Supplemental Material

Epicardial Adipose Tissue Volume and the Naples Prognostic Score as Complementary Predictors of MACE After TAVR

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Supplemental Methods

Study design and ethics

This single-center retrospective cohort study was conducted at the Affiliated Hospital of Qingdao University and approved by the Medical Ethics Committee of the hospital (approval No. QYFYWZLL50843). The study strictly followed the ethical principles of the Declaration of Helsinki and the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines [47]. Since the study was a retrospective analysis, all data were derived from routine clinical practice and anonymized, involving no additional risk to patients or privacy disclosure. Therefore, informed consent was waived.

Study population

A total of 472 consecutive patients with severe aortic stenosis who underwent TAVR at our hospital from January 2020 to July 2025 were initially screened. Patients were excluded step by step according to the exclusion criteria: 8 patients with valvular disease who had previously received TAVR; 7 patients with acute myocardial infarction, active infection or active malignant tumor within 3 months before surgery; 28 patients with poor CT image quality that precluded EAT measurement or missing key data; 2 patients lost to follow-up after surgery. Finally, 427 patients meeting the inclusion and exclusion criteria were enrolled (Figure 1).

Inclusion criteria

Patients with aortic stenosis presenting with clinical symptoms such as chest pain, dyspnea and syncope; meeting the echocardiographic diagnostic criteria for severe AS: aortic valve peak velocity > 4.0 m/s, or mean transvalvular pressure gradient ≥ 40 mmHg (1 mmHg = 0.133 kPa), or valve area < 1.0 cm^2; or effective aortic valve area index < 0.6 cm^2/m^2; assessed by the multidisciplinary heart team as suitable for TAVR on the basis of anatomical suitability, frailty, comorbidity and patient preference, and who underwent TAVR. All patients underwent TAVR successfully via the femoral approach. Complete computed tomography angiography (CTA) images within 3 months before surgery were available for epicardial adipose tissue volume measurement. Complete results of routine blood tests and biochemistry tests within 1 week before surgery were available for calculating the Naples Prognostic Score (NPS).

Exclusion criteria

Patients were excluded if they had a malignant tumor, active infection or active autoimmune disease; had previously undergone TAVR; had congenital aortic stenosis; had combined severe mitral stenosis; or had hypertrophic cardiomyopathy with left ventricular outflow tract obstruction, pericardial disease (constrictive pericarditis or massive pericardial effusion) affecting EAT volume measurement, missing coronary CTA data, or had been lost to follow-up.

Data collection

Baseline clinical, imaging, laboratory and surgical data were retrospectively collected through the hospital electronic medical record system, imaging system and laboratory system.

Baseline clinical data

Data collected included demographic characteristics (sex, age, body mass index (BMI), smoking history, NYHA class), past medical history (hypertension, diabetes, hyperlipidemia, chronic pulmonary disease, cerebrovascular disease, atrial fibrillation history, myocardial infarction history, previous percutaneous coronary intervention (PCI) history), echocardiographic indicators (bicuspid aortic valve, left ventricular ejection fraction (LVEF), Doppler velocity index (DVI), peak aortic valve velocity, peak transvalvular pressure gradient, mean transvalvular pressure gradient, aortic valve area, pulmonary artery systolic pressure), surgical data (type of implanted valve), and laboratory indicators (white blood cells, neutrophils, lymphocytes, monocytes, hemoglobin, platelets, NLR, lymphocyte-to-

monocyte ratio (LMR), D-dimer, NT-proBNP, albumin, HDL-C, LDL-C, lipoprotein(a), Cr, estimated glomerular filtration rate (eGFR)). The Doppler velocity index (DVI) is the ratio of the left ventricular outflow tract velocity-time integral to the aortic valve velocity-time integral (equivalently, the ratio of the corresponding peak velocities), a dimensionless measure of the hemodynamic severity of aortic stenosis; a DVI below 0.25 is consistent with severe stenosis.

CT image acquisition

CTA images of all enrolled patients were acquired preoperatively. CT examination was performed with a 128-slice dual-source multislice spiral CT scanner (Revolution CT; GE MEDICAL SYSTEMS) with contrast-enhanced scan. The contrast medium dosage was 100.0 mL, and the flow rate was not recorded. Scanning parameters included: tube voltage 100 kV, tube current 649 mA, rotation time 0.28 s/rotation, slice thickness 0.625 mm, interval 0.625 mm.

