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Identification of specific risk factors and predictive analytics for cardio-cerebral arterial stenosis: a comparative study utilizing framingham risk stratification insights

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Abstract

Atherosclerotic diseases are systemic, and stroke patients often present with both intracranial artery stenosis (ICAS) and coronary artery stenosis (COAS). This study aimed to investigate the prevalence of ICAS and COAS among ischemic stroke patients across different risk strata and to construct a predictive model for assessing atherosclerosis risk. This retrospective study included patients admitted for ischemic stroke at the Affiliated Hospital of Xuzhou Medical University from December 2020 to December 2021. All patients underwent CTA, with significant stenosis defined as exceeding 50% for both cerebral and coronary arteries.Patients were categorized into low-, moderate-, and high-risk groups on the basis of the Framingham risk scale. A total of 5,816 patients were included, with a mean age of 66.54 years. Dual arterial stenosis was found in 2,258 patients (38.8%), single ICAS in 399 (6.8%), and single COAS in 3,159 (54.3%). The moderate- and high-risk groups had significantly lower risks of single ICAS and COAS. Comparing the differences in risk factors between single arterial stenosis and dual arterial stenosis, the key risk factors included hyperlipidemia, smoking, hypertension, and diabetes, with a model accuracy of 73.61% and an AUC values of 0.8562 for dual stenosis. Significant differences in age, sex, and the risk factors were observed among risk groups. The predictive model demonstrated high accuracy, highlighting the importance of personalized medicine in clinical decision-making.

Keywords Atherosclerosis, Intracranial artery stenosis, Coronary artery stenosis, Framingham Stroke Scale, Risk factor stratification, Dual artery stenosis

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1. Introduction

Stroke represents a significant public health challenge characterized by high rates of incidence, recurrence, and associated mortality and disability [1]. Currently, specific treatments for stroke are limited, making early prevention particularly crucial. Risk assessment tools can help identify high-risk populations, and the Framingham Stroke Scale serves as a straightforward assessment instrument that effectively predicts stroke risk [2]. Intracranial artery stenosis (ICAS) is a prevalent cause of stroke, especially among Asian, Hispanic, and African-American populations. Patients with ICAS face a heightened risk of recurrence and mortality, with studies indicating a 5-year survival rate of only 60% [3]. Furthermore, individuals with coronary artery stenosis (COAS) also present an increased risk of death [4], and the coexistence of these two conditions significantly elevates the risk of cardiovascular and cerebrovascular events [5]. According to the 2017 China Cardiovascular Disease Report, vascular diseases account for more than 40% of all deaths, with approximately 13 million and 11 million individuals suffering from cerebrovascular and coronary artery diseases, respectively. The presence of both conditions further exacerbates the risk of cardiovascular and cerebrovascular events [6].

Atherosclerosis is a common underlying mechanism contributing to stenosis in both intracranial and coronary arteries. The 2019 Blue Book on the Prevention and Control of Panvascular Diseases in China highlights the correlation between cardiovascular and cerebrovascular stenosis, summarizing the epidemiology and risk factors associated with panvascular diseases, as well as the current status of therapeutic management and treatment models both domestically and internationally [7]. However, there are notable anatomical, genetic, and risk factor differences between intracranial and coronary stenosis, leading to inconsistencies in lesion presentation. The development of arterial stenosis is influenced primarily by lifestyle-related risk factors. Traditional cardiovascular disease risk factors, such as hypertension, hyperlipidemia, diabetes mellitus, and smoking, are also relevant for predicting cerebrovascular disease [8].

In recent years, advancements in medical imaging technology, particularly computed tomography angiography (CTA), have demonstrated high sensitivity and specificity in assessing ICAS and COAS [9]. This study aims to analyze the impact of various risk factors on intracranial and coronary atherosclerosis on the basis of computed tomography angiography (CTA) results and to construct a predictive scoring system. This initiative will contribute to the establishment of a standardized management model grounded in risk factor stratification and enhance public awareness regarding the integrated treatment of cardiovascular and cerebrovascular diseases.

Materials and methods

Subjects

This retrospective study included 5,816 stroke patients. Using the modified Framingham Stroke Scale, we screened predictors such as age, systolic blood pressure, systolic blood pressure after antihypertensive treatment, history of diabetes mellitus, smoking, history of cardiovascular disease, history of atrial fibrillation, and electrocardiographically diagnosed left ventricular hypertrophy. Each predictor was assigned a score weight, and patients were categorized into low-, medium-, and high-risk groups on the basis of their scores. These patients underwent arteriography at Xuzhou Medical University and were classified into three groups on the basis of the results: (1) intracranial artery stenosis combined with coronary artery stenosis, (2) coronary artery stenosis alone, and (3) intracranial artery stenosis alone.

Enrollment and exclusion criteria

Enrollment criteria

Patients who underwent CTA of the head and neck and coronary arteries as outpatients or were hospitalized in our facility from 2020 to 2022.

Age ≥ 40 years

The exclusion criteria for patients were cardiac embolic cerebral infarction (e.g., rheumatic heart disease, bacterial thrombotic endocarditis, nonbacterial thrombotic endocarditis, mitral valve prolapse, and patent foramen ovale) and other etiological factors (e.g., hyperthyroidism, systemic lupus erythematosus, and aortitis) according to the TOAST classification.

Detailed and complete case information.

Exclusion criteria

Incomplete clinical information.

Cerebral hemorrhage, subarachnoid hemorrhage, or severe craniocerebral trauma.

Organic heart diseases such as pericarditis, myocarditis, cardiomyopathy, rheumatic heart disease, and connective tissue or autoimmune diseases.

Serious medical conditions, including acute coronary syndrome, respiratory failure, severe immune system diseases, severe infections, and liver or kidney failure.

Poor image quality prevents accurate assessment of the degree of stenosis.

This study was approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (Ethics No. XYFY2023-KL014-01).

Methods for collecting clinical data and assessing arterial stenosis

Clinical data collection

This retrospective study collected data from the electronic medical record system and outpatient clinic system of the Affiliated Hospital of Xuzhou Medical University, including the following:

a) Imaging data: CTA results of the head, neck, and coronary arteries;
b) demographic characteristics: age and sex; lifestyle habits: smoking and alcohol consumption history;
c) preexisting medical history: hypertension, diabetes mellitus, cerebrovascular accidents, and peripheral artery disease (PAD);
d) laboratory indicators: coagulation function, D-dimer, and fibrinogen (FIB); glucose metabolism indicators, including glycated hemoglobin (HbA1c) and fasting blood glucose; renal function assessed by serum creatinine (Cr) and blood urea nitrogen (BUN); and hyperlipidemia defined as elevated lipid levels in the blood, primarily total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C), with thresholds set at TC > 240 mg/dL, TG > 150 mg/dL, LDL-C > 160 mg/dL, or HDL-C < 40 mg/dL. Additionally, apolipoprotein A (ApoA), apolipoprotein B (ApoB), lipoprotein (a) (Lp(a)), and homocysteine (HCY) levels were monitored.

Vascular assessment criteria

a) Intracranial artery stenosis was assessed via the Warfarin-Aspirin for Symptomatic Intracranial Artery Stenosis (WASID) calculator, which focuses on the intracranial segments of the internal carotid artery, anterior cerebral artery, middle cerebral artery, posterior cerebral artery, vertebral artery, and basilar artery.The grading criteria included mild stenosis: <50%; moderate stenosis: 50-69%; severe stenosis: 70-99%; and complete occlusion: 100%.
b) Internal carotid artery stenosis was evaluated via the North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria, with grading as follows: normal; mild stenosis: >30%; moderate stenosis: 30-70%; severe stenosis or occlusion: ≥70%. The side with the more severe lesion was selected as representative.
c) Coronary artery stenosis was calculated via the following formula: degree of stenosis (%) = [(normal diameter - lesion diameter)/normal diameter] × 100, which was used to assess the right coronary artery, left main stem, left anterior descending branch, circumflex branch, moderate branch, obtuse marginal branch, and diagonal branch. The grading criteria included mild stenosis: <50%; moderate stenosis: 50-69%; severe stenosis: 70-99%; and complete occlusion: 100%.

