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Association of Aortic Elasticity with Graft Patency in Patients After Coronary Artery Bypass Grafting: A Preliminary Analysis

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Abstract

Background

Aortic elasticity is an important indicator of vascular function, yet its relationship with graft patency after coronary artery bypass grafting (CABG) remains inadequately studied. This study aimed to evaluate the association between aortic elasticity parameters and graft patency after CABG, and to determine whether these parameters provide incremental predictive value beyond traditional clinical risk factors.

Methods

A total of 118 patients who underwent CABG (368 grafts) were retrospectively enrolled. Aortic elasticity parameters including diameter change rate (%Ao), distensibility, compliance, and stiffness index were measured using coronary computed tomography angiography (CCTA). Graft patency was assessed by CCTA. A generalized linear mixed model (GLMM) was applied to account for clustering effects of multiple grafts within the same patient. Three prediction models were constructed and compared using receiver operating characteristic (ROC) curves.

Results

Aortic compliance was significantly lower in the occluded graft group than in the patent group (1.1 ± 0.48 vs. 1.31 ± 0.65 mm²/mmHg, P = 0.007). In both arterial and venous graft subgroups, occluded grafts showed significantly higher stiffness and lower distensibility and compliance (all P < 0.001). Multivariate GLMM analysis identified %Ao (OR = 0.32, 95% CI: 0.18–0.62, P < 0.001) and LVEF (OR = 0.96, 95% CI: 0.93–0.99, P < 0.001) as independent protective factors for graft patency. The joint model combining clinical factors with %Ao demonstrated significantly improved predictive performance (AUC = 0.82, 95% CI: 0.77–0.87) compared with the clinical model alone (AUC = 0.68, P < 0.05).

Conclusions

Reduced aortic elasticity is independently associated with graft occlusion after CABG. Incorporating aortic diameter change rate into traditional clinical risk models provides incremental predictive value for graft patency, which may facilitate individualized risk stratification and antithrombotic management in CABG patients.

Introduction

Coronary artery disease (CAD) remains one of the leading causes of mortality and morbidity worldwide. Its pathological basis is coronary atherosclerosis, which can lead to myocardial ischemia, infarction, heart failure, and other serious adverse outcomes [1]. According to the Global Burden of Disease Study,

CAD causes over 9 million deaths annually, and its incidence continues to rise in China [2]. Despite advances in pharmacotherapy and interventional techniques, coronary artery bypass grafting (CABG) remains the widely accepted "gold standard" treatment for complex multivessel disease, especially in patients with concomitant diabetes mellitus, left ventricular dysfunction, or diffuse lesions [3, 4].

CABG surgical techniques have become highly mature, with perioperative mortality significantly reduced to 1%–3%. However, long-term graft patency remains a critical factor affecting patients' long-term quality of life and major adverse cardiovascular events (MACE). The long-term patency rates of different graft conduits differ significantly: the 10-year patency rate of the left internal mammary artery (LIMA) exceeds 95%, whereas the 1-year occlusion rate of saphenous vein grafts (SVG) can reach 10%–25%, and the 5-year occlusion rate is as high as 40%–50% [5, 6]. The 10-year patency rate of the radial artery can also reach 91% [7]. Graft occlusion can lead to myocardial ischemia, recurrent angina, heart failure, arrhythmias, and even death; therefore, preventing graft failure is a key determinant of successful CABG. However, current clinical risk prediction for graft disease relies mainly on traditional risk factors (e.g., age, diabetes, dyslipidemia), with limited predictive accuracy. There is an urgent need for novel biomarkers to improve individualized risk stratification.

Aortic elasticity is an important indicator of vascular function, reflecting the relative changes in luminal diameter and cross-sectional area per unit pressure. Loss of aortic elasticity is considered an early biomechanical marker of adverse vascular wall remodeling, leading to increased pulse wave velocity (PWV), increased systolic afterload, and decreased diastolic perfusion pressure. Numerous studies have confirmed that increased aortic stiffness is an independent predictor of cardiovascular events [8]. For CABG patients, the ascending aorta is the core operative area (cannulation, cross-clamping, proximal anastomosis), and its increased stiffness may affect graft outcomes through multiple mechanisms: on one hand, the reduced aortic expansion during the cardiac cycle in less elastic aortas leads to more concentrated cyclic stress at the anastomotic site, potentially promoting local intimal hyperplasia and anastomotic stenosis; on the other hand, increased aortic stiffness reduces diastolic perfusion pressure, decreasing graft blood flow—especially in arterial grafts that rely on diastolic perfusion—and inducing competitive flow and even thrombosis [9, 10]. Furthermore, aortic stiffness is a surrogate marker of systemic atherosclerotic burden; patients with poor elasticity often have diffuse vascular disease, and their grafts (particularly venous grafts) are more prone to atherosclerotic changes [11].

Although studies have shown that reduced aortic elasticity is associated with severity of coronary artery disease and poor prognosis in CAD patients [12], research specifically examining the relationship between aortic elasticity and graft patency after CABG remains scarce. The few existing studies have limited sample sizes, short follow-up durations, inadequate control for confounders, and have not systematically explored whether this association differs by graft type (arterial vs. venous). Therefore, whether aortic elasticity can serve as an independent predictor of graft occlusion after CABG currently lacks sufficient evidence-based support.

To this end, the present study aims to systematically evaluate the association between aortic elasticity parameters (diameter change rate, distensibility, compliance, stiffness index) and graft patency after CABG, and to investigate whether these parameters can serve as prognostic indicators independent of traditional risk factors. Additionally, by integrating traditional clinical risk factors with aortic elasticity metrics, we seek to construct a more comprehensive risk assessment model to provide a theoretical basis for postoperative graft occlusion risk stratification and individualized antithrombotic management in CABG patients.

Materials and Methods

This was a single-center, retrospective observational study approved by the Medical Ethics Review Committee of Yan'an Hospital Affiliated to Kunming Medical University (approval No. 2025-139-01). All patients provided written informed consent.

Patients

A total of 118 patients who underwent CCTA re-examination after CABG between September 2023 and December 2025 were enrolled, comprising 368 grafts. Inclusion criteria: (1) first-time CABG; (2) at least one postoperative coronary CTA examination with image quality meeting diagnostic requirements; (3) complete clinical and imaging data; (4) baseline sinus rhythm and no contraindications to the examination. Exclusion criteria: (1) surgery not performed at our institution; (2) concurrent other cardiac surgeries (valve replacement, ascending aortic replacement, ventricular aneurysmectomy, etc.); (3) image quality deemed poor for diagnostic purposes.