Epicardial adipose tissue volume measurement

EAT volume was quantified on preoperative routine aortic CTA images using a semi-automatic volumetric method (TIMESlice), the accuracy of which has been validated against manual measurement by radiology experts [48]. The software automatically defined the cardiac range (1 cm above the aortic annulus to the cardiac base), covering the total epicardial adipose tissue in line with the accepted anatomical definition for EAT quantification [49], and applied a preset adipose tissue threshold (−190 to −30 HU) together with an anatomical recognition algorithm to identify the inner edge of the visceral pericardium and the outer myocardial surface (Figure 2A–C). Two physicians with more than 5 years of experience in cardiovascular imaging independently reviewed and corrected the boundaries, after which the software calculated the total EAT volume (Figure 2D), converted from mm^3 to cm^3. Patients were divided into a low EAT group (≤ median) and a high EAT group (> median) according to the cohort median, consistent with previous TAVR cohort studies in which CT-derived EAT volume has typically been categorized by the median, tertiles or quartiles rather than by reference values [28,50,51]; a sensitivity analysis modeling EAT volume as a continuous variable yielded consistent results (Supplemental Table S1). Inter-observer agreement was assessed by the intraclass correlation coefficient (ICC), which was 0.92 (95% CI 0.88–0.95), and the average of the two measurements was used for analysis.

Naples prognostic score calculation

Based on fasting venous blood test results within 1 week before surgery, the total NPS was calculated using the established criteria, comprising four indicators, with 1 point for each abnormality, total score 0–4: serum albumin < 4 g/dL; total cholesterol < 180 mg/dL; neutrophil-to-lymphocyte ratio (NLR) > 2.96; lymphocyte-to-monocyte ratio (LMR) ≤ 4.44. A score of 0–2 was defined as the low-NPS group, and 3–4 as the high-NPS group. The cutoff values of the four indicators used in this study are consistent with the original scoring criteria proposed by Galizia et al. [34], and related studies in the TAVR field have all adopted the same thresholds [41–43], ensuring cross-study comparability. The optimal cutoff value fitted from the study population data was not used to avoid overfitting risk and facilitate clinical promotion.

EuroSCORE II

Calculated via the official online calculator and included in the analysis as a continuous variable[52].

Follow-up and endpoint

Patients were followed up through outpatient reexamination and telephone follow-up. The follow-up start point was the day of surgery, and the follow-up cutoff date was July 2026. The primary endpoint was major adverse cardiovascular events (MACE), defined according to the Valve Academic Research Consortium-3 (VARC-3) criteria [53], as a composite endpoint including all-cause death, myocardial infarction, ischemic stroke and heart failure rehospitalization. Myocardial infarction was defined as elevated myocardial injury biomarkers accompanied by

symptoms of myocardial ischemia, new ischemic changes on electrocardiogram or new evidence of myocardial necrosis on imaging. Ischemic stroke was defined as new focal neurological deficit confirmed to be of ischemic etiology by imaging. Heart failure rehospitalization was defined as hospitalization due to worsening heart failure symptoms, which met the diagnostic criteria for heart failure and responded to intensified diuretic, vasodilator and other anti-heart failure treatments. The first occurrence of any of these events during follow-up was classified as MACE.

Statistical analysis

Statistical analyses were performed with R 4.5.3 (R Foundation for Statistical Computing, Vienna, Austria). All tests were two-tailed and $P < 0.05$ was considered statistically significant. Continuous variables were summarized as mean ± SD or median (interquartile range) according to the Shapiro–Wilk test and compared with the independent-samples t test or the Mann–Whitney U test; categorical variables were summarized as n (%) and compared with the χ^2 test or Fisher exact test. Baseline characteristics were compared between patients with and without MACE. No missing values were present for any analyzed variable.

Before modeling, the correlation between the two core exposures (EAT volume and NPS) was assessed by Spearman rank correlation, and multicollinearity was assessed by the variance inflation factor (VIF), with VIF < 5 considered acceptable. Univariable Cox proportional hazards regression was first used to screen candidate variables, but covariates for the multivariable models were selected according to clinical prior knowledge rather than univariable P values, in order to avoid data-driven selection and over-adjustment. EuroSCORE II was used as the baseline adjustment term; hypertension, NYHA class ≥ III and the Doppler velocity index (DVI) were additionally included to account for inflammatory comorbidity, baseline cardiac function and the hemodynamic severity of aortic stenosis, respectively. Age, sex and eGFR are components of EuroSCORE II, and hemodynamic variables (valve area and peak velocity) were excluded because they are highly correlated with DVI. Four progressively nested models were constructed: Model 1 (baseline clinical model: hypertension, NYHA class ≥ III, DVI and EuroSCORE II); Models 2 and 3 (Model 1 plus high EAT and high NPS, respectively); and Model 4 (Model 1 plus both markers).