Clinical definitions

(a) Smoking: an average of > 5 cigarettes per day for ≥ 6 months or cessation for < 6 months. (b) Alcohol consumption: continuous consumption for ≥ 6 months or abstinence for < 6 months. (c) Hypertension: previous diagnosis or treatment history or systolic blood pressure > 140 mmHg or diastolic blood pressure > 90 mmHg (graded according to AHA hypertension guidelines).d) Diabetes mellitus: previous diagnosis or fulfillment of current diagnostic criteria.e) Previous cerebrovascular events: history of stroke or transient ischemic attack (TIA).f) Internal carotid artery stenosis (ICA): stenosis of > 30%. g) Peripheral artery stenosis of the lower extremities: meets the AHA/ACC diagnostic criteria.

Data statistics

Study design

Patients were stratified via the Framingham Stroke Risk Factor Scale, and risk factors and the incidence rates of intracranial artery stenosis (ICAS) and coronary artery stenosis (COAS) were compared. Logistic regression analysis was used to assess risk factors in patients with different types of simple arterial stenosis, comparing single-site stenosis with dual stenosis, including simple coronary stenosis and simple intracranial stenosis. Significantly associated risk factors were identified ($P < 0.05$). We summarized the significant risk factors for the three patient types and assessed their relevance and effects on different clinical types by constructing multinomial logistic regression models.

Data analysis and model construction

We employed multinomial logistic regression models to predict three types of stenosis: dual stenosis, simple intracranial stenosis, and simple coronary stenosis. The target variable "diagnosis type" was converted to a factor type, and related categorical variables (e.g., sex, hypertension, alcohol consumption, smoking, diabetes mellitus, stroke, carotid artery stenosis, peripheral vascular disease, and hyperlipidemia) were also converted to factor types. The independent variables included sex, hypertension (HTN), alcohol consumption, smoking, diabetes, stroke, internal carotid artery stenosis (ICA), hyperlipidemia, age, BMI, homocysteine (HCY), creatinine (CR), and uric acid (BUA). A full model was constructed, and the stepAIC method was used for variable selection to identify the most important predictors. The final model formula was as follows:

$$stenosis\_type \sim HTN + drink + smoke + DM + stroke + ICA + age + bmi + HCY + CR + BUA.$$

Data division

During model training, the dataset was randomly divided into a training set and a test set, typically 70% for training and 30% for testing.

Model evaluation: Model evaluation was conducted by generating a confusion matrix to assess the classification performance on the test set. The confusion matrix compares true labels with predicted labels to calculate model accuracy. Additionally, we calculated the AUC value, with values closer to 1 indicating better model performance.

Feature Importance Analysis and Hyperparameter Tuning: This involves extracting model coefficients and calculating the absolute value of each feature. We summarized the importance scores of the features and visualized them to compare their effects on stenosis types. Hyperparameter tuning was performed via methods such as cross-validation to optimize model performance, ensure generalization across different datasets, and identify features that significantly affect the type of stenosis.

Statistical Software and statistical methods

All the data analyses were performed via R statistical analysis software. Continuous variables are described as the means ± standard deviations (SDs) or medians (IQRs), whereas categorical variables are expressed as percentages. The Shapiro–Wilk test was used to assess the normality of continuous variables, and the independent samples t test or Mann–Whitney test was used for between-group comparisons of continuous variables. For categorical variable comparisons, the chi-square test or Fisher's exact test was employed.

Results

Comparison of clinical data among patients with different diagnostic types

A total of 5,816 patients were included in this study, comprising those with dual arterial stenosis ($n = 2{,}258$), simple intracranial arterial stenosis ($n = 399$), and simple coronary stenosis ($n = 3{,}159$). A comparison of the baseline characteristics of the three patient groups (Table 1) revealed that the highest percentage of patients had pure coronary artery stenosis (54.3%), whereas the lowest percentage had pure intracranial artery stenosis (6.8%). The overall median age was 66 years, with the oldest patients in the dual artery stenosis group (median age 69 years) and the youngest in the simple coronary artery stenosis group (median age 64 years) ($P < 0.001$).The percentage of males was 58.25% ($P = 0.048$). The median body mass index (BMI) was 25.73, with the highest BMI in the simple coronary stenosis group (26.12) and the lowest BMI in the dual stenosis group (24.96), indicating a significant difference ($P < 0.001$). Homocysteine (HCY) levels were highest in the dual stenosis group (13.06) and lowest in the simple coronary stenosis group (10.76) ($P < 0.001$). D-dimer levels were similar across groups ($P = 0.006$), whereas fibrinogen levels did not significantly differ ($P = 0.808$). Uric acid levels were highest in the simple intracranial stenosis group (451.00, $P < 0.001$).The overall prevalence of hypertension (HTN) was 60.95%, with the highest prevalence in the dual arterial stenosis group (67.71%, $P < 0.001$). The prevalence of diabetes mellitus (DM) was 30.74%, which was also highest in the dual arterial stenosis group (47.21%, $P < 0.001$). The prevalence of smoking was 22.85%, with the highest rate in the dual stenosis group (31.67%, $P < 0.001$). The overall prevalence of hyperlipidemia (HLP) was 66.30%, peaking in the simple intracranial stenosis group (88.97%, $P < 0.001$). The percentage of patients with a history of stroke was 32.69%, which was highest in the simple intracranial artery stenosis group (41.35%, $P < 0.001$).The proportion of internal carotid artery disease was highest in the dual artery stenosis group (46.32%) and lowest in the simple coronary artery stenosis group (20.45%). The incidence of peripheral vascular disease (PVD) was low (approximately 1–2%), with no significant differences observed between the groups.

Differences in the incidence of intracranial and coronary artery stenosis among patients in different risk classes

Our analysis revealed significant differences in the distribution of patients with the three types of arterial stenosis across various risk classes. By constructing a league table and conducting a chi-square test (Table 2; Fig. 1), we found statistically significant differences in the distribution of each diagnostic group among the different risk classes (chi-square statistic = 298.66, degrees of freedom = 4, $p < 2.2e\text{-}16$). Notably, there was a predominance of low-risk patients and a relatively small number of high-risk patients.

Multiple logistic regression analyses, in which dual stenosis was used as the reference category, revealed that the odds ratio for the occurrence of intracranial artery stenosis in the moderate-risk group compared with the low-risk group was 0.471 (95% CI: 0.351–0.633, $p < 0.001$). In the high-risk group, the odds ratio was 0.279 (95% CI: 0.178–0.437, $p < 0.001$). Similarly, the occurrence of coronary artery stenosis had an odds ratio of 0.446 (95% CI: 0.388–0.512, $p < 0.001$) in the moderate-risk group and 0.255 (95% CI: 0.209–0.311, $p < 0.001$) in the high-risk group(Fig. 2).

In conclusion, the risk of developing simple intracranial artery stenosis (ICAS) versus coronary artery stenosis (COAS) significantly decreases with increasing risk. These findings underscore the importance of

