multivariate logistic regression analyses were performed to identify independent risk factors associated with CAS. Variables with $P < 0.05$ in univariate logistic regression were introduced into a multivariate model. A nomogram was constructed based on the final predictors using the R rms package. The model underwent internal validation within the training set and external validation in the validation set. Discriminatory ability was assessed using the area under the receiver operating characteristic (ROC) curve (AUC), with AUC > 0.70 indicating satisfactory performance. Calibration curves were generated to evaluate prediction accuracy, and decision curve analysis (DCA) was applied to examine clinical utility. A two-sided p-value < 0.05 was considered statistically significant.

Results

Characteristics of the Research Participants

The characteristics of the study participants are presented in Table 1. A total of 1,014 patients were included and randomized into a training set (n=710) and a validation set (n=304). The overall cohort had a mean age of 58.65± 11.95 years, was 68.1% male, and had a CAS prevalence of 59.7%. The baseline characteristics, including age, gender, BMI, blood pressure (SBP, DBP), liver enzymes (ALT, AST, GGT), lipid profiles (TC, TG, LDL-C, HDL-C), FBG, and renal function markers (Cr, SUN, SUA), were comparable between the training and validation sets, with no statistically significant differences observed (Table 1). The prevalence of CAS was also well-balanced between the two sets (60.1% vs 58.6%).

Table 1 Clinical and Biochemical Characteristics of Study Participants and the Comparisons of Factors Between Training and Validation Datasets

General Indexes	All Patients (n=1014)	Training Dataset (n=710)	Validation Dataset (n=304)	*P* Value
Gender, male (%)	691 (68.1%)	481 (67.7%)	210 (69.1%)	0.713
Age (yr)	58.65±11.95	58.72±11.56	58.48±12.83	0.768
BMI (kg/m2)	23.4 (22.22–24.28)	23.35 (22.19–24.29)	23.54 (22.31–24.24)	0.497
SBP (mmHg)	135.75±19.38	135.72±19.78	135.81±18.46	0.947
DBP (mmHg)	80.04±11.20	79.76±11.13	80.70±11.36	0.220
ALT (IU/L)	19 (14–26)	19 (14–26)	18 (14–25)	0.244
AST (IU/L)	21 (18–26)	22 (18–26)	21 (18–25)	0.539
GGT (IU/L)	24 (18–35)	24 (18–33)	24 (18–38.75)	0.32
TC (mmol/L)	5.22±1.19	5.25±1.18	5.16±1.23	0.25
TG (mmol/L)	1.39 (1.0–2.04)	1.41 (1.01–2.1)	1.37 (1.0–1.94)	0.533
HDL-C (mmol/L)	1.38±0.33	1.39±0.34	1.37±0.31	0.331
LDL-C (mmol/L)	3.26±0.80	3.29±0.82	3.20±0.77	0.959
FBG (mmol/L)	8.3 (7.5–9.8)	8.4 (7.6–9.9)	8.3 (7.4–9.6)	0.1
BUN (mmol/L)	5.59±1.48	5.60±1.52	5.58±1.38	0.811
Cr (umol/L)	65.81±15.54	65.29±15.08	67.0±16.53	0.109
SUA (umol/L)	325.37±85.30	324.35±84.48	327.76±87.28	0.56
CAS (%)	605 (59.7%)	427 (60.1%)	178 (58.6%)	0.657

Abbreviations: BMI, body mass index; SBP, systolic pressure; DBP, diastolic pressure; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, γ-glutaryl transferase; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; FBG, fasting blood glucose; BUN, blood urea nitrogen; Cr, creatinine; SUA, serum uric acid; CAS, carotid atherosclerosis.

Identification of Independent Predictors for CAS

Univariate logistic regression analysis identified several factors significantly associated with CAS (Table 2), including older age, male sex, and higher levels of SBP, TC, LDL-C, FBG, and Cr (all $P < 0.05$). These significant variables from