The proportional hazards (PH) assumption was tested using Schoenfeld residuals and was considered violated at $P < 0.05$. For models in which it was violated, a time-varying coefficient model was additionally fitted with $\beta(t) = \beta_0 + \beta_1 \times \log(t)$; time-specific hazard ratios were derived at 3, 6, 12, 18, 24, 36, 48 and 60 months, and this model was compared with the standard PH model by likelihood-ratio test. Hazard ratios from the standard Cox models were therefore interpreted as average effects over the follow-up period.

Model performance and incremental value were evaluated as follows: likelihood-ratio tests for nested model comparisons; Harrell's C-index for overall discrimination, with 95% CI derived from the robust standard error; time-dependent ROC curves with Kaplan–Meier marginal weighting for the 12- and 24-month AUCs; calibration curves comparing observed (Kaplan–Meier) with predicted 24-month MACE incidence across quintiles of the predicted risk, with the 95% CI of the observed estimate, assessed by the Grønnesby–Borgan (Nam–D'Agostino) goodness-of-fit test, and the calibration slope obtained by refitting a Cox model on the linear predictor; decision curve analysis across threshold probabilities; and the net reclassification index (NRI) and integrated discrimination improvement (IDI) at 24 months (tertile-based primary analysis and binary sensitivity analysis), with 95% CIs and P values obtained from 1,000 bootstrap resamples. Kaplan–Meier curves with the log-rank test were used to compare MACE-free survival across risk strata. The interaction between high EAT and high NPS was assessed with a product term and likelihood-ratio test, with stratified analyses. Subgroup analyses were performed for sex, age (< 75 / ≥ 75 years), NYHA class, diabetes and aortic valve anatomy, using the likelihood-ratio test for interaction. Restricted cubic splines (3 knots at the 10th, 50th and 90th percentiles of EAT volume, with the median as reference) were used to assess the dose–response relationship between EAT volume and MACE. Internal validation used 1,000 bootstrap resamples to derive optimism-corrected C-index and 24-month AUC values. Sensitivity analyses excluded 30-day perioperative events and modeled EAT volume as a continuous variable. With 89 events and 6 variables in the final model (event-to-variable ratio ≈ 14.8:1), the analysis satisfied the conventional requirement of at least 10 events per variable.

Supplemental Table S1. Sensitivity analysis using continuous EAT volume.

Model type	HR per 10 cm³ increase (95% CI)	*P* value
Base + continuous EAT	1.16 (1.07–1.25)	<0.001
Combined model (continuous EAT)	1.17 (1.08–1.27)	<0.001

EAT volume was modelled as a continuous variable (per 10 cm³ increase). CI, confidence interval; EAT, epicardial adipose tissue; HR, hazard ratio.

Supplemental Table S2. Univariable Cox regression analysis of all 44 candidate variables.