Table 1 Baseline characteristics

Risk Factors	Total (*n* = 5816)	Dual Arterial Stenosis (*n* = 2258)	Single Intracranial Arterial Stenosis (*n* = 399)	Single Coronary Arterial Stenosis (*n* = 3159)	Statistic	*P*
Age, M (Q_1, Q_3)	66.00 (57.00, 73.00)	69.00 (62.00,74.00)	66.00 (58.00,73.00)	64.00 (55.00,71.00)	χ^2=251.35	< 0.001
Bmi, M (Q_1, Q_3)	25.73 (24.22, 27.68)	24.96 (22.99,27.34)	25.25 (22.96,27.34)	26.12 (24.82,27.77)	χ^2=262.30	< 0.001
HCY, M (Q_1, Q_3)	11.63 (7.73, 15.84)	13.06 (9.07,17.93)	11.43 (7.16,15.82)	10.76 (6.86,14.51)	χ^2=199.13	< 0.001
D-Dimer, M (Q_1, Q_3)	0.34 (0.22, 0.46)	0.35 (0.22,0.48)	0.35 (0.21,0.49)	0.34 (0.22,0.45)	χ^2=10.33	0.006
FIB, M (Q_1, Q_3)	3.00 (2.02, 4.02)	3.04 (2.04,4.02)	2.97 (2.14,4.08)	2.98 (1.99,4.02)	χ^2=0.43	0.808
CR, M (Q_1, Q_3)	72.00 (54.00, 89.00)	72.00 (54.00,89.00)	69.00 (53.00,85.00)	72.00 (54.00,90.00)	χ^2=6.91	0.032
BUA, M (Q_1, Q_3)	328.00 (218.00, 447.00)	282.00 (182.00,374.00)	451.00 (414.00,480.50)	341.00 (235.00,501.00)	χ^2=654.31	< 0.001
ApoA, M (Q_1, Q_3)	1.40 (1.25, 1.55)	1.41 (1.25,1.56)	1.39 (1.26,1.56)	1.39 (1.25,1.55)	χ^2=0.21	0.900
ApoB, M (Q_1, Q_3)	1.00 (0.85, 1.15)	0.99 (0.84,1.14)	0.99 (0.85,1.15)	1.01 (0.85,1.16)	χ^2=3.04	0.219
Apo a, M (Q_1, Q_3)	250.00 (173.75, 365.25)	214.00 (107.00,307.75)	266.00 (206.00,360.50)	268.00 (206.00,412.00)	χ^2=262.35	< 0.001
Hscrp, M (Q_1, Q_3)	1.63 (0.92, 2.32)	1.63 (0.94,2.32)	1.57 (0.90,2.21)	1.63 (0.91,2.33)	χ^2=1.23	0.541
Grade, *n*(%)					χ^2=298.66	< 0.001
low-risk	4227 (72.68)	1368 (60.58)	317 (79.45)	2542 (80.47)		
moderate-risk	1066 (18.33)	550 (24.36)	60 (15.04)	456 (14.43)		
high-risk	523 (8.99)	340 (15.06)	22 (5.51)	161 (5.10)		
Sex, *n*(%)					χ^2=6.09	0.048
Male	3388 (58.25)	1358 (60.14)	220 (55.14)	1810 (57.30)		
Female	2428 (41.75)	900 (39.86)	179 (44.86)	1349 (42.70)		
HTN, *n*(%)					χ^2=72.60	< 0.001
None	2271 (39.05)	729 (32.29)	161 (40.35)	1381 (43.72)		
Yes	3545 (60.95)	1529 (67.71)	238 (59.65)	1778 (56.28)		
Drink, *n*(%)					χ^2=3.59	0.166
None	5058 (86.97)	1941 (85.96)	353 (88.47)	2764 (87.50)		
Yes	758 (13.03)	317 (14.04)	46 (11.53)	395 (12.50)		
Smoke, n(%)					χ^2=163.27	< 0.001
None	4487 (77.15)	1543 (68.33)	324 (81.20)	2620 (82.94)		
Yes	1329 (22.85)	715 (31.67)	75 (18.80)	539 (17.06)		
DM, n(%)					χ^2=475.94	< 0.001
None	4028 (69.26)	1192 (52.79)	297 (74.44)	2539 (80.37)		
Yes	1788 (30.74)	1066 (47.21)	102 (25.56)	620 (19.63)		
Stroke, n(%)					χ^2=101.20	< 0.001
None	3915 (67.31)	1376 (60.94)	234 (58.65)	2305 (72.97)		
Yes	1901 (32.69)	882 (39.06)	165 (41.35)	854 (27.03)		
ICA, n(%)					χ^2=425.46	< 0.001
None	3956 (68.02)	1212 (53.68)	231 (57.89)	2513 (79.55)		
Yes	1860 (31.98)	1046 (46.32)	168 (42.11)	646 (20.45)		
PVD, n(%)					χ^2=2.28	0.320
None	5740 (98.69)	2224 (98.49)	392 (98.25)	3124 (98.89)		
Yes	76 (1.31)	34 (1.51)	7 (1.75)	35 (1.11)		
HLP, n(%)					χ^2=673.66	< 0.001
None	1960 (33.70)	1210 (53.59)	44 (11.03)	706 (22.35)		
Yes	3856 (66.30)	1048 (46.41)	355 (88.97)	2453 (77.65)		
Glucose Control, n(%)					χ^2=143.19	< 0.001
None	3906 (67.16)	1311 (58.06)	272 (68.17)	2323 (73.54)		
Yes	1910 (32.84)	947 (41.94)	127 (31.83)	836 (26.46)		

#: Kruskal-wailles test, χ^2: Chi-square test

M: Median, Q_1: 1st Quartile, Q_3: 3 st Quartile

Table 2 Associations between cerebrovascular stenosis type and risk level

Stenosis Type	Low Risk	Moderate Risk	High Risk
Dual Arterial Stenosis	1368	550	340
Single Intracranial Arterial Stenosis	317	60	22
Single Coronary Arterial Stenosis	2542	456	161

Chi-square test results: Chi-square value: 298.66, degrees of freedom: 4, *P* value: $P < 0.001$

Pearson's chi-square test: X-square = 298.66, df = 4, *p* value < 2.2e-16

understanding the differential risk of ICAS and COAS among patients in various risk categories.

Effects of various variables on intracranial and coronary artery stenosis(refer to attachment 1)

The impact of variables such as sex, alcohol consumption, smoking, hypertension, and diabetes mellitus on intracranial and coronary artery stenosis was assessed via multicategorical logistic regression analysis. Logistic regression was performed for different risk class groups, focusing on statistically significant *P* values < 0.05.

The mean age of patients significantly increased with increasing risk class: low risk (60.2 years), moderate risk (65.4 years), and high risk (71.8 years) ($p < 0.001$). The percentage of females also increased with increasing risk: 43.2% in the low-risk group, 51.6% in the moderate-risk group, and 58.4% in the high-risk group ($p = 0.002$). The prevalence of hypertension was 38.7% in the low-risk group, 52.1% in the moderate-risk group, and 68.3% in the high-risk group ($p < 0.001$), demonstrating a clear increasing trend with increasing risk. Similarly, the prevalence of diabetes mellitus was 21.5%, 29.8%, and 38.2% in the low-, moderate-, and high-risk groups, respectively ($p < 0.001$). Conversely, the percentage of patients who smoked was lower in the high-risk group (25.6%, $p = 0.048$).

When patients with single intracranial stenosis were compared with those with single coronary stenosis, a history of stroke, internal carotid artery stenosis, and dyslipidemia were identified as independent risk factors for intracranial stenosis in the low-risk group, whereas these factors were not significant in the coronary stenosis group. Age, homocysteine levels, uric acid, and apolipoprotein (Apo(a)) were positively associated with intracranial artery stenosis, whereas independent risk factors for coronary artery stenosis included BMI and creatinine levels.In the moderate-risk group, a history of stroke, internal carotid artery stenosis, and age were significantly more prevalent in the intracranial artery stenosis group than in the coronary artery stenosis group. In the high-risk group, internal carotid artery stenosis, age, and elevated D-dimer levels were more closely associated with intracranial artery stenosis, whereas high BMI, and renal dysfunction emerged as key features of high-risk coronary artery stenosis.

Comparison of risk factors between concordant and discordant groups of intracranial and coronary artery lesions

Compared with single coronary artery stenosis, hypertension, diabetes mellitus, and carotid stenosis were consistently recognized as significant risk factors for double stenosis across all risk groups(refer to Attachment 2). Smoking was significant in the low- and moderate-risk groups, and women had a lower risk of double stenosis than men did in the high-risk group. Increasing age was

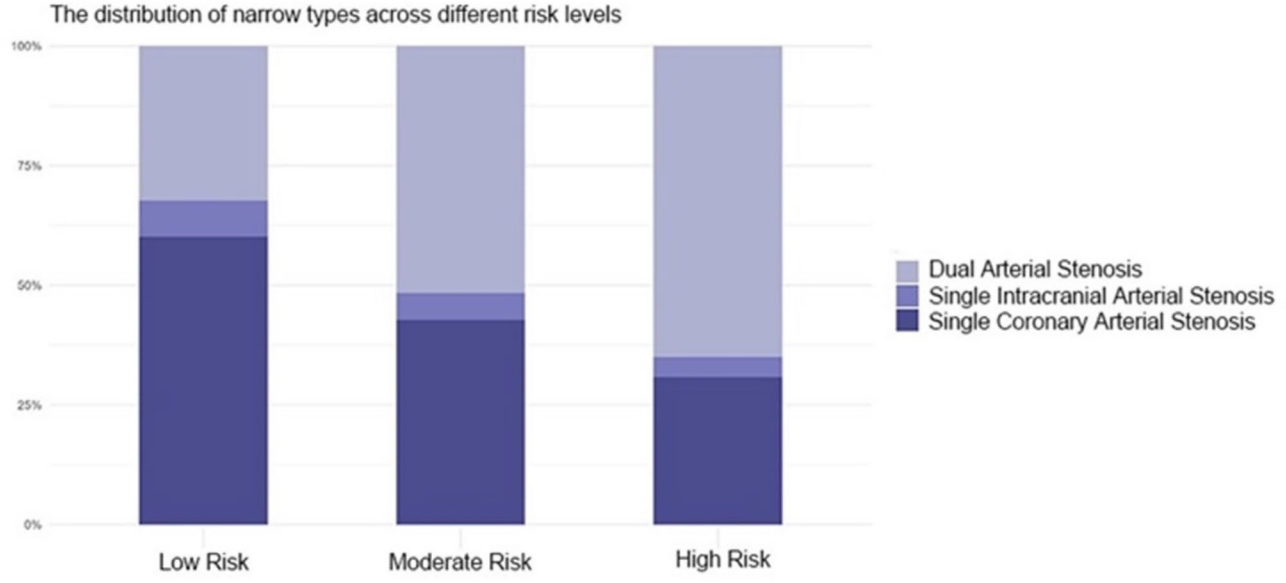

Fig. 1 Analysis of arterial stenosis type distribution across different risk levels