Table 2 Univariate and Multivariate Analysis for the Prediction of CAS

Variables	Univariate Logistic Regression Analysis			Multivariate Logistic Regression Analysis		
	OR	95% CI	*p*	OR	95% CI	*p*
Gender (male/female)	1.69	1.228–2.326	0.002*	2.852	1.762–4.616	<0.001*
Age (yr)	1.104	1.083–1.124	<0.001*	1.118	1.093–1.143	<0.001*
BMI (kg/m2)	0.991	0.905–1.086	0.853			
SBP (mmHg)	1.036	1.027–1.046	<0.001*	1.02	1.009–1.031	<0.001*
DBP (mmHg)	1.013	0.999–1.027	0.071			
ALT (IU/L)	1.003	0.994–1.012	0.474			
AST (IU/L)	1.016	0.998–1.035	0.084			
GGT (IU/L)	1.001	0.997–1.004	0.635			
TC (mmol/L)	1.476	1.281–1.702	<0.001*			
TG (mmol/L)	1.021	0.93–1.119	0.668			
HDL-C (mmol/L)	1.177	0.754–1.837	0.473			
LDL-C (mmol/L)	1.787	1.456–2.194	<0.001*	2.443	1.412–4.227	0.001*
FBG (mmol/L)	1.115	1.045–1.189	0.001*	1.163	1.074–1.259	<0.001*
BUN (mmol/L)	1.099	0.992–1.217	0.07			
Cr (umol/L)	1.017	1.006–1.028	0.002*			
SUA (umol/L)	1.002	1.000–1.003	0.097			

*$P<0.05$ was considered a statistically significant difference.

Abbreviations: BMI, body mass index; SBP, systolic pressure; DBP, diastolic pressure; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, γ-glutaryl transferase; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; FBG, fasting blood glucose; BUN, blood urea nitrogen; Cr, creatinine; SUA, serum uric acid.

the univariate analysis were subsequently entered into a multivariate logistic regression model. The final model established five independent predictors of CAS: age, male sex, SBP, LDL-C, and FBG (Table 2).

Construction of the Nomogram

Based on the results of the multivariate logistic regression, a nomogram was constructed to visualize the model and facilitate individualized prediction of CAS probability in non-obese T2DM patients (Figure 1). The nomogram assigns a points scale to each of the five independent predictors. To estimate an individual's risk, a vertical line is drawn from each variable value to the "Points" axis to obtain the corresponding score. The sum of these scores corresponds to a total points value, which is then projected down to the "Risk of CAS" axis to obtain the predicted probability. As an illustration, for a 55-year-old male with an SBP of 150 mmHg, LDL-C of 4.5 mmol/L, and FBG of 10 mmol/L, the nomogram predicts a CAS probability of approximately 80%.