A total of 118 patients who underwent coronary artery bypass grafting (CABG) with 368 grafts were included in the final analysis after applying inclusion and exclusion criteria.

Examination Methods

Blood Pressure Measurement

Within 30 minutes before CTA scanning, brachial artery blood pressure was measured twice on the right upper arm using an Omron electronic sphygmomanometer (HEM-1020), and the average value was recorded. Systolic pressure (Ps), diastolic pressure (Pd), and pulse pressure (dP = Ps − Pd) were documented.

CTA Examination

Cardiac and great vessel CTA was performed using a Siemens dual-source CT (SOMATOM Definition Flash) with retrospective ECG-gated sequencing. Patients were placed in the supine position with a head-to-foot scanning direction, ECG leads attached, and the scan range from the thoracic inlet to the diaphragm level. The contrast medium used was iohexol 350 (350 mg I/100 ml). Scan parameters: slice

thickness 0.6 mm, rotation time 0.28 s, tube voltage 100–120 kV, tube current 500 mA. Contrast injection was performed via a dual-syringe high-pressure injector through the antecubital vein using a three-phase protocol: first, 75 ml of contrast at 5 ml/s; then 30 ml of a 3:7 (volume ratio) mixture of contrast and saline; followed by 30 ml of saline. The actual delay time was obtained by adding 5 s to the peak attenuation time in a region of interest (ROI) placed in the ascending aorta. Full-dose exposure was set at 20%–90% of the R-R interval.

Image Post-processing and Analysis

Raw data were reconstructed at 5% intervals from 20% to 90% of the R-R interval and transferred to the Syngo.via workstation for post-processing, including multiplanar reconstruction (MPR), curved planar reconstruction (CPR), and volume rendering (VR). Graft connection patterns, number of grafts, and patency status were carefully evaluated.

All graft images were assessed comprehensively by two cardiovascular radiologists with over 10 years of experience; disagreements were resolved by consensus.

Image quality grading: Excellent (high clarity, no artifacts); Good (moderately clear, minor artifacts, still diagnostic); Poor (blurred, significant artifacts). Only images rated Excellent or Good were included in subsequent analyses.

Graft patency evaluation criteria: Based on imaging findings, graft status was classified into two categories: Patent (good visualization, lumen stenosis < 50%) and Adverse Patency (significant stenosis with lumen stenosis ≥ 50% or total occlusion). Patients were accordingly divided into Patent group and Occluded group based on graft status.

Aortic Elasticity Measurement

ROI for the ascending aorta: set at 25 mm above the sinotubular junction (at the level of the right pulmonary artery). Aortic inner diameter and cross-sectional area were measured at each phase; measurements were taken at every 45° angle and averaged. Systolic diameter (Ds), diastolic diameter (Dd), systolic area (Ss), and diastolic area (Sd) were obtained.

Based on references from Ning, Lalande, Broyd et al., the following aortic elasticity parameters were calculated at the ROI level: diameter change rate (%Ao), aortic distensibility (AoD, $mmHg^{-1}$), aortic compliance (AoC, $mm^2/mmHg$), and aortic stiffness index (AoSI). The formulas are:

$$\%Ao = 100\times(Ds-Dd)/Dd$$

$$AoD=[(Ss-Sd)/Sd]/dP$$

$$AoC=(Ss-Sd)/dP$$

AoSI = Ln(Ps/Pd)/[(Ds-Dd)/Dd]

Where Ds and Dd are the maximum and minimum diameters of the ascending aorta at the ROI during the cardiac cycle, Ss and Sd are the corresponding maximum and minimum areas, Ps and Pd are peripheral systolic and diastolic pressures, dP is pulse pressure, and ln is the natural logarithm.

The region of interest (ROI) was set at 25 mm above the sinotubular junction (at the level of the right pulmonary artery). Aortic diameter and cross-sectional area were measured at end-systole and end-diastole, with four measurements taken at 45° intervals and averaged.

Statistical Analysis

All raw data were collated using Excel and analyzed with SPSS version 27.0. Categorical variables were compared using the χ^2 test. Continuous variables were tested for normality; normally distributed data are expressed as mean ± standard deviation (SD), and non-normally distributed data as median (interquartile range). Intergroup comparisons were performed using independent-samples t-test or Mann-Whitney U test as appropriate. Graft outcome (patent/adverse) was used as the dependent variable, and a generalized linear mixed model (GLMM) was applied to account for the clustering effect of multiple grafts within the same patient, with patient ID included as a random intercept. Variables with $P < 0.10$ in univariate analysis were entered into the multivariate model. Variable selection was performed using stepwise regression (forward selection). Three prediction models were constructed: a Clinical model (age, diabetes, graft type, LVEF), an Aortic Elasticity model (diameter change rate, %Ao), and a Joint model (Clinical + %Ao). Receiver operating characteristic (ROC) curves were used to calculate the area under the curve (AUC), and differences between models were compared using the DeLong test. Sensitivity, specificity, positive predictive value, and negative predictive value were reported. The net reclassification improvement (NRI) was used to evaluate the incremental predictive value of the Joint model over the Clinical model. All tests were two-sided, with $\alpha = 0.05$ considered statistically significant.

Results

Baseline Clinical Characteristics of the Study Population

A total of 118 patients who underwent CABG were included, with a total of 368 grafts. Based on graft patency status at follow-up, grafts were divided into Patent group (n = 314) and Occluded group (n = 54). Baseline characteristics of patients corresponding to grafts are summarized in Table 1. Both groups were predominantly male (80.3% vs. 66.7%). Patients in the Patent group were younger than those in the Occluded group (59.61 ± 9.2 vs. 63.89 ± 10.76 years), while LVEF (60.63 ± 7.10 vs. 53.36 ± 9.55, p = 0.003) and BMI (25.31 ± 3.17 vs. 24.21 ± 2.53) were slightly higher in the Patent group. No statistically significant differences were observed between the two groups in history of diabetes (38.2% vs. 50.0%), hypertension (65.6% vs. 68.5%), or smoking history (35.2% vs. 40.0%). These results indicate that baseline demographic and clinical characteristics were comparable between groups.

Aortic parameters for the Patent and Occluded groups are summarized in Table 2. Aortic compliance was significantly better in the Patent group than in the Occluded group (1.31 ± 0.65 vs. 1.1 ± 0.48, P = 0.007). The proportion of arterial grafts was 46.8% in the Patent group versus 25.9% in the Occluded group. Other aortic parameters (e.g., aortic distensibility) did not show significant differences.