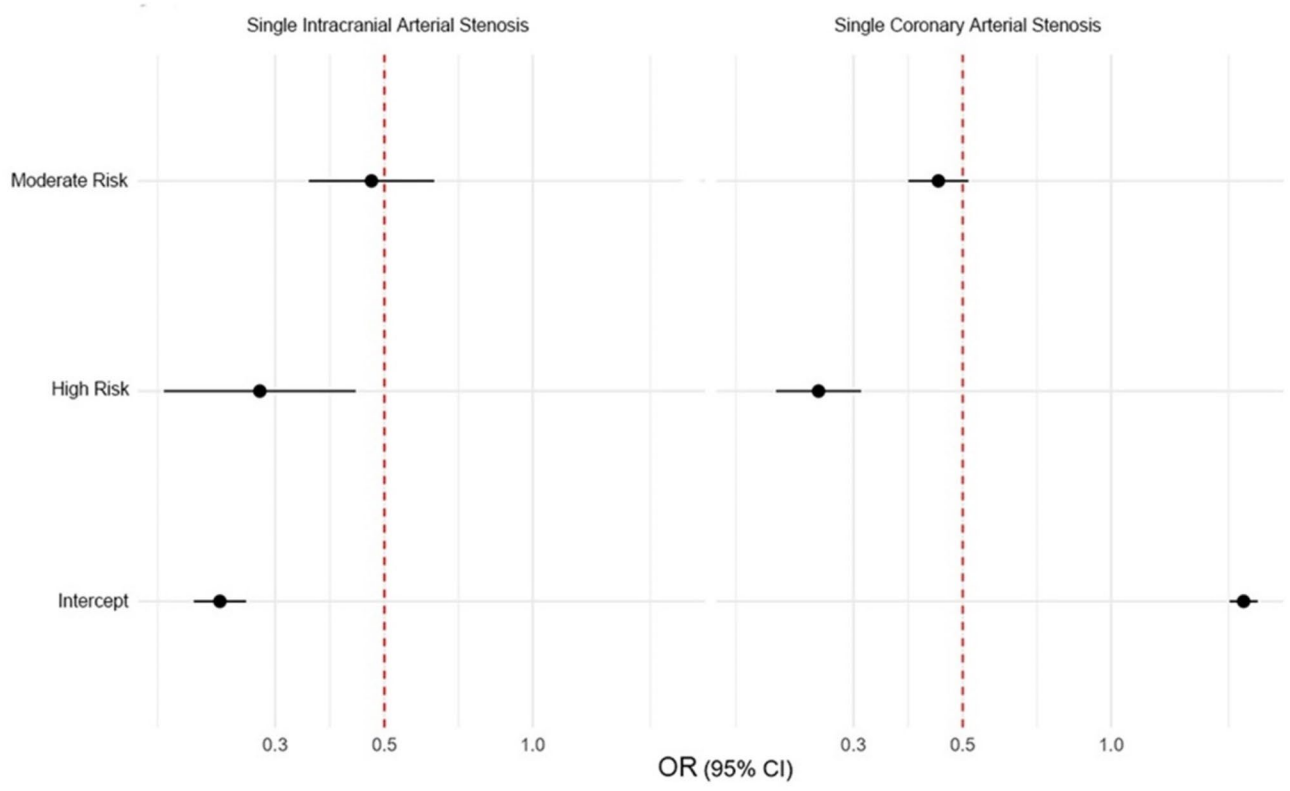

Fig. 2 Risk Assessment of arterial stenosis: intracranial vs. coronary

positively associated with an elevated risk of double stenosis. Additionally, changes in BMI and creatinine levels were negatively associated with the risk of double stenosis, highlighting the potential importance of weight management and renal function monitoring in cardiovascular disease prevention. In summary, the effects of sex, hypertension, diabetes mellitus, and carotid stenosis on double stenosis became more pronounced with increasing risk class. Hyperlipidemia was negatively associated with dual stenosis across all risk groups but was linked to coronary stenosis.

A comparison of patients with single intracranial artery stenosis and dual stenosis of the cardiac and cerebral arteries(>refer to Attachment 3), the analysis revealef that smoking significantly elevated the risk of dual stenosis, with a regression coefficient (B value) of 1.04 and a *P* value of 0.04. Additionally, diabetes had a B value of 1.05 and an odds ratio (OR) of 2.85, indicating a strong positive influence on the risk of stenosis. In contrast, peripheral vascular disease (PVD) and hyperlipidemia (HLP) have B values of -1.81 and – 2.13, respectively, suggesting that these factors may more readily contribute to the development of single intracranial arterial stenosis. Moreover, there has been an increase in the proportion of elderly female patients diagnosed with single intracranial arterial stenosis has increased.

Multinomial logistic regression was used to analyze the effects of multiple factors on different diagnostic types

The statistically significant factors identified from the risk factor stratification were selected for multinomial logistic regression analysis to predict three types of arterial stenosis: dual stenosis, single intracranial stenosis, and single coronary stenosis. The stepAIC method was employed for variable selection, constructing a full model with double stenosis as the baseline. The final selected model equation was as follows:

$$stenosis\ type \sim HTN + drink + smoke + DM + stroke + ICA + age + BMI + HCY + CR + BUA.$$

Table 3 presents the coefficients of the model along with their standard errors. The results of the polynomial regression model from this study highlight the effects of various variables on single intracranial and coronary stenosis, with dual stenosis serving as the reference category, indicating the baseline risk for this group. Notably, the coefficients for hyperlipidemia (HLP), hypertension (HTN), alcohol consumption (drink), and smoking (smoke) were significantly high.

The model's residual bias was 7975.005, and the Akaike information criterion (AIC) was 8023.005, indicating

Table 3 Summary of Model results

Category	Variable	Coefficient	StdError	Z Value	*P* Value
Single Intracranial Arterial Stenosis	(Intercept)	-1.434	0.111	-12.955	0.000
	HTN	-0.327	0.120	-2.715	0.007
	drink	0.253	0.216	1.171	0.242
	smoke	-0.795	0.174	-4.580	< 0.001
	DM	-1.066	0.132	-8.060	< 0.001
	HLP	1.802	0.171	10.536	< 0.001
	Stroke	0.245	0.121	2.030	0.042
	ICA	-0.213	0.120	-1.778	0.075
	age	-0.026	0.005	-5.437	< 0.001
	BMI	-0.008	0.014	-0.589	0.556
	HCY	-0.040	0.009	-4.320	< 0.001
	CR	-0.011	0.003	-4.083	< 0.001
	BUA	0.007	0.000	16.627	< 0.001
Single Coronary Arterial Stenosis	(Intercept)	0.376	0.359	1.047	0.295
	HTN	-0.383	0.071	-5.396	< 0.001
	drink	0.531	0.123	4.318	< 0.001
	smoke	-1.036	0.099	-10.493	< 0.001
	DM	-1.348	0.075	-18.045	< 0.001
	HLP	1.173	0.072	16.205	< 0.001
	Stroke	-0.397	0.073	-5.417	< 0.001
	ICA	-1.192	0.074	-16.129	< 0.001
	age	-0.041	0.003	-12.650	< 0.001
	BMI	0.118	0.011	10.985	< 0.001
	HCY	-0.063	0.006	-11.391	< 0.001
	CR	-0.005	0.002	-2.966	0.003
	BUA	0.004	0.000	16.837	< 0.001

Table 4 AUC values for each category and the macroaveraged AUC

Category	Training Set AUC	Testing Set AUC
Dual Arterial Stenosis	0.8499	0.8562
Single Intracranial Stenosis	0.7660	0.7514
Single Coronary Stenosis	0.8025	0.8206
Macro-Average	0.8061	0.8094

a good fit. The trend of the AIC value demonstrated a stepwise selection process (Fig. 3), with the final model AIC value reduced to 8023.000 compared with the initial model. This reduction indicates a favorable balance between model complexity and goodness of fit.