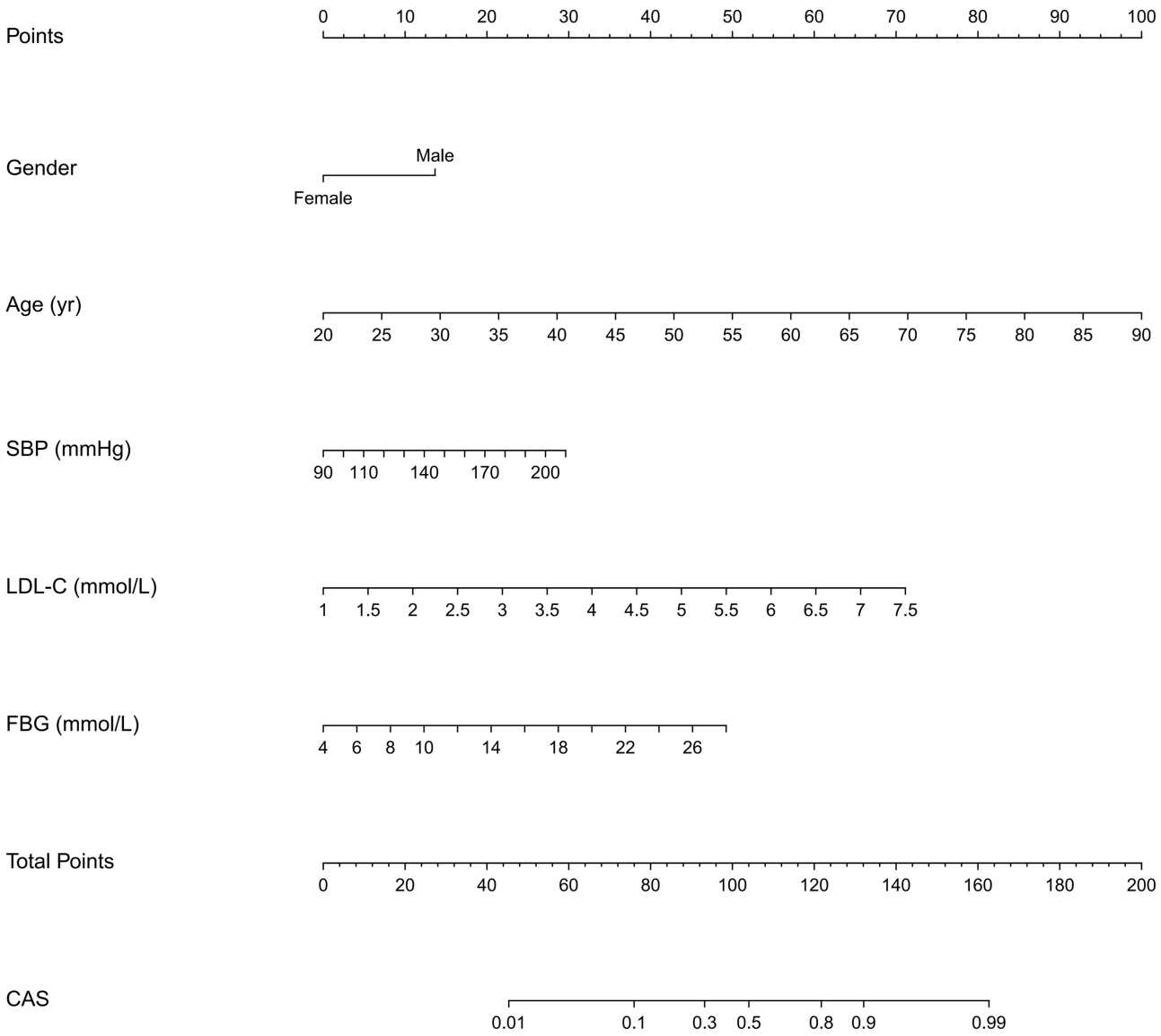

Figure 1 Nomogram for predicting the presence of carotid atherosclerosis (CAS) in the training cohort. The nomogram incorporates five predictors: gender, age, systolic pressure (SBP), low-density lipoprotein cholesterol (LDL-C), and fasting blood glucose (FBG).

https://doi.org/10.2147/DMSO.S572295

Performance Evaluation of the Nomogram

The performance of the constructed nomogram was rigorously evaluated in both the training and validation cohorts. Receiver operating characteristic (ROC) analysis demonstrated strong discriminative ability, with area under the curve (AUC) values of 0.828 (95% CI: 0.796–0.859) in the development set (Figure 2A) and 0.824 (95% CI: 0.778–0.870) in the validation set (Figure 2B). Corresponding cut-off, sensitivity and specificity were 0.537, 0.820 and 0.721 for the development cohort (Figure 2A), and 0.505, 0.803 and 0.706 for the validation cohort (Figure 2B), indicating consistent performance. Calibration curves revealed close alignment with the ideal 45° line in both development cohort (Figure 3A)