Table 1
Baseline clinical characteristics of the study population

Variable	**Patent(n = 314)**	**Occluded(n = 54)**	t/x^2	***P* value**
Gender (Male,%)	252 (80.3%)	36 (66.7%)	1.991	0.047
Patient_Age	59.61 ± 9.2	63.89 ± 10.76	-2.752	0.008
BMI (kg/m²)	25.31 ± 3.17	24.21 ± 2.53	2.829	0.006
Systolic_BP (mmHg)	119.52 ± 13.24	116.44 ± 11.98	1.714	0.091
Diastolic_BP (mmHg)	78.27 ± 9.66	76.04 ± 9.16	1.642	0.105
Pulse_Pressure (mmHg)	41.25 ± 7.68	40.41 ± 6.99	0.804	0.424
Hypertension (N,%)	206 (65.6%)	37 (68.5%)	0.295	0.768
Hyperlipidemia (N,%)	39 (12.4%)	4 (7.4%)	-0.735	0.462
Diabetes (N,%)	120 (38.2%)	27 (50%)	1.202	0.229
Smoking_History (N,%)	147 (46.8%)	18 (33.3%)	-1.181	0.237
Drinking (N,%)	83 (26.4%)	12 (22.2%)	-0.577	0.564
LVEF%	60.63 ± 7.10	53.36 ± 9.55	-2.98	0.003
Total_Cholesterol (mmol/L)	2.68 ± 1.23	2.75 ± 1.14	-0.453	0.652
Triglycerides (mmol/L)	0.98 ± 0.22	1.04 ± 0.25	-1.731	0.088
HDL-C (mmol/L)	11.16 ± 0.77	11.34 ± 0.78	-1.528	0.131
LDL-C (mmol/L)	27.42 ± 3.03	27.88 ± 3.87	-0.837	0.406
HBA1c (%)	5.54 ± 10.28	5.13 ± 6.29	0.352	0.726
CRP (mg/L)	6.81 ± 1.62	6.31 ± 1.52	2.196	0.031
WBC (10^9/L)	4.13 ± 1.27	3.83 ± 1.19	1.728	0.088
RBC (10^{12}/L)	1.91 ± 0.57	1.75 ± 0.53	2.006	0.048
HGB (g/L)	0.54 ± 0.24	0.53 ± 0.22	0.48	0.633
PLT (10^9/L)	216.79 ± 56.27	214.8 ± 64.39	0.214	0.831

Data are presented as mean ± standard deviation (SD) for continuous variables and as number (percentage) for categorical variables. P values were calculated using independent-samples t-test for continuous variables and χ^2 test for categorical variables. BMI, body mass index; BP, blood pressure; LVEF, left ventricular ejection fraction; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; CRP, C-reactive protein; WBC, white blood cell count; RBC, red blood cell count; HGB, hemoglobin; PLT, platelet count.

Table 2
Aortic parameters in Patent vs. Occluded graft groups

Variable	**Patent(n = 314)**	**Occluded(n = 54)**	***t/x²***	***P* value**
Systolic_Diameter (cm)	3.36 ± 0.37	3.3 ± 0.36	1.246	0.217
Diastolic_Diameter (cm)	3.24 ± 0.36	3.19 ± 0.36	0.95	0.345
Systolic_Area (cm²)	9.14 ± 2.05	8.75 ± 1.81	1.425	0.158
Diastolic_Area (cm²)	8.6 ± 1.9	8.3 ± 1.75	1.155	0.252
Diameter_Change_Rate (%)	3.72 ± 1.4	3.38 ± 1.46	1.548	0.126
Arterial_Distensibility (10^{-3}/mmHg)	1.54 ± 0.73	1.42 ± 0.7	1.145	0.256
Arterial_Compliance (mm²/mmHg)	1.31 ± 0.65	1.1 ± 0.48	2.78	0.007
Arterial_Stiffness	12.98 ± 5.47	14.04 ± 6.21	-1.185	0.240
Graft_Type (Artery,%)	147 (46.8%)	14 (25.9%)	2.561	0.010
Aortic_Sinus_Diameter (mm)	33.73 ± 3.53	33.37 ± 4.34	0.555	0.581
Ascending_Aortic_Diameter (mm)	34.42 ± 4.01	33.72 ± 3.49	1.332	0.187

Data are presented as mean ± standard deviation (SD) for continuous variables and as number (percentage) for categorical variables. P values were calculated using independent-samples t-test for continuous variables and χ^2 test for categorical variables. Patent grafts were defined as those with lumen stenosis < 50%; occluded grafts were defined as those with lumen stenosis ≥ 50% or total occlusion. %Ao, diameter change rate; AoD, aortic distensibility; AoC, aortic compliance; AoSI, aortic stiffness index.

Comparison of Aortic Elasticity Parameters Between Graft Types

We further analyzed aortic elasticity parameters according to graft type. In the arterial graft subgroup (Table 3 and Fig. 3a), compared with occluded arterial grafts, patent arterial grafts exhibited significantly better aortic elasticity. Specifically, the patent group had significantly higher diameter change rate (7.9 ± 2.1 vs. 5.2 ± 1.7, P < 0.001), aortic distensibility (4.3 ± 1.4 vs. 2.8 ± 0.8 ×10^{-3}/mmHg, P < 0.001), and aortic

compliance (6.9 ± 1.0 vs. 4.5 ± 1.3 mm²/mmHg, P < 0.001). Conversely, the aortic stiffness index was significantly lower in the patent group (8.1 ± 2.8 vs. 12.3 ± 3.5, P < 0.001).

In the venous graft subgroup (Table 4 and Fig. 3b), similar trends were observed. Compared with occluded venous grafts, patent venous grafts had significantly higher aortic compliance (7.5 ± 1.8 vs. 5.2 ± 1.5 mm²/mmHg, P < 0.001) and distensibility (4.8 ± 1.3 vs. 3.1 ± 0.9 ×10⁻³/mmHg, P < 0.001). The occluded venous graft group showed significantly higher aortic stiffness index (10.6 ± 3.1 vs. 7.2 ± 2.5, P < 0.001). These findings suggest that impaired aortic elasticity is closely associated with graft disease in both arterial and venous conduits.

Table 3
Comparison of aortic elasticity parameters between patent and occluded arterial grafts

Variable	**Patent(n = 147)**	**Occluded(n = 14)**	**HR(95% CI)**	***P* value**
Diameter_Change_Rate (%)	7.9 ± 2.1	5.2 ± 1.7	2.7(2.1–3.3)	< 0.001
Arterial_Distensibility (10^{-3}/mmHg)	4.3 ± 1.4	2.8 ± 0.8	1.5(1.1–1.9)	< 0.001
Arterial_Compliance (mm²/mmHg)	6.9 ± 1.0	4.5 ± 1.3	2.4(1.9–2.9)	< 0.001
Arterial_Stiffness	8.1 ± 2.8	12.3 ± 3.5	−4.2(−5.1-−3.3)	< 0.001

Data are presented as mean ± standard deviation (SD). HR, hazard ratio; CI, confidence interval. Patent grafts were defined as those with lumen stenosis < 50%; occluded grafts were defined as those with lumen stenosis ≥ 50% or total occlusion. %Ao, diameter change rate; AoD, aortic distensibility (×10^{-3}/mmHg); AoC, aortic compliance (mm²/mmHg); AoSI, aortic stiffness index. P values were calculated using independent-samples t-test.