The matrix indicates that the number of patients correctly predicted to have dual stenosis was high, whereas the number of single patients incorrectly predicted as having either intracranial stenosis alone or coronary stenosis alone was low (Fig. 4). Specifically, fewer samples were predicted for simple intracranial stenosis, whereas the highest number of samples were accurately predicted for simple coronary stenosis.

For the group with single intracranial arterial stenosis, the coefficient for the intercept term was – 1.434, indicating a relatively low baseline risk compared with dual stenosis. Hyperlipidemia (HLP) had a coefficient of 1.802, reflecting a strong positive association with the risk of stenosis. Conversely, hypertension (HTN) had a coefficient of -0.327 ($p = 0.007$), indicating a significant negative correlation with the risk of intracranial stenosis. The coefficient for smoking (smoke) was – 0.795 ($p < 0.001$), also suggesting a significant negative effect. The coefficient for diabetes mellitus (DM) was – 1.066 ($p < 0.001$), indicating that the risk of disease in diabetic patients is lower than that in those with dual stenosis. The age coefficient (age) was – 0.026 ($p < 0.001$), which was significantly negatively associated with risk. While the coefficients for alcohol consumption (drink) and history of stroke (stroke) did not significantly affect the risk of stenosis, the coefficient for homocysteine (HCY) was – 0.040 ($p < 0.001$), indicating a noteworthy negative association.

For single coronary arterial stenosis, the intercept term coefficient was 0.376, indicating a lower baseline risk in this group than in the dual stenosis group. The coefficient for hypertension (HTN) was – 0.383 ($p < 0.001$), which was significantly negatively correlated with the risk of coronary stenosis. The coefficient for smoking was – 1.036 ($p < 0.001$), indicating that smoking is associated with a lower risk of coronary stenosis. The coefficient for diabetes mellitus (DM) was – 1.348 ($p < 0.001$), suggesting that diabetic patients have a lower risk than those with dual stenosis. The age coefficient was – 0.041 ($p < 0.001$),

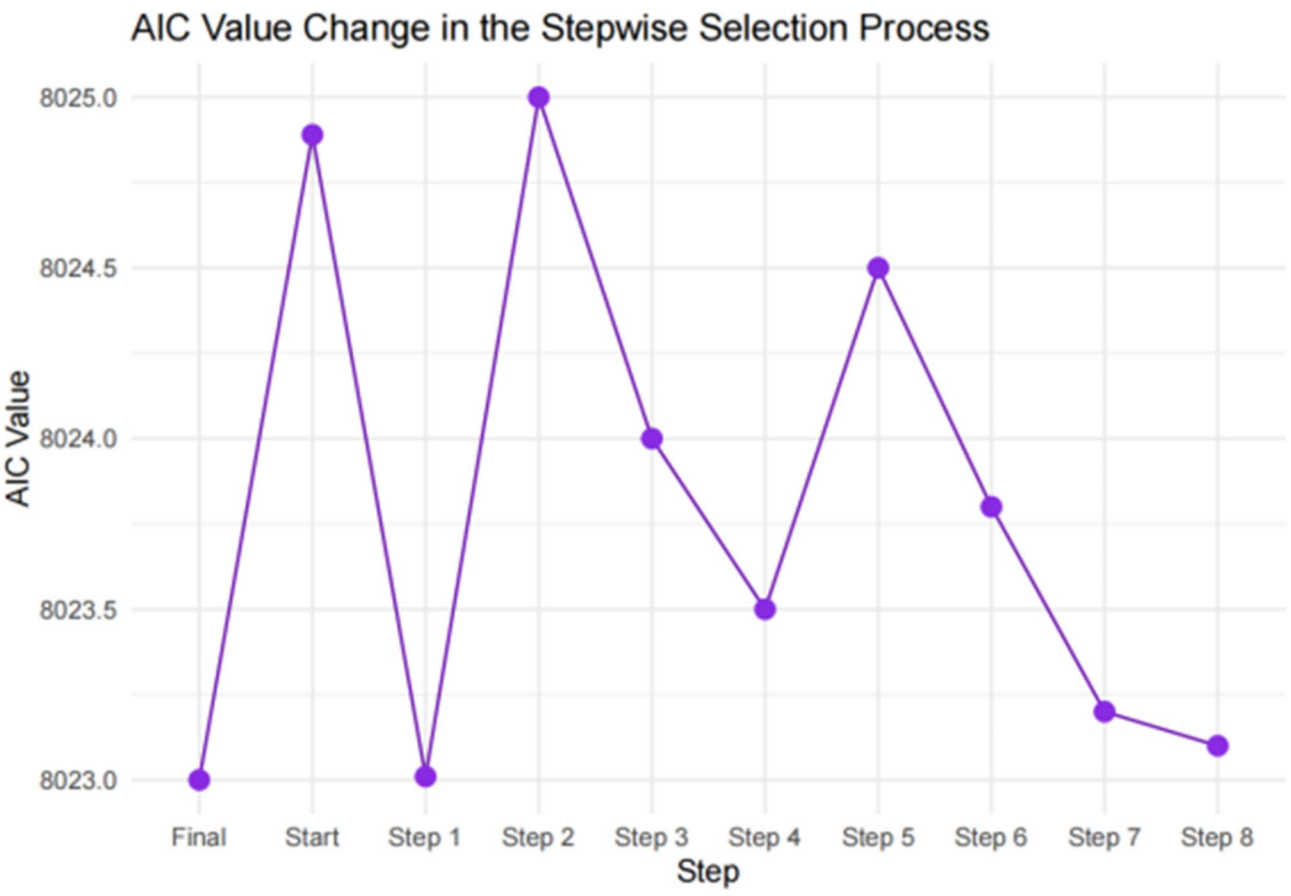

Fig. 3 AIC in model selection

indicating a significant negative association with risk. Additionally, both body mass index (BMI) with a coefficient of 0.118 ($p < 0.001$) and uric acid (BUA) with a coefficient of 0.004 ($p < 0.001$) had significant positive effects on this group.

Subsequently, we constructed a polynomial regression model and adjusted it using a test set, achieving a final convergence value of 2818. The model's classification performance was further assessed via AUC values, which were 0.8562 for the dual stenosis category, 0.8206 for coronary stenosis alone, 0.7514 for intracranial stenosis alone, and 0.8094 for the grand mean AUC.

We evaluated the relative importance of features in the model to identify the factors that had the greatest impact on predicting arterial stenosis(Fig. 5). Hyperlipidemia (HLP) received the highest importance score of 3.078, followed by diabetes mellitus (DM), with a score of 2.5134; smoking (smoking), with a score of 1.6081; and internal carotid artery stenosis (ICA), with a score of 1.4051.

To analyze risk factors for intracranial and coronary stenosis in comparison with patients with double stenosis, we examined characteristics associated with "simple intracranial stenosis" and "simple coronary stenosis," distinguishing between positive and negative effects (Fig. 6). The results indicated that diabetes mellitus, smoking, internal carotid artery (ICA) stenosis, and hypertension had strong negative effects on both simple intracranial and simple coronary artery stenosis. Conversely, hyperlipidemia (HLP), body mass index (BMI), and alcohol consumption demonstrated strong positive effects, specifically in simple coronary artery stenosis.