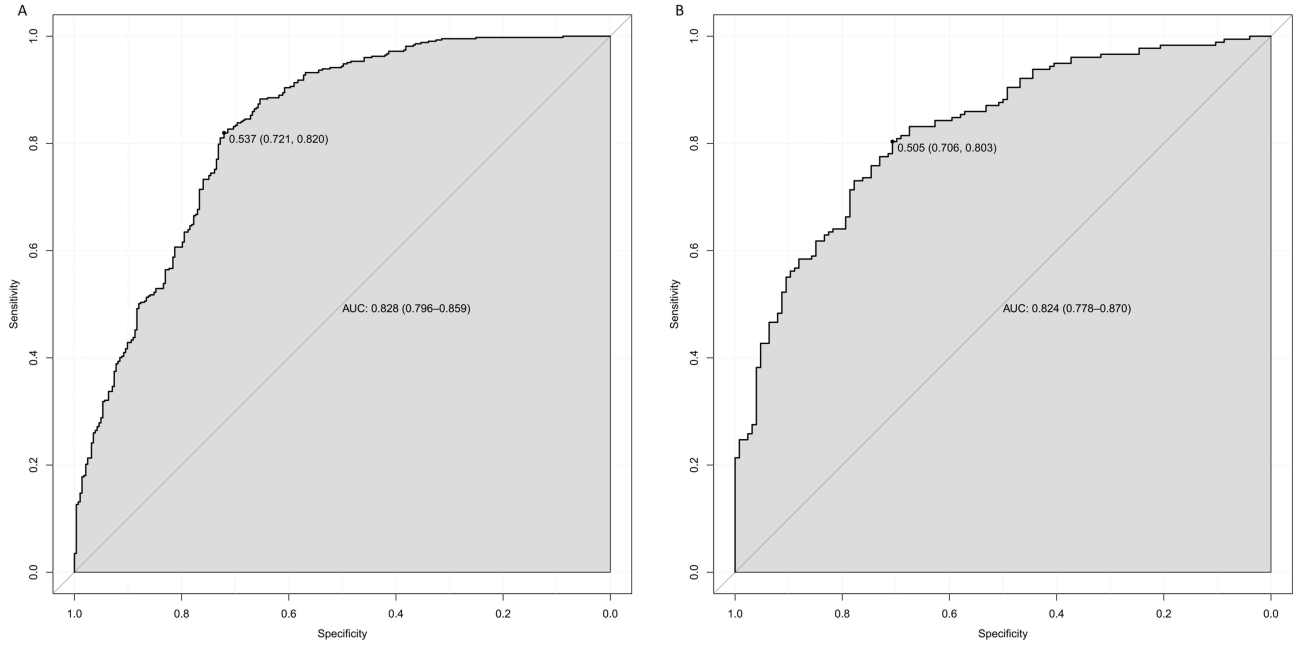

Figure 2 Receiver operating characteristic (ROC) curves of the nomogram. (**A**) The ROC curve for the training group. The area under the curve (AUC) value is 0.828 (0.796–0.859). (**B**) The ROC curve for the validation group. The AUC value is 0.824 (0.778–0.870).

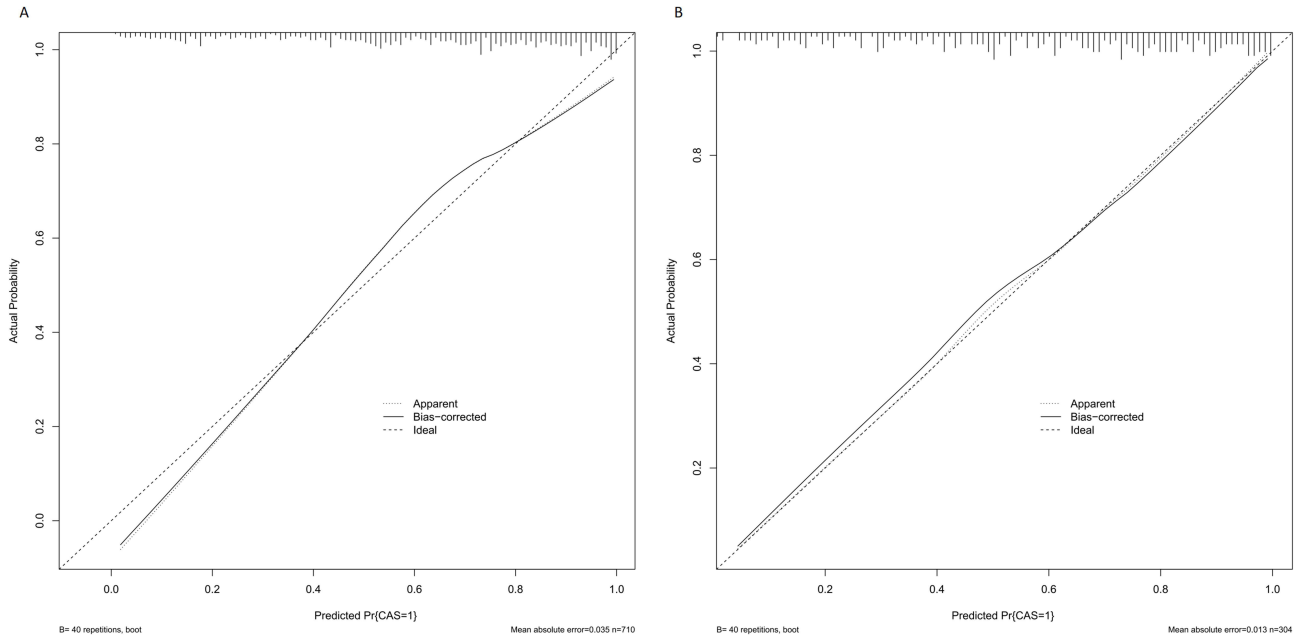

Figure 3 Calibration curves of the nomogram. (**A**) The calibration plot for the training group. (**B**) The calibration plot for the validation group. The plots compare the predicted probability of CAS (x-axis) with the observed frequency (y-axis). The solid line represents the model's performance, while the diagonal dotted line represents ideal calibration.