Table 4
Comparison of aortic elasticity parameters between patent and occluded venous grafts

Variable	**Patent(n = 167)**	**Occluded(n = 40)**	**HR(95% CI)**	***P* value**
Diameter_Change_Rate (%)	8.5 ± 2.3	5.8 ± 1.9	2.7(2.1–3.3)	< 0.001
Arterial_Distensibility (10^{-3}/mmHg)	4.8 ± 1.3	3.1 ± 0.9	1.7(1.3–2.1)	< 0.001
Arterial_Compliance (mm²/mmHg)	7.5 ± 1.8	5.2 ± 1.5	2.3(1.8–2.8)	< 0.001
Arterial_Stiffness	7.2 ± 2.5	10.6 ± 3.1	−3.4(−4.2-−2.6)	< 0.001

Data are presented as mean ± standard deviation (SD). HR, hazard ratio; CI, confidence interval. Patent grafts were defined as those with lumen stenosis < 50%; occluded grafts were defined as those with lumen stenosis ≥ 50% or total occlusion. %Ao, diameter change rate; AoD, aortic distensibility ($\times 10^{-3}$/mmHg); AoC, aortic compliance (mm^2/mmHg); AoSI, aortic stiffness index. P values were calculated using independent-samples t-test.

Univariate and Multivariate GLMM Analysis for Graft Disease After CABG

To account for the clustering effect of multiple grafts within the same patient, a generalized linear mixed model (GLMM) was constructed with graft outcome (patent/adverse) as the dependent variable, and stepwise regression was applied to identify independent influencing factors.

Univariate analysis (Table 5) showed that patient age (P = 0.039), BMI (P = 0.041), LVEF% (P < 0.001), graft type (arterial, P = 0.010), and aortic diameter change rate (P < 0.001) were significantly associated with adverse graft patency. Hypertension, diabetes, smoking history, ascending aortic dimensions, and aortic stiffness index showed no statistical association in this study (all P > 0.05). After adjusting for confounders in multivariate analysis (Table 5), the final independent factors retained in the model were:

Aortic diameter change rate (%Ao) (OR = 0.32, 95% CI: 0.18–0.62, P < 0.001): as the core manifestation of aortic elasticity, each unit increase in %Ao reduced the risk of adverse graft outcome by approximately 66%, making it the strongest independent protective factor for long-term graft patency.

LVEF% (OR = 0.96, 95% CI: 0.93–0.99, P < 0.001): each 1% increase in left ventricular systolic function reduced the risk of adverse outcome by 4%, confirming the protective role of adequate cardiac output in maintaining forward graft flow.

Graft type (arterial bridge) (OR = 0.45, 95%CI: 0.17–0.84, P = 0.020): After adjusting for other confounding factors, the use of arterial bridge grafts was identified as an independent protective factor against graft lesions post-CABG (OR = 0.45), indicating a 55% reduced risk of lesion occurrence in arterial bridges compared to the reference group (typically venous bridges).

Patient age became marginally significant in the multivariate model (OR = 1.62, P = 0.055), suggesting that its effect was partially mediated by aortic elasticity and LVEF.

Table 5
Univariate and multivariate GLMM analysis for graft disease after CABG

Univariate analysis	**Odds Ratio (95% CI)**	**P value**
Patient_Age	1.65 (1.03–2.65)	0.039
BMI (kg/m²)	0.57 (0.34–0.98)	0.041
Systolic_BP (mmHg)	0.71 (0.42–1.19)	0.190
Diastolic_BP (mmHg)	0.75 (0.45–1.24)	0.263
Pulse_Pressure (mmHg)	0.79 (0.47–1.34)	0.385
LVEF%	0.94 (0.90–0.98)	< 0.001
LVEDV/ml	0.56 (0.3–1.03)	0.061
Aortic_Sinus_Diameter (mm)	0.78 (0.47–1.29)	0.331
Ascending_Aortic_Diameter (mm)	0.73 (0.43–1.21)	0.223
Graft_Type(artery)	0.79 (0.27–0.93)	0.010
Surgical_Technique	0.54 (0.11–2.61)	0.442
Hypertension	1.17 (0.41–3.38)	0.768
Hyperlipidemia	0.54 (0.11–2.78)	0.462
Diabetes	1.84 (0.68–4.98)	0.229
Smoking_History	0.55 (0.2–1.48)	0.237
Drinking	0.71 (0.22–2.28)	0.564
Diameter_Change_Rate (%)	0.34 (0.14–0.68)	< 0.001
Arterial_Distensibility (10^{-3}/mmHg)	0.56 (0.03–12.1)	0.709
Arterial_Compliance (mm²/mmHg)	0.39 (0.01–15.08)	0.614
Arterial_Stiffness	2.48 (0.28–22.34)	0.418
Multivariate analysis		
LVEF%	0.96 (0.93–0.99)	0.0008
Graft_Type (artery)	0.45 (0.17–0.84)	0.020
Diameter_Change_Rate (%)	0.32 (0.18–0.62)	< 0.001

Data are presented as odds ratio (OR) with 95% confidence interval (CI). GLMM, generalized linear mixed model; CABG, coronary artery bypass grafting; BMI, body mass index; BP, blood pressure; LVEF, left ventricular ejection fraction; LVEDV, left ventricular end-diastolic volume; %Ao, diameter change rate;

AoD, aortic distensibility; AoC, aortic compliance; AoSI, aortic stiffness index. The multivariate model was constructed using stepwise forward selection, including variables with P < 0.10 in univariate analysis. Patient ID was included as a random intercept to account for the clustering effect of multiple grafts within the same patient.

Comparison of Generalized Linear Mixed Models

Based on the independent factors identified in multivariate analysis, we constructed three GLMM prediction models of different dimensions and evaluated their predictive performance for adverse graft patency using C-statistic (AUC) and calibration metrics (Table 6, Fig. 5).

Model construction and performance:

Clinical model: included traditional risk factors (age, diabetes, graft type, LVEF). This model achieved an AUC of 0.68 (95% CI: 0.62–0.74), with sensitivity 65% and specificity 64%, indicating only modest predictive ability relying solely on demographic and comorbidity information.