Discussion

This study compares different risk groups and offers a targeted risk assessment tool for clinical practice. It analyzes 5,816 ischemic stroke patients from the Affiliated Hospital of Xuzhou Medical University, all of whom underwent routine coronary CTA examinations. The findings reveal a significant relationship between intracranial arterial stenosis (ICAS) and coronary artery stenosis (COAS) and their associated risk factors in stroke patients, although data from non-stroke patients were not included.While ischemic stroke and coronary events share several risk factors, differences exist. Stroke patients are more likely to have multiple vascular lesions and a higher risk of cardiovascular events, particularly due to cumulative effects of reversible factors like hypertension, diabetes, and

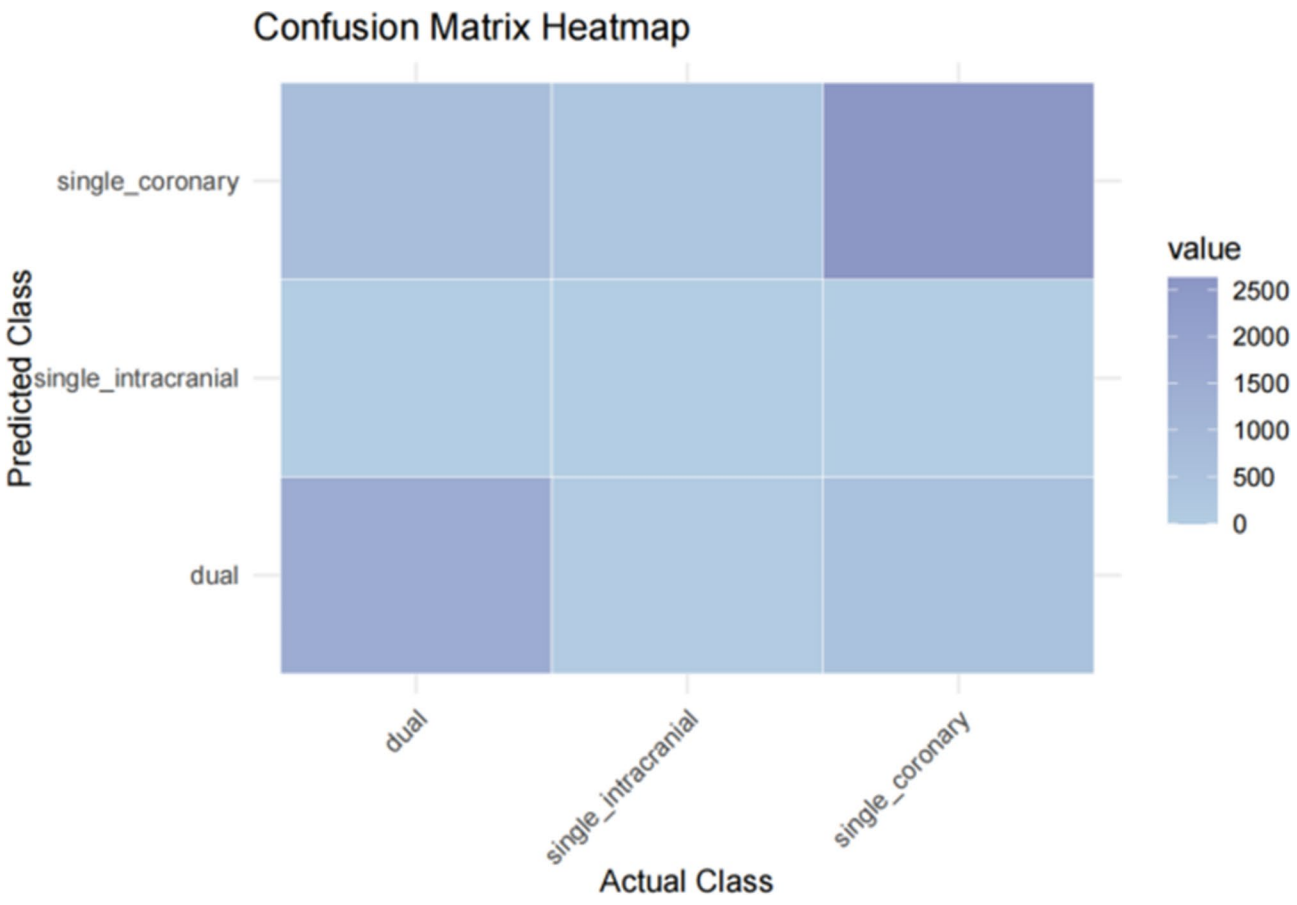

Fig. 4 Confusion matrix in medical classification

dyslipidemia [10]. Thus, close cardiovascular risk assessment and personalized prevention strategies for stroke patients are essential.The study shows that the incidence of ICAS and COAS in ischemic stroke patients is closely linked to their risk stratification. Although we did not specifically examine responsible lesions and their roles in single versus multiple lesions, previous research indicates these factors are significant in stroke pathophysiology [11]. Responsible lesions refer to arterial stenosis that directly leads to a stroke and are associated with local risk factors, such as atherosclerotic plaques. Notably, 38.8% of patients had dual arterial stenosis, suggesting a higher risk of systemic atherosclerosis. While we did not analyze risk factors for single versus multiple lesions directly, prior studies suggest that patients with multiple lesions often require more aggressive interventions [12].

The primary risk factors for atherosclerotic stenosis of intracranial arteries include hypertension, smoking, diabetes mellitus, hyperlipidemia, and age [13]. In contrast, the main risk factors for coronary atherosclerosis are hypercholesterolemia, obesity, heavy alcohol consumption, hypertension, diabetes mellitus, and a higher prevalence among males [14]. Hypertension, diabetes, smoking, and dyslipidemia are widely recognized in panvascular disease studies because of their roles as systemic disease risk factors [15]. Some studies suggest differences in the degree of intracranial versus coronary atherosclerosis, attributed to anatomical structure, genetic differences, and tolerance to risk factors [16]. However, there are only a few differences in anatomical structure and genetic factors. Notably, the compensatory mechanisms of coronary arteries differ from those of intracranial arteries. Outward remodeling of coronary arteries may serve as a protective mechanism or become a risk factor for plaque destabilization later [17].

Risk factors exhibit competitive or antagonistic effects on the heart and brain. Previous studies have revealed that notable trends in risk factors for cardio-cerebral arterial stenosis indicate varying effects on the vasculature [18]. Analyses of patients with cerebral infarction and coronary artery disease have identified both unmodifiable (age, sex, race) and modifiable risk factors (e.g., hypertension, dyslipidemia, diabetes) [19]. Other studies have identified diabetes, internal carotid artery stenosis, and elevated homocysteine levels as independent risk factors for cerebral infarction with coronary artery disease [20–22]. This study revealed that in the low-risk group, a history of stroke, internal carotid artery stenosis,