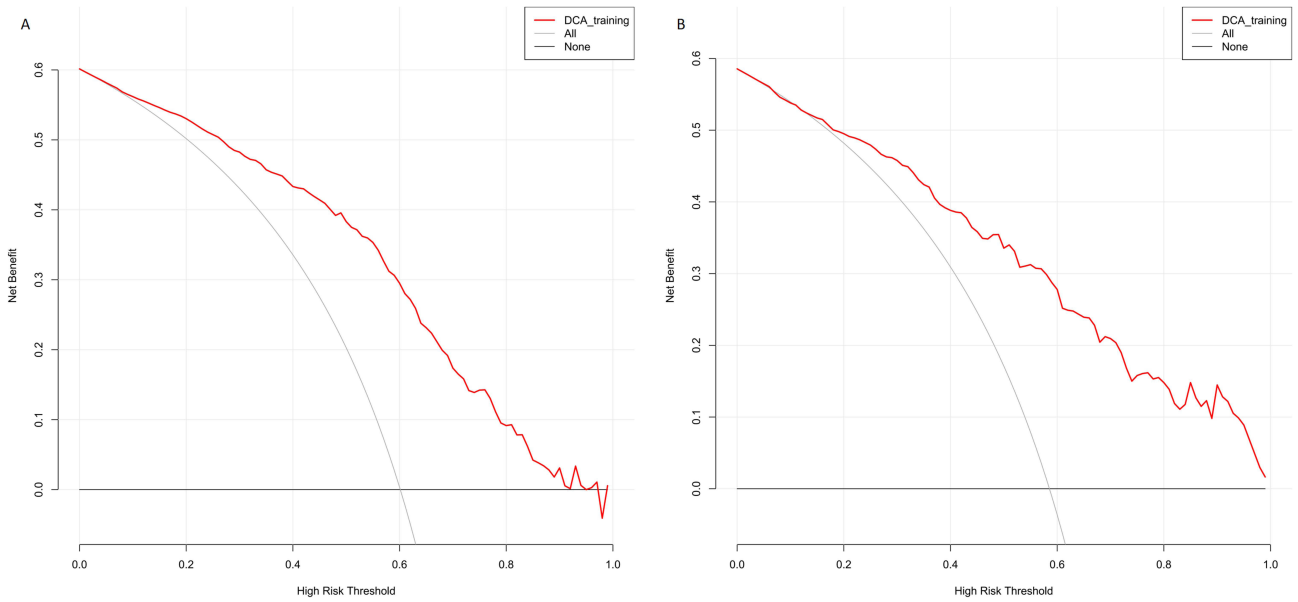

Figure 4 Decision curve analysis (DCA) for the nomogram. (**A**) The DCA for the training group. (**B**) The DCA for the validation group. The model (red solid line) is compared against the strategies of assuming no patients have CAS ("None", gray solid line) and assuming all patients have CAS ("All", black solid line). The model demonstrates clinical utility where its net benefit exceeds that of the "None" and "All" strategies.

and validation cohort (Figure 3B), reflecting excellent agreement between predicted probabilities and observed outcomes. Furthermore, decision curve analysis (DCA) indicated that the nomogram provided a superior net benefit across a wide range of clinically relevant risk thresholds in both development set (Figure 4A) and validation set (Figure 4B), supporting its practical utility and generalizability for clinical risk stratification.

Discussion

This study developed and validated a novel nomogram for predicting carotid atherosclerosis disease risk in non-obese individuals with type 2 diabetes mellitus. Multivariate logistic regression identified five independent predictors, including age, male sex, systolic blood pressure, low-density lipoprotein cholesterol, and fasting plasma glucose, that were incorporated into the model. The nomogram showed strong discriminative performance (AUC > 0.8), good calibration, and positive net clinical benefit on decision curve analysis (DCA), supporting its potential utility for risk stratification in this cohort.