Elasticity model: included aortic diameter change rate (%Ao) alone. Its AUC reached 0.75 (95% CI: 0.69–0.81), significantly outperforming some clinical indicators, suggesting that local biomechanical properties of the ascending aorta are effective imaging biomarkers for graft prognosis.

Joint model: integrated the Clinical model with %Ao. This model showed significantly improved predictive performance, with an AUC of 0.82 (95% CI: 0.77–0.87), sensitivity 78%, specificity 76%, and a net reclassification improvement (NRI) of 0.42.

Clinical incremental value:

Compared with the Clinical model alone, the Joint model yielded an AUC increase of 0.14 (DeLong test, P < 0.05). This result clearly indicates that incorporating the aortic diameter change rate—measured via routine CCTA—provides incremental predictive information beyond traditional risk factors. This model may assist clinicians in identifying patients at high risk for graft occlusion early after CABG, providing quantitative support for individualized antithrombotic and follow-up strategies.

Table 6
Predictive models for graft disease after CABG using independent risk factors

Model	C statistic(95% CI)	Sensitivity	Specificity	Positive predictive value	Negative predictive value	
Clinical model	0.68(0.62–0.74)	0.65	0.64	0.62	0.67	0.31
Aortic Elasticity model	0.75(0.69–0.81)	0.73	0.70	0.69	0.74	0.28
Joint model	0.82(0.77–0.87)	0.78	0.76	0.74	0.80	0.42

Data are presented with 95% confidence intervals (CI) where applicable. AUC, area under the curve; NRI, net reclassification improvement. The Clinical model included age, diabetes, graft type, and LVEF. The Aortic Elasticity model included aortic diameter change rate (%Ao) alone. The Joint model combined the Clinical model with %Ao. Model performance was evaluated using the C-statistic (AUC), with differences between models compared using the DeLong test .

The clinical model (age, diabetes, graft type, LVEF) demonstrated moderate predictive ability (AUC = 0.68, 95% CI: 0.62–0.74). The elasticity model (diameter change rate, %Ao, alone) achieved an AUC of 0.75 (95% CI: 0.69–0.81). The joint model (clinical model + %Ao) showed the best discrimination, with an AUC of 0.82 (95% CI: 0.77–0.87; DeLong test vs. clinical model, $P < 0.05$), indicating that adding %Ao to traditional clinical risk factors provides incremental predictive value for graft adverse patency.

Discussion

This study analyzed 368 grafts from 118 patients after CABG and found that aortic elasticity parameters were significantly associated with graft patency. The main findings are: (1) Aortic compliance was significantly lower in the Occluded group compared with the Patent group, and the proportion of arterial grafts was lower in the Occluded group (25.9% vs. 46.8%); (2) For both arterial and venous grafts, the Occluded groups had significantly higher aortic stiffness and significantly lower distensibility and compliance (all $P < 0.001$); (3) Multivariate GLMM analysis showed that aortic diameter change rate, LVEF and arterial graft type were independent protective factors; (4) The model combining aortic elasticity parameters had significantly better predictive performance than the clinical model alone (AUC increased from 0.68 to 0.82).

Loss of vascular elasticity is one of the earliest manifestations of adverse structural and functional changes in the vessel wall. Increased aortic stiffness is not only an independent risk factor for cardiovascular disease but also a strong predictor of cardiovascular morbidity and mortality [8,12]. After CABG, this systemic vascular dysfunction may directly affect the long-term outcomes of grafts. Our study confirms that impaired aortic elastic function (manifested as reduced compliance and increased stiffness) is closely associated with an elevated risk of graft occlusion, and this association is consistent in both arterial and venous graft subgroups. The underlying mechanisms can be explained from hemodynamic and biomechanical perspectives. First, increased aortic stiffness accelerates pulse wave velocity (PWV), leading to increased systolic afterload and decreased diastolic pressure, thereby reducing diastolic perfusion pressure of the graft. For arterial grafts that rely mainly on diastolic perfusion (e.g., internal mammary artery), this pressure reduction can directly decrease graft blood flow and induce competitive flow and even thrombosis [13]. Aortic stiffness also leads to lower diastolic pressure, which not only directly reduces flow but also causes disturbed laminar flow and decreased shear stress within the graft—particularly in venous grafts—which are core molecular mechanisms that activate endothelium and promote intimal hyperplasia [14]. Second, the reduced expansion amplitude of the stiffened aorta during the cardiac cycle leads to more concentrated cyclic stress at the anastomotic site, potentially promoting local intimal hyperplasia and anastomotic stenosis [15]. Moreover, aortic

stiffness is a surrogate marker of systemic atherosclerotic burden; patients with poor aortic elasticity often have diffuse vascular disease, and their grafts (especially venous grafts) are more prone to atherosclerotic changes [11]. In our study, both arterial and venous grafts in the Occluded groups demonstrated worse aortic elasticity parameters, supporting the aforementioned hypothesis of systemic vascular damage.

The long-term patency of arterial and venous conduits directly determines the clinical benefit of CABG [16]. Among the 54 occluded grafts in this study, venous grafts accounted for 74.9% and arterial grafts for only 25.9%; in the Patent group, arterial grafts comprised 46.8%. This distribution is consistent with the classic understanding that venous grafts have higher long-term occlusion rates than arterial grafts [17]. The pathophysiological mechanisms of arterial and venous graft disease differ fundamentally. Venous graft occlusion typically follows three phases: thrombosis predominates within the first month, neointimal hyperplasia from 1 to 12 months, and progressive atherosclerosis as the main driver after 1 year [18]. Vein grafts have thin walls and sparse smooth muscle layers, making them susceptible to endothelial injury and intimal hyperplasia under arterial pressure; thus, they are more sensitive to the "host aortic status." Our study found significantly lower aortic compliance in patients with occluded venous grafts (Table 4), which may further exacerbate hemodynamic stress on venous grafts. In contrast, arterial grafts (e.g., internal mammary artery, radial artery) have more robust vessel walls and intact endothelial function; their long-term patency depends mainly on competitive flow—i.e., whether the native coronary stenosis is severe enough to ensure forward laminar flow in the graft [19]. If the target vessel stenosis is insufficient (<70–80%), competitive flow may lead to slow or even retrograde flow in the arterial graft, inducing spasm and occlusion. Furthermore, our study identified LVEF as an independent protective factor for graft patency after CABG. This finding aligns with physiological expectations: LVEF reflects left ventricular systolic functional reserve; patients with preserved LVEF have better matching between myocardial perfusion demand and graft supply, and adequate postoperative cardiac output helps maintain forward laminar flow in grafts, reducing thrombosis risk [20]. Previous large registry studies have also shown that preoperative LVEF < 40% is a strong predictor of postoperative graft occlusion and cardiovascular death [21]. In our study, each 1-standard-deviation increase in LVEF (approximately 10%) was associated with a 4% reduction in graft occlusion risk, a considerable effect size. Age was a risk factor in univariate analysis (OR = 1.65, P = 0.039) but only marginally significant in the multivariate model (OR = 1.62, P = 0.055), suggesting that the effect of age on graft prognosis is partially mediated by aortic elasticity, LVEF, and other factors. Moreover, age exhibited significant collinearity with aortic elasticity parameters (e.g., diameter change rate); vascular elasticity naturally declines with age, so when elasticity indices entered the model, the independent effect of age was diluted, which is consistent with the pathophysiology of vascular aging [22].