Variable	HR (95% CI)	*P* value
EuroSCORE II, per 1% increase	1.15 (1.09–1.21)	<0.001
High EAT	3.84 (2.31–6.38)	<0.001
High NPS	2.64 (1.73–4.03)	<0.001
DVI	81.30 (11.80–559.99)	<0.001
Hypertension	2.47 (1.58–3.86)	<0.001
Age, years	1.06 (1.03–1.10)	<0.001
Epicardial adipose tissue volume, cm^3	1.01 (1.01–1.02)	<0.001
Hemoglobin, g/L	0.98 (0.97–0.99)	<0.001
eGFR, mL/min/1.73 m^2	0.99 (0.98–0.99)	0.002
NYHA class ≥ III	1.78 (1.15–2.76)	0.009
LMR	0.84 (0.74–0.96)	0.013
Sex (male vs female)	0.60 (0.40–0.91)	0.017
Aortic valve peak velocity, m/s	0.69 (0.51–0.94)	0.019
Peak transvalvular gradient, mmHg	0.99 (0.98–1.00)	0.020
Serum albumin, g/L	0.94 (0.90–0.99)	0.024
Mean transvalvular gradient, mmHg	0.98 (0.97–1.00)	0.026
Aortic valve area, cm^2	3.23 (1.09–9.59)	0.034
Myocardial infarction	0.26 (0.06–1.06)	0.061
Total cholesterol, mmol/L	0.84 (0.69–1.01)	0.069
NLR	1.03 (1.00–1.06)	0.073
Cerebrovascular disease	1.58 (0.92–2.73)	0.097
LDL-C, mmol/L	0.81 (0.64–1.04)	0.097
Lymphocyte count, $\times 10^9$/L	0.74 (0.52–1.06)	0.099
D-dimer, ng/mL	1.00 (1.00–1.00)	0.145
Monocyte count, $\times 10^9$/L	1.79 (0.72–4.43)	0.208
Bicuspid aortic valve	0.64 (0.31–1.35)	0.241
HDL-C, mmol/L	0.74 (0.39–1.41)	0.366
Hyperlipidemia	0.83 (0.55–1.27)	0.396
Prosthesis type	1.35 (0.67–2.71)	0.398
Smoking history	1.21 (0.77–1.90)	0.415
LVEF, %	1.01 (0.99–1.03)	0.438
Diabetes mellitus	1.17 (0.75–1.82)	0.481

Variable	HR (95% CI)	*P* value
BMI, kg/m²	1.02 (0.96–1.08)	0.516
Platelet count, ×10⁹/L	1.00 (1.00–1.00)	0.548
Atrial fibrillation	1.20 (0.62–2.31)	0.596
Triglycerides, mmol/L	0.93 (0.67–1.27)	0.635
Neutrophil count, ×10⁹/L	1.02 (0.92–1.13)	0.691
Lipoprotein(a), mg/L	1.00 (1.00–1.00)	0.693
WBC, ×10⁹/L	0.98 (0.89–1.08)	0.711
Chronic lung disease	1.10 (0.53–2.29)	0.791
Cr, μmol/L	1.00 (1.00–1.00)	0.812
Pulmonary hypertension	1.04 (0.68–1.59)	0.868
Prior PCI	1.04 (0.55–1.96)	0.905
NT-proBNP, pg/mL	1.00 (1.00–1.00)	0.907

BMI, body mass index; CI, confidence interval; Cr, creatinine; DVI, Doppler velocity index; EAT, epicardial adipose tissue; eGFR, estimated glomerular filtration rate; HDL-C, high-density lipoprotein cholesterol; HR, hazard ratio; LDL-C, low-density lipoprotein cholesterol; LMR, lymphocyte-to-monocyte ratio; LVEF, left ventricular ejection fraction; MACE, major adverse cardiovascular events; NLR, neutrophil-to-lymphocyte ratio; NPS, Naples prognostic score; NT-proBNP, N-terminal pro-B-type natriuretic peptide; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; TAVR, transcatheter aortic valve replacement; WBC, white blood cell count. Hazard ratios for the Doppler velocity index are expressed per 1-unit increase. Hazard ratios for sex are expressed as male versus female (female as reference).

Supplemental Table S3. Variance inflation factors for collinearity assessment.

Variable	VIF	Conclusion
Hypertension	1.07	No collinearity
NYHA class ≥ III	1.09	No collinearity
Doppler velocity index (DVI)	1.13	No collinearity
EuroSCORE II	1.12	No collinearity
High EAT	1.03	No collinearity
High NPS	1.08	No collinearity

VIF, variance inflation factor. VIF < 5 was considered to indicate acceptable collinearity.

Supplemental Table S4. Global test of the proportional hazards assumption.

Model	Global P value	Conclusion
Model 1: Base model	0.131	PH assumption met
Model 2: Base + high EAT	0.006	PH assumption violated
Model 3: Base + high NPS	0.098	PH assumption met
Model 4: Combined model	0.003	PH assumption violated

PH, proportional hazards. The global test is based on Schoenfeld residuals; $P < 0.05$ indicates violation of the PH assumption.

Supplemental Table S5. Proportional hazards assumption test by variable.