Atherosclerosis (AS), characterized by arterial plaque accumulation, is the primary driver of cardiovascular complications, which constitute the leading cause of mortality and disability in patients with T2DM.[22,23] The metabolic disturbances in diabetes promote the onset and progression of AS by inducing endothelial injury and dysfunction.[24] While obesity is a major risk factor for CVD,[25] studies indicate that non-obese individuals with T2DM face a moderately higher rate of CVD mortality than their obese counterparts.[26] Consequently, identifying non-obese T2DM patients at high risk of AS is critical for primary prevention, as this group might otherwise be overlooked. Carotid atherosclerosis, a recognized marker of subclinical AS, closely reflects the systemic disease burden and is a strong predictor of future cardiovascular events.[27,28] While there is growing interest in identifying risk factors and developing screening models for carotid atherosclerosis in T2DM,[29,30] no study to date has been specifically designed for non-obese T2DM patients.

Accelerated CAS in diabetes is considered a consequence of the combined effect of traditional risk factors, including advanced age, male sex, smoking, hypertension, hyperglycemia, increased BMI, and dyslipidemia, although the relative contribution of each factor differs across studies.[31–34] Our study also demonstrated that, after adjustment for multiple confounders, age, male sex, SBP, LDL-C, and FBG were independently associated with an increased risk of CAS in patients with T2DM. The role of advanced age as a risk factor for CAS is well established.[29] A progressive increase in the prevalence of increased carotid intima-media thickness, carotid plaque, and carotid stenosis is observed with advancing age.[9] In addition, studies have reported a significantly higher prevalence of CAS in men than in women,[35]

https://doi.org/10.2147/DMSO.S572295

and male sex is considered one of the main risk factors for carotid plaque formation in T2DM subjects.[24] Blood pressure is a major determinant of CAS onset and progression. A Japanese study demonstrated a positive correlation between mean systolic blood pressure and carotid intima-media thickness.[36] This is corroborated by data from a Chinese population, which showed a 1.1% increase in CAS risk for every 1-mmHg rise in SBP.[37] The underlying mechanism is primarily attributed to impaired vascular endothelial function, wherein the mechanical stress from elevated pressure directly damages endothelial cells.[38] Lipid accumulation in the arterial wall represents a key event in the complex pathogenesis of atherosclerosis.[39] Circulating LDL-C is currently recognized as the major source of intracellular lipid accumulation in plaques.[40] High LDL-C levels are significantly related to the prevalence and severity of CAS[41,42] and remain the primary lipid target for preventing CVD in patients with T2DM.[43] Moreover, emerging evidence from histological studies indicates that other atherogenic lipid components, particularly elevated remnant cholesterol and triglycerides, work synergistically with LDL-C to significantly increase the risk of carotid plaque instability and thrombosis, underscoring the need for a comprehensive approach to lipid management.[44] Chronic hyperglycemia induces the formation of advanced glycation end products, leading to vascular endothelial damage and decreased arterial wall elasticity.[6] Furthermore, it can induce oxidative stress and inflammation, which form the pathological basis of AS.[45] Previous studies have shown that elevated fasting glucose levels are significantly associated with carotid artery stenosis and increase susceptibility to CAS.[46,47] These included predictive factors are easily measurable through routine tests, making them accessible without the need for costly procedures.

The nomogram model is a reliable statistical tool that uses an intuitive graphical representation to provide a simple interpretation of risk models.[17] It has been widely used in predicting cardiovascular disease and have demonstrated favorable performance. Xiao et al[48] developed a reliable nomogram to assess CVD risk in patients with prediabetes, which showed robust predictive accuracy and provided a simple yet individualized risk estimation tool. In another study, Huang et al[19] constructed a nomogram that aids in the early identification and prevention of carotid artery stenosis in the general population. Currently, few studies have evaluated the diagnostic accuracy of nomograms for detecting CAS in patients with T2DM. To our knowledge, only Feng et al[30] have developed one nomogram, based on age, non-alcoholic fatty liver disease (NAFLD), smoking status, HDL-C, and LDL-C in a T2DM cohort. However, this model is not specifically designed for non-obese T2DM patients, and thus does not account for their unique clinical characteristics. We developed the first nomogram describing CAS risk factors in non-obese patients with T2DM. Our nomogram exhibited excellent discriminative power for predicting CAS risk, reflected by a high AUC value, along with substantial sensitivity and specificity. Calibration and decision curve analysis confirmed that the model is well calibrated and possesses notable clinical utility. Consistent performance was observed across both training and validation cohorts, highlighting the strong clinical applicability. Furthermore, a clinical cut-off value was established to assist clinicians in efficiently and promptly identifying high-risk patients in real-world practice.