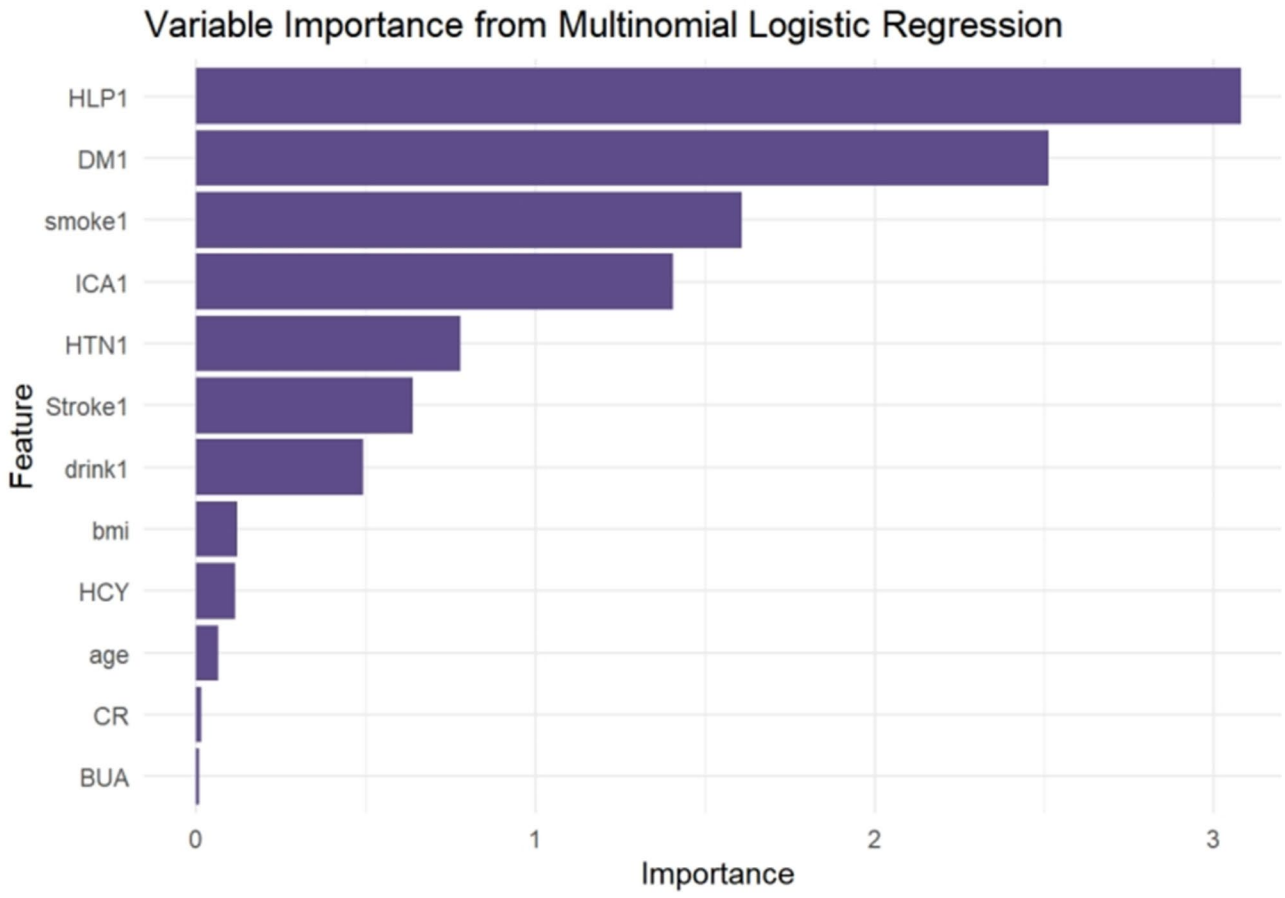

Fig. 5 Feature importance analysis for predicting arterial stenosis

and dyslipidemia were independent risk factors for intracranial stenosis. In the moderate-risk group, those with intracranial artery stenosis had a significantly greater incidence of stroke, a history of internal carotid artery stenosis, and older age than did those in the coronary artery stenosis group. In the high-risk group, internal carotid artery stenosis, age, and elevated D-dimer levels were prominent, whereas single coronary artery stenosis tended to occur in younger patients, as well as those who were obese or had renal dysfunction.

Using the modified Framingham Stroke Risk Score [23], we correlated risk scores with stroke incidence, categorizing patients into low-, medium-, and high-risk classes. Statistical analyses revealed that patients with dual arterial stenosis were older and had more risk factors, whereas those with single intracranial artery stenosis had unique characteristics (e.g., hyperlipidemia and prior strokes). Single coronary artery stenosis patients were younger and had a higher BMI but fewer risk factors. Epidemiological studies have identified smoking, diabetes, hyperlipidemia, and hypertension as significant contributors to coronary heart disease [24].Obesity has been reported as a common cause of cardiovascular death in developed countries [25]. Elevated homocysteine levels are thought to be associated with the development of atherosclerosis [26], and there is a notable relationship between hyperuricemia and the risk of coronary heart disease [27]. Homocysteine and blood uric acid levels are significantly different across various types of arterial stenosis, potentially reflecting distinct pathological mechanisms.These findings underscore the importance of developing personalized preventive and therapeutic strategies for patients with different types of arterial stenosis to increase the efficacy of interventions. Additionally, as the risk level increases, the risk factors within patients may exhibit a cumulative effect. For instance, factors such as hyperlipidemia, alcohol consumption, and high BMI may interact synergistically, leading to increased arterial fat deposition and exacerbated inflammatory responses. Therefore, categorizing patients the basis of risk factor stratification is essential for analyzing the influencing factors across various diagnostic types. This categorization not only aids in identifying high-risk patients but also provides a foundation for clinical decision-making. We observed variations in influencing factors among the different diagnostic categories. Previous

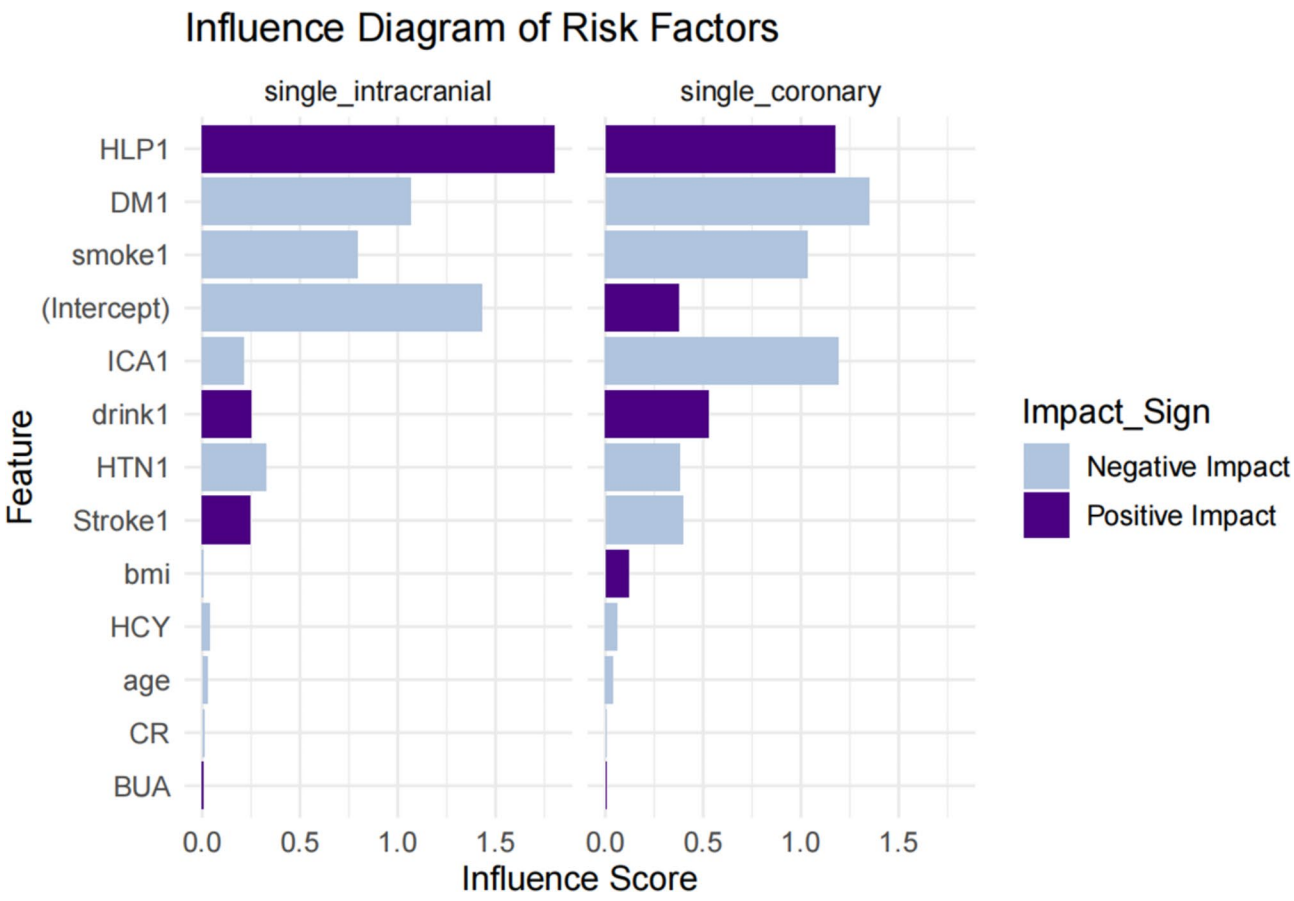

Fig. 6 Comparison of Risk Factors for Isolated Cerebral and Coronary Artery Stenosis in the Context of Dual Arterial Stenosis: Positive impact indicates factors that help reduce the risk of stenosis in a sin-gle arterial site, while negative im-pact indicates factors that increase the risk of stenosis in a single arte-rial site

studies have indicated that the specific risk factors for cardiac and cerebral artery stenosis may evolve over time [8]. This underscores the necessity for regular assessment of patients' risk factors in clinical practice to facilitate timely adjustments to treatment plans.

We identified hyperlipidemia, diabetes, carotid stenosis, and smoking as primary risk factors, followed by hypertension and a history of stroke. Elevated creatinine and glucose levels are also associated with increased disease risk. Some individuals who consumed large amounts of alcohol presented moderate to severe coronary artery stenosis, suggesting potential information bias. Further research is needed to explore the impact of alcohol consumption on both intracranial and coronary arteries.