By comparing the three GLMM models, we found that the model containing only clinical indicators (age, diabetes, graft type, LVEF) had moderate predictive performance (AUC = 0.68); the aortic elasticity model alone achieved an AUC of 0.75; and the joint model (clinical + aortic elasticity) increased the AUC to 0.82 (95% CI: 0.77–0.87), with sensitivity 78% and specificity 76%. The significant improvement in model performance suggests that traditional clinical risk assessment (relying mainly on demographics and

comorbidities) has limited ability to predict graft outcomes, and incorporating vascular functional metrics provides incremental predictive information. International studies have also found that adding PWV to the Framingham risk score significantly improves cardiovascular event prediction [23]; our study extends this concept to graft outcomes after CABG. Clinically, for patients with preoperative evidence of reduced aortic elasticity, intensified antiplatelet therapy (e.g., ticagrelor instead of aspirin) or earlier imaging follow-up (e.g., coronary CTA at 6 months postoperatively) could be considered to detect asymptomatic graft disease early.

Conclusion

This study systematically evaluated, for the first time in a relatively large sample, the relationship between aortic elasticity parameters and graft patency after CABG. We found that reduced ascending aortic diameter change rate (%Ao)、decreased LVEF and arterial graft type were independent protective factors for graft occlusion. Combining %Ao with traditional clinical models significantly improved the predictive performance for adverse graft outcomes, facilitating risk stratification and individualized antithrombotic management after CABG.

Limitations

This study has several limitations:Single-center, retrospective design: selection bias and residual confounding cannot be fully excluded, and causal inference should be made with caution.Inconsistent follow-up timing: the time points of postoperative graft assessment varied among patients; as graft occlusion rates accumulate over time, results from different follow-up windows are not directly comparable.Lack of target vessel characteristics: target vessel diameter, stenosis severity, and competitive flow significantly affect graft outcomes, especially for arterial grafts. Failure to adjust for these factors may have overestimated the risk effect of arterial grafts.Relatively small number of positive events (54 occluded grafts): this limited the ability to include more variables in the multivariate model (typically requiring at least 10–15 events per variable).Future prospective, multicenter studies with more detailed anatomical and therapeutic variables, and standardized elasticity measurement methods (e.g., PWV), are needed to validate our findings.

Declarations

Data availability statement

The datasets presented in this study can be found in article/supplementary material. Raw data are available from the corresponding author upon reasonable request.

Ethics statement

Ethics approval was obtained from the Ethics Committee of Yan‘an Hospital Affiliated to Kunming Medical University, and all participants provided written informed consent (2025-139-01).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Figures

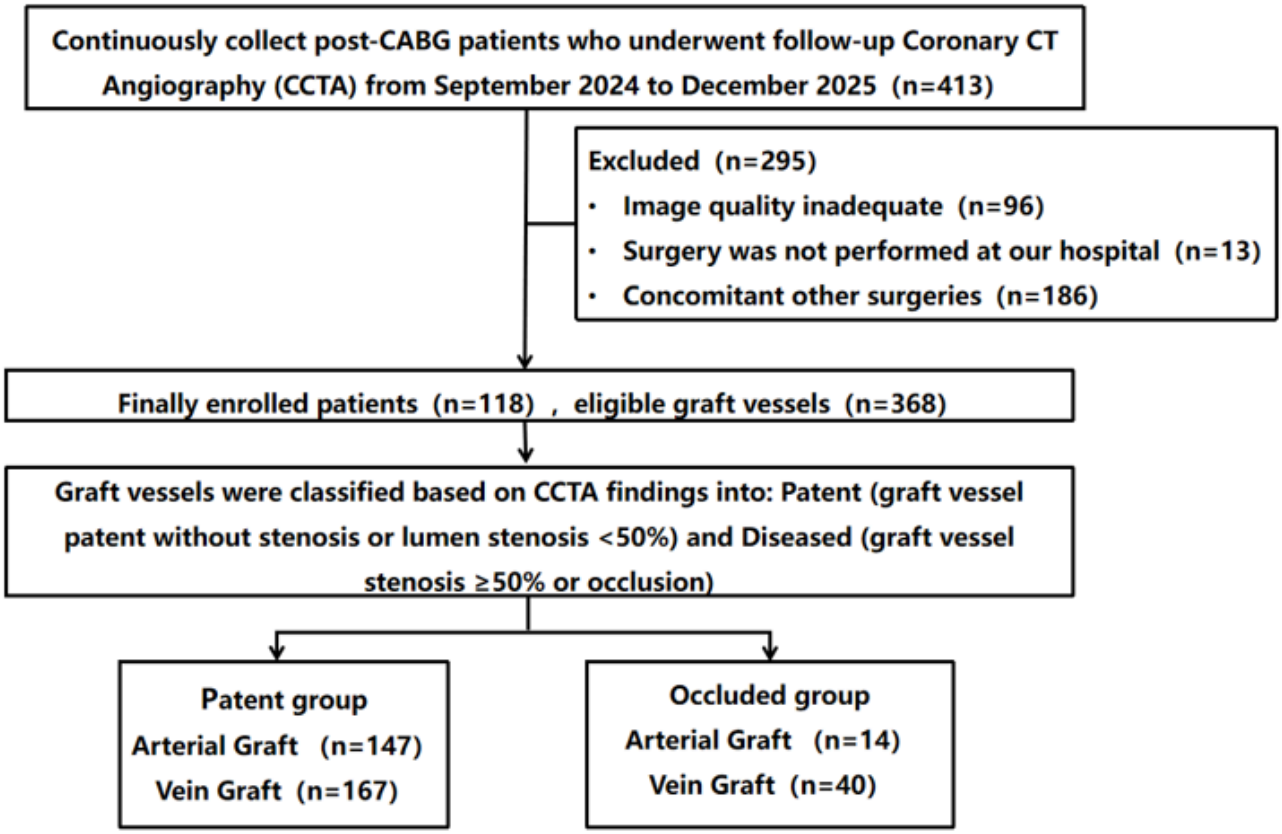


Figure 1

Study flow chart.