Model	Variable	Chi-square	P value
Model 1: Base model	Hypertension	0.089	0.765
Model 1: Base model	NYHA class ≥ III	5.574	0.018
Model 1: Base model	Doppler velocity index (DVI)	0.576	0.448
Model 1: Base model	EuroSCORE II	0.195	0.659
Model 1: Base model	Global test	7.095	0.131
Model 2: Base + high EAT	Hypertension	0.104	0.747
Model 2: Base + high EAT	NYHA class ≥ III	5.856	0.016
Model 2: Base + high EAT	Doppler velocity index (DVI)	2.031	0.154
Model 2: Base + high EAT	EuroSCORE II	0.277	0.599
Model 2: Base + high EAT	High EAT	6.595	0.010
Model 2: Base + high EAT	Global test	16.175	0.006
Model 3: Base + high NPS	Hypertension	0.107	0.743
Model 3: Base + high NPS	NYHA class ≥ III	5.140	0.023
Model 3: Base + high NPS	Doppler velocity index (DVI)	0.653	0.419
Model 3: Base + high NPS	EuroSCORE II	0.038	0.845
Model 3: Base + high NPS	High NPS	2.281	0.131
Model 3: Base + high NPS	Global test	9.286	0.098
Model 4: Combined model	Hypertension	0.067	0.795
Model 4: Combined model	NYHA class ≥ III	5.844	0.016
Model 4: Combined model	Doppler velocity index (DVI)	1.741	0.187
Model 4: Combined model	EuroSCORE II	0.291	0.589
Model 4: Combined model	High EAT	6.837	0.009
Model 4: Combined model	High NPS	2.167	0.141
Model 4: Combined model	Global test	19.785	0.003

PH, proportional hazards. Chi-square, chi-square statistic of the scaled Schoenfeld residual test; the global test summarizes the joint test within each model.

Supplemental Table S6. Time-varying effect of high EAT and high NPS on MACE.

Variable	Time point	HR (95% CI)	P value
High EAT	3 months	3.64 (2.04–6.50)	<0.001
High EAT	6 months	4.35 (2.26–8.36)	<0.001
High EAT	12 months	5.19 (2.46–10.97)	<0.001
High EAT	18 months	5.76 (2.56–12.95)	<0.001
High EAT	24 months	6.20 (2.63–14.61)	<0.001
High EAT	36 months	6.88 (2.73–17.35)	<0.001
High EAT	48 months	7.40 (2.79–19.63)	<0.001
High EAT	60 months	7.84 (2.84–21.63)	<0.001
High NPS	3 months	1.89 (1.21–2.96)	0.006
High NPS	6 months	1.66 (1.03–2.67)	0.036
High NPS	12 months	1.46 (0.86–2.48)	0.159
High NPS	18 months	1.36 (0.77–2.40)	0.296
High NPS	24 months	1.29 (0.70–2.35)	0.416
High NPS	36 months	1.19 (0.62–2.30)	0.599
High NPS	48 months	1.13 (0.56–2.27)	0.730
High NPS	60 months	1.08 (0.52–2.25)	0.827

Time-specific hazard ratios were derived from a time-varying coefficient model with $\beta(t) = \beta_0 + \beta_1 \times \log(t)$. CI, confidence interval; EAT, epicardial adipose tissue; HR, hazard ratio; NPS, Naples prognostic score.

Supplemental Table S7. Subgroup analysis of the combined prediction model.

Subgroup	Stratum	No. of patients	MACE events	High vs low HR (95% CI)	Within-stratum *P* value	*P* for interaction
Sex	Female	165	43	8.21 (2.87–23.53)	<0.001	0.537
	Male	262	46	7.90 (3.08–20.26)	<0.001	
Age	<75 years	223	31	6.40 (2.21–18.51)	<0.001	0.672
	≥75 years	204	58	6.39 (2.83–14.41)	<0.001	
NYHA class	NYHA class I–II	204	31	8.37 (2.50–28.06)	<0.001	0.523
	NYHA class III–IV	223	58	7.93 (3.34–18.82)	<0.001	
Diabetes mellitus	No	305	59	10.31 (4.08–26.05)	<0.001	0.548
	Yes	122	30	6.60 (1.93–22.56)	0.003	
Bicuspid aortic valve	Tricuspid aortic valve	377	81	8.78 (4.19–18.41)	<0.001	0.681
	Bicuspid aortic valve	50	8	3.49 (0.39–31.39)	0.264	

HRs compare the high-risk with the low-risk group of the combined model within each stratum. CI, confidence interval; EAT, epicardial adipose tissue; HR, hazard ratio; MACE, major adverse cardiovascular events; NPS, Naples prognostic score; NYHA, New York Heart Association.