Compared to other clinical models, the key advantage of the nomogram lies in its user-friendly interface. It allows clinicians to estimate individualized risk probabilities by plotting patient-specific variables on its scales, eliminating the need for complicated calculations. This intuitive design facilitates efficient, interpretable, and informed decision-making at the point of care. Furthermore, by incorporating readily available clinical indicators into a simple scoring system, the nomogram enables a wide range of healthcare providers across primary, secondary, and tertiary care settings, including non-specialists and researchers, to identify and manage high-risk patients early. Additionally, it can serve as a visual aid for patient education, helping them understand and monitor key metabolic factors, which may contribute to reducing cardiovascular risk. Finally, our nomogram integrates multiple traditional risk factors, enhancing its ability to capture the multifactorial nature of cardiovascular disease and thus addressing the limitations of single-predictor models. It is important to emphasize that, in clinical practice, this nomogram is intended as a risk stratification tool to identify patients at high risk of CAS and guide clinical decision-making, rather than as a standalone diagnostic instrument. In the future, this model could be integrated into large-scale primary care screening programs and deployed as a web- or mobile-based calculator within digital health platforms, enabling rapid point-of-care risk assessment and facilitating targeted interventions.

Despite its strengths, this study has several limitations. First, the cross-sectional nature of the dataset precludes the establishment of causal relationships. Second, the sample was drawn from a single center, and the model was only validated internally. The lack of external validation with cohorts from diverse countries and ethnic backgrounds limits the generalizability of our findings. Additionally, some key variables, such as dietary habits, physical activity, insulin

resistance indices such as HOMA-IR, smoking status, other anthropometric measures, and a comprehensive assessment of rheumatological diseases (eg, systemic lupus erythematosus, rheumatoid arthritis) that could cause early atherosclerosis were absent. These factors may have led to unmeasured confounding. Finally, the reliance on BMI for defining non-obesity, to the exclusion of adiposity distribution measures like waist circumference, may have led to the misclassification of some individuals with normal-weight obesity. Future prospective studies with larger, multicenter cohorts that incorporate these additional risk factors are needed to improve the reliability and applicability of the nomogram.

Conclusions

In conclusion, this is the first validated predictive model for CAS in non-obese diabetic patients, a population often neglected in risk prediction research. This model, which integrates readily available clinical parameters including age, gender, SBP, LDL-C, and FBG, demonstrates good discrimination and calibration. It represents a practical tool for the early identifying of high-risk individuals in clinical settings. To advance this research, the critical next steps include external validation of the model in diverse populations and its exploration for integration into clinical decision-support systems to assess real-world impact.

Abbreviations

T2DM, type 2 diabetes mellitus; CAS, carotid atherosclerosis; ROC, receiver operating characteristic; DCA, decision curve analysis; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, γ-glutaryl transferase; TC, total cholesterol; TG, triglycerides; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; FBG, fasting blood glucose; BUN, blood urea nitrogen; Cr, creatinine; SUA, serum uric acid.

Data Sharing Statement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Informed Consent

The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki (6th revision, 2008) as reflected in a priori approval by the ethics committees of Qilu Hospital of Shandong University Dezhou Hospital (ethical approval number: 2025099). Written informed consent was provided by each participant.

Consent for Publication

Informed consent for publication was obtained from each participant included in the study.

Acknowledgments

The authors would be grateful for language services by Duoease Scientific Service Center.

Author Contributions

Yuliang Cui - Methodology, Formal analysis, Writing – original draft; Lingling Li - Resources, Software, Writing – review and editing; Ying Li - Investigation, Data curation, Writing – review and editing; Pei Yu - Conceptualization, Project administration, Supervision, Validation, Writing – review and editing, Funding acquisition. All authors gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

This article was founded by the National Key Research and Development Program of China [grant numbers 2024YFC3607400]; the Tianjin Institute of Urology talent funding program [grant numbers MYSRC2024]; the First Level Leading Talent Project of 123 Climbing Plan for Clinical Talents of Tianjin Medical University; the Tianjin Medical Talents project, the second batch of

high-level talents selection project in health industry in Tianjin [grant numbers TJSJMYXYC-D2-014]; the Key Project of Natural Science Foundation of Tianjin, [grant numbers 22JCZDJC00590] and the Tianjin Key Medical Discipline (Specialty) Construct Project [grant numbers TJYXZDXK-032A].

Disclosure

The author(s) report no conflicts of interest in this work.

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