A total of 118 patients who underwent coronary artery bypass grafting (CABG) with 368 grafts were included in the final analysis after applying inclusion and exclusion criteria.

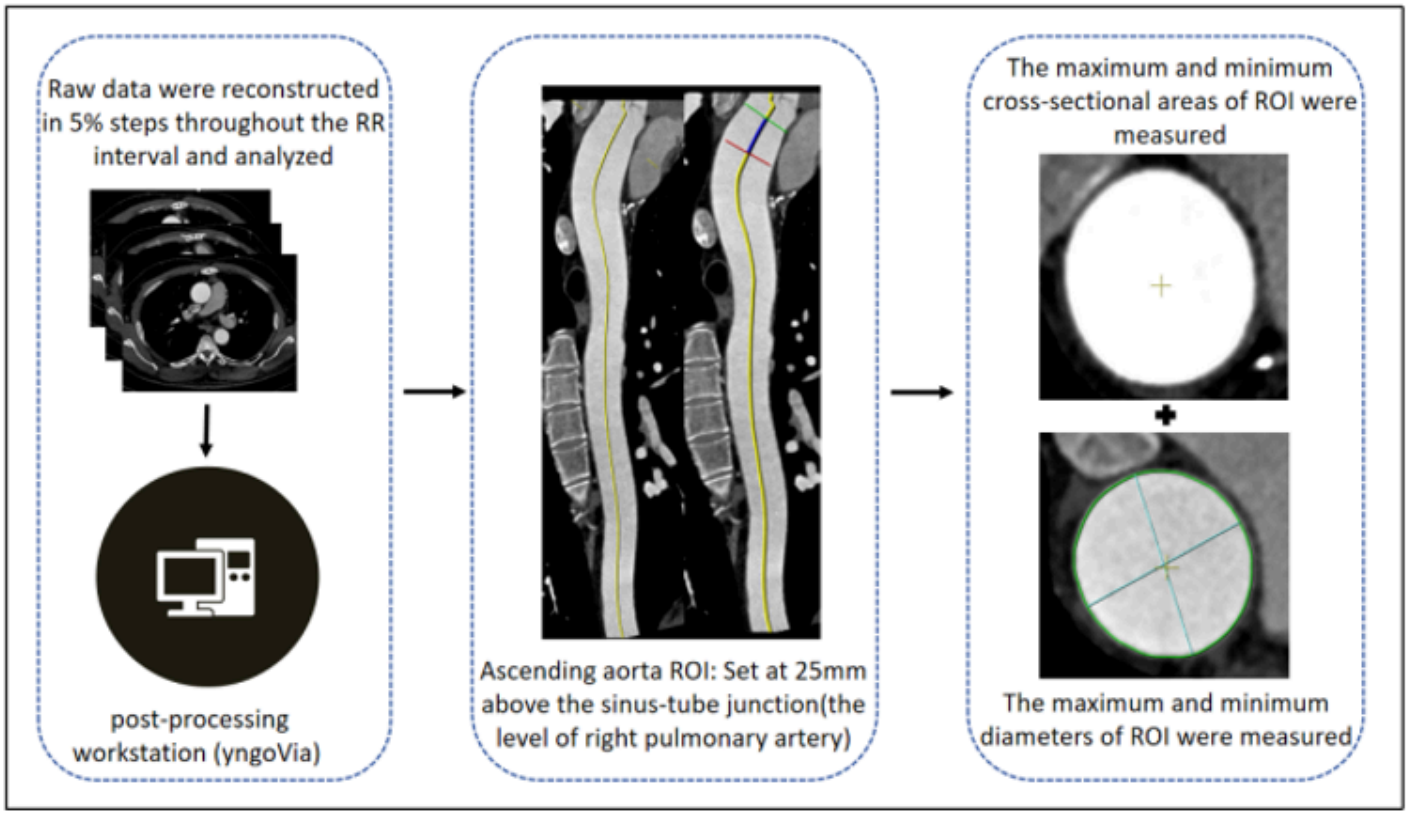


Figure 2

Aortic related parameter measure method.

The region of interest (ROI) was set at 25 mm above the sinotubular junction (at the level of the right pulmonary artery). Aortic diameter and cross-sectional area were measured at end-systole and end-diastole, with four measurements taken at 45° intervals and averaged.