Supplemental Table S8. Key estimates from the restricted cubic spline analysis of EAT volume.

EAT volume, cm^3	HR	95% CI
96.4	1.02	(0.85–1.22)
100.5	1.00	(0.90–1.11)
107.2	1.00	(1.00–1.00)
112.7	1.05	(1.01–1.10)
119.9	1.18	(1.09–1.28)

Estimates were derived from a restricted cubic spline with 3 knots at the 10th, 50th and 90th percentiles of EAT volume, with the median (107.2 cm^3) as the reference. CI, confidence interval; EAT, epicardial adipose tissue; HR, hazard ratio.

Supplemental Table S9. Bootstrap internal validation of the combined model.

Metric	Apparent performance	Optimism	Optimism-corrected performance
C-index	0.751	0.008	0.742
24-month AUC	0.757	−0.005	0.762

Internal validation used 1,000 bootstrap resamples. Optimism-corrected performance = apparent performance − optimism. AUC, area under the receiver operating characteristic curve; C-index, concordance index.

Supplemental Table S10. Sensitivity analysis excluding 30-day perioperative events: predictive performance.

Metric	Original	After excluding perioperative events	Difference
C-index	0.751	0.746	−0.005
24-month AUC	0.757	0.760	0.003

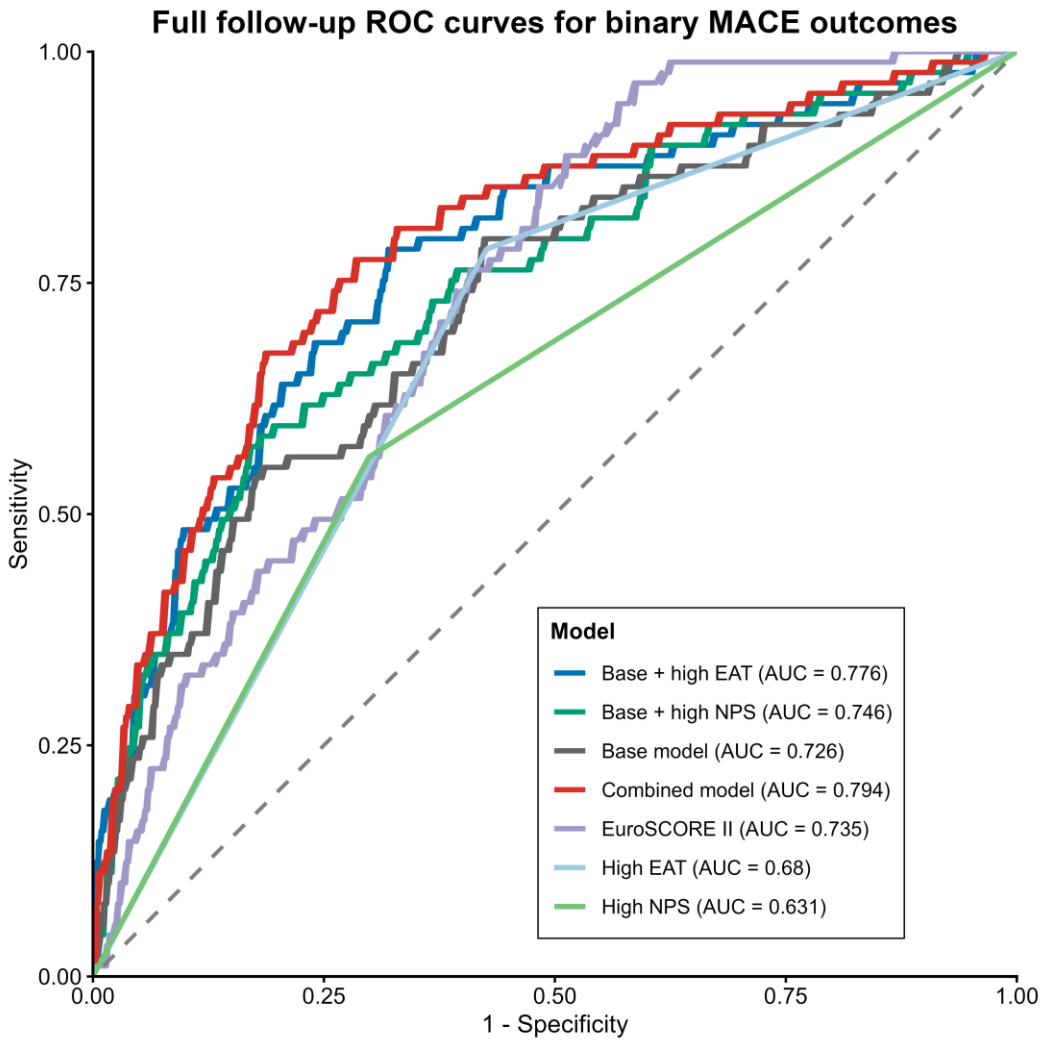
Sensitivity analysis after excluding 30-day perioperative events. AUC, area under the receiver operating characteristic curve; C-index, concordance index.