This study uses dual arterial stenosis as a baseline, highlighting changes in the impact of single intracranial and coronary stenosis. Risk factors for both arterial stenoses may interact synergistically, causing effects that exceed their individual impacts [28, 29]. Previous studies have identified hypertension, smoking, diabetes, hyperlipidemia, and age as significant risk factors for cardiocerebral comorbidities [8]. In our study, patients aged 69 years or older were categorized as high risk, which is consistent with previous findings.Gender differences play a crucial role in cardiovascular stenosis; the proportion of female patients was similar to that of male patients. Young and middle-aged women are often protected by estrogen, whereas postmenopausal women face greater risk [30]. Diabetes mellitus plays a critical role in the progression of both intracranial and coronary artery stenosis, reducing fibrinolytic activity and exacerbating atherosclerosis. High lipid levels were prevalent among our study population, which consisted primarily consisting of middle-aged and elderly patients, some of whom had a history of stroke.Numerous studies have concluded that internal carotid artery stenosis is an important predictor of both coronary and intracranial artery stenosis [31, 32]. Our findings support these findings, indicating that carotid ultrasonography could serve as an effective screening tool. Smoking and hypertension are significant risk factors for atherosclerosis, particularly among men, with a noted trend between smoking quantity and arterial stenosis [33]. Additionally, the severity of hypertension is correlated with the number and degree of severely

affected arterial stenoses [34].Homocysteine and creatinine were confirmed to have predictive value in this study [25, 35], whereas ApoA was negatively correlated with atherosclerosis.The low prevalence of peripheral vascular disease (PVD) may be due to clinical practices where asymptomatic patients do not routinely undergo ultrasound, resulting in low detection rates. Body mass index (BMI) is significantly correlated with coronary artery stenosis [36] but not directly with intracranial stenosis, which is influenced by lipid levels. The lack of statistical significance for fasting glucose may be due to stable glycemic control in long-term diabetic patients. Some studies suggest that D-dimer, fibrinogen, and urea may have predictive significance for cardiovascular disease [21, 37, 38]. ApoB is also recognized as a risk factor for atherosclerosis [39].

Furthermore, we consider that dual arterial stenosis may involve more complex systemic pathological changes than single-site stenosis, such as metabolic syndrome and systemic inflammation [40]. Certain factors may exert competitive effects between the heart and brain, potentially reducing the risk of dual stenosis. When blood flow in one area is restricted, the body may compensate through alternative pathways, offsetting the effects of risk factors in one region with compensatory mechanisms in another. For example, carotid artery stenosis may be compensated for by the dilation of other vessels, mitigating its impact on cerebral blood flow [41]. This compensatory mechanism may protect cerebral blood flow in patients with dual arterial stenosis, contributing to the lower incidence of single intracranial artery stenosis. Additionally, inflammation may create competitive effects between the heart and brain, leading to further compensation through collateral circulation to maintain the blood supply.

We utilized a stepwise regression-based model to predict outcomes within our dataset, specifically focusing on patients with dual stenosis. The analysis of the model's prediction results is essential for evaluating its performance. We estimated that 2,131 patients would fall into the dual stenosis category, and among these predictions, 1,499 patients were confirmed to belong to this group. Thi sfinding indicates that the model demonstrates high accuracy in predicting dual stenosis cases. The accuracy can be quantified as the ratio of actual dual cases to the total predictions, confirming the model's effectiveness in this area. Importantly, among those patients who were predicted to have dual stenosis, 527 patients were actually classified as having simple coronary stenosis. This finding highlights a certain false-positive rate, suggesting that some cases were incorrectly classified as dual stenosis. Further analysis of the prediction probabilities revealed that the average probability for the dual category was 70.03%, indicating a high level of confidence in the model's predictions. The maximum prediction probability reached 99.17%, whereas the minimum was 37.80%, reflecting variability in the model's predictions across different samples.High-confidence predictions may indicate the model's strong performance in specific cases, whereas low-confidence predictions could reveal its limitations in handling more complex or borderline situations. In conclusion, while the model exhibited high accuracy and reasonable confidence in predicting arterial stenosis cases, further optimization is needed to reduce the false-positive rate and improve its ability to manage complex cases effectively. This ongoing refinement will be crucial for enhancing the model's clinical applicability and reliability.

The key risk factors identified in this study may have varying impacts on different types of arterial stenosis. Future research should explore these factors further to strengthen the basis for personalized treatment. This study highlights the importance of personalized medicine in assessing and managing arterial stenosis risks.However, there are limitations. As a single-center study, there may be selection bias, and the study population could differ significantly from the broader population in terms of genetics, lifestyle, and environmental factors. This heterogeneity may affect the mechanisms of atherosclerosis and its complications. While the study provides valuable insights into ischemic stroke patients in a specific region, the findings' external validity is limited. Future research should expand the sample size and include multicenter cohorts from diverse geographic areas to enhance generalizability. Additionally, the exclusion criteria may have led to insufficient representation of patients with multiple comorbidities, which are common in clinical practice. To improve the clinical applicability of the findings, it is essential to include more patients with multiple diseases.Finally, this study defined significant stenosis as greater than 50%. However, vascular events depend not only on stenosis degree but also on plaque characteristics. Relying solely on this criterion may overlook high-risk patients with stenosis below this threshold. Future research should adopt a more comprehensive assessment approach, considering plaque morphology, stability, and other risk factors to accurately evaluate patients' vascular risks.

Conclusion

This study examines the risk factors for isolated stenosis in cerebral and coronary arteries, highlighting key differences between them. We identified that the primary risk factors for intracranial artery stenosis include hyperlipidemia, a history of stroke, internal carotid artery stenosis, advanced age, and elevated D-dimer levels. In contrast, coronary artery stenosis is more influenced by obesity, alcohol consumption, and renal function.

Patients with dual arterial stenosis often show more complex systemic changes, leading to significant interactions among risk factors. The cumulative effect of these factors can increase disease risk, while single stenoses may be independently influenced by specific factors independently.

The developed predictive model developed showed high accuracy in identifying dual stenosis cases, but further refinement is needed to reduce the number of false positives. Future research should involve larger, multicenter studies to validate these findings and explore the interactions of risk factors in cerebral and coronary artery stenosis.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12883-025-04024-8.

Supplementary Material 1: Table S1: Regression analysis of risk factors in patients with low-risk single intracranial artery stenosis and single coronary artery stenosis.

Supplementary Material 2: Table S2: Regression analysis of risk factors in patients with low-risk single coronary artery stenosis and cardio-cerebral dual artery stenosis.

Supplementary Material 3: Table S3: Regression analysis of risk factors in patients with low-risk single intracranial artery stenosis and cardio-cerebral dual stenosis.

Supplementary Material 4: Table S4: Summary of regression analysis.

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Author contributions
Conceptualization, H.D. and R.D.; Data collection, G.Z. and S.D.; Data analysis, G.Z. and S.D.; Investigation, F.F. and W.K.; Writing—original draft preparation, G.Z.; Writing—review and editing, H.D. and R.D. All authors have read and agreed to the published version of the manuscript.G.Z.: Gege Zhang, S.D.: Sijie Dong, F.F.: Fanfan Feng, W.K.: Weihao Kan, H.D.: Hongmei Ding, R.D.: Ruiguo Dong.This section combines your provided information, assigning contributions to each author according to the CRediT (Contributor Roles Taxonomy) definitions. It ensures that authorship is limited to those who have contributed substantially to the work reported.

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This research received no external funding.

Data availability
The data and R codes are available from the corresponding author upon reasonable request.

Declarations

Ethics approval
This retrospective study was conducted in accordance with the Declaration of Helsinki and approved by Clinical Trial Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (approval number: XYFY2023-KL014-01, approved on January 19, 2023). Due to the retrospective nature of the study, the requirement for individual informed consent was waived by the ethics committee. The study strictly adhered to medical research regulations and patient privacy protection guidelines, with all clinical data being anonymized. The researchers ensured that data collection and usage complied with ethical standards, and all clinical information was kept strictly confidential.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Consent for participation
Clinical Trial Ethics Committee of the Affiliated Hospital of Xuzhou Medical University has waived the requirement for individual informed consent due to the retrospective nature of this study.

Informed consent
Not applicable.

Conflict of interest
The authors declare no conflicts of interest.

Institutional Review Board Statement
Not applicable.

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