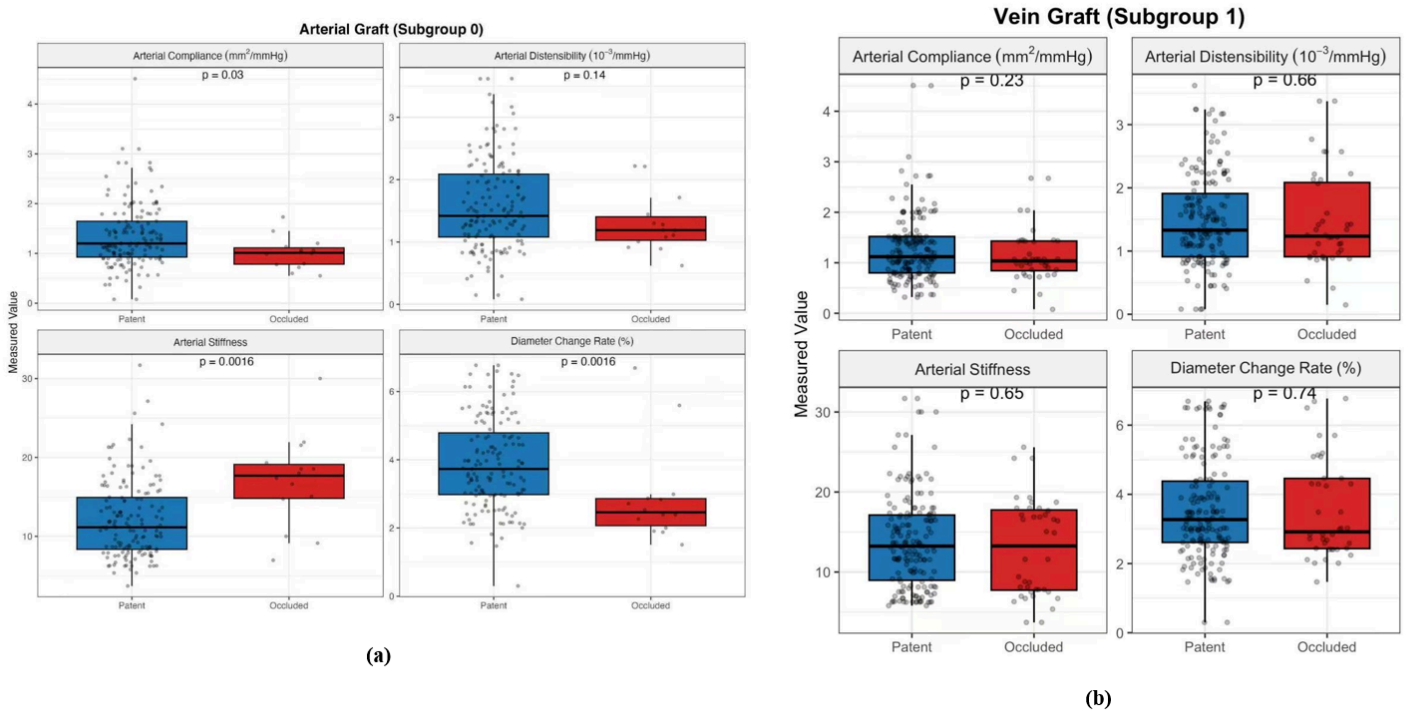


Figure 3

Comparison of aortic elasticity parameters between patent and occluded grafts stratified by graft type.

(a) Arterial graft subgroup (internal mammary artery or radial artery); (b) Venous graft subgroup (great saphenous vein). In both subgroups, patent grafts exhibited significantly higher diameter change rate (%Ao), aortic distensibility, and aortic compliance, as well as significantly lower aortic stiffness index compared with occluded grafts. All P values < 0.001. Data are presented as mean ± standard deviation. Abbreviations: Patent, graft stenosis < 50%; Occluded, graft stenosis ≥ 50% or total occlusion; %Ao, diameter change rate; DIS, aortic distensibility (×10⁻³/mmHg); COMP, aortic compliance (mm²/mmHg); STIF, aortic stiffness index.

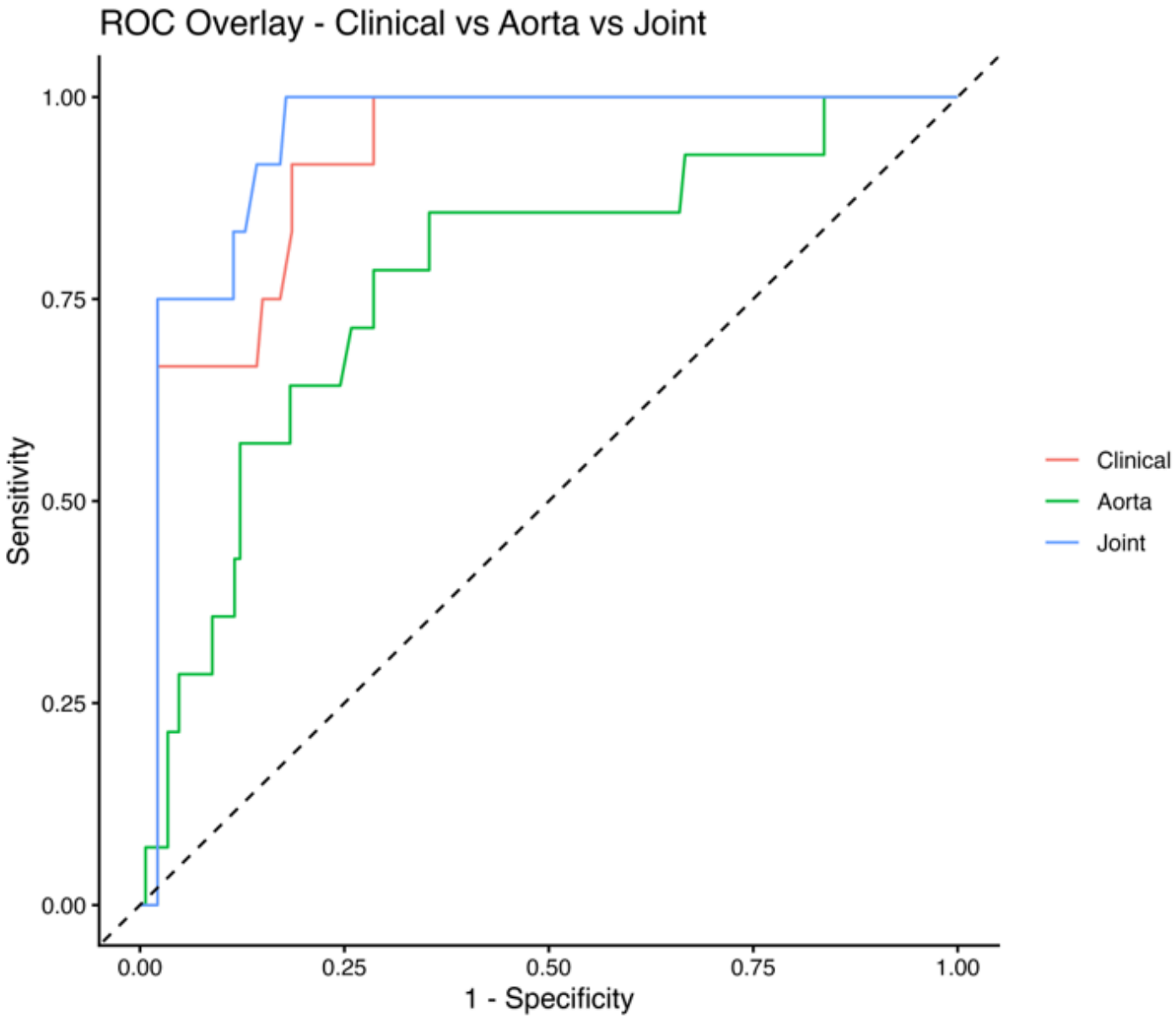


Figure 4

Receiver operating characteristic (ROC) curves of three generalized linear mixed models for predicting graft adverse patency.

The clinical model (age, diabetes, graft type, LVEF) demonstrated moderate predictive ability (AUC = 0.68, 95% CI: 0.62–0.74). The elasticity model (diameter change rate, %Ao, alone) achieved an AUC of 0.75 (95% CI: 0.69–0.81). The joint model (clinical model + %Ao) showed the best discrimination, with an AUC of 0.82 (95% CI: 0.77–0.87; DeLong test vs. clinical model, $P < 0.05$), indicating that adding %Ao to traditional clinical risk factors provides incremental predictive value for graft adverse patency.

Abbreviations: ROC, receiver operating characteristic; AUC, area under the curve; CI, confidence interval; GLMM, generalized linear mixed model; %Ao, diameter change rate.