Supplemental Table S11. Sensitivity analysis excluding 30-day perioperative events: hazard ratio comparison.

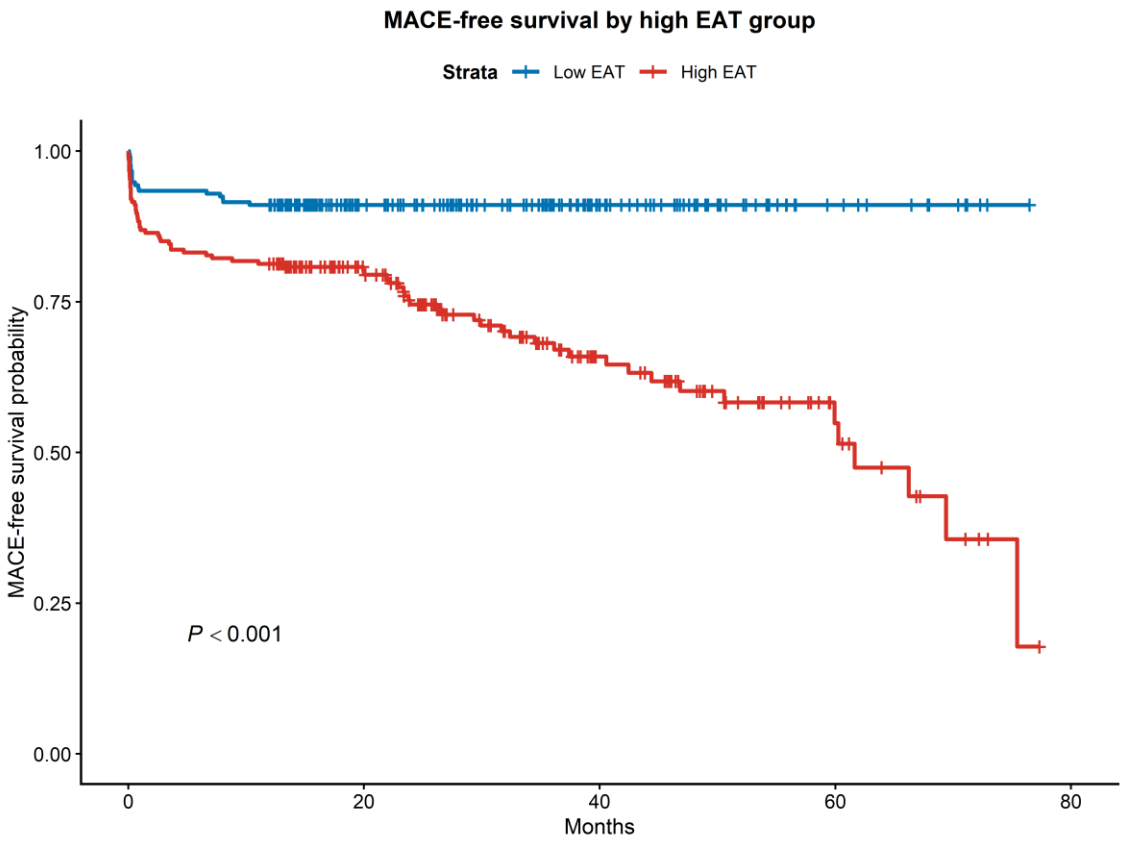
Variable	Original HR	Original 95% CI	Original P value	Sensitivity HR	Sensitivity 95% CI	Sensitivity P value
Hypertension	2.11	1.33–3.35	0.001	1.73	0.93–3.20	0.082
NYHA class ≥ III	1.49	0.94–2.35	0.088	0.87	0.49–1.57	0.646
DVI, per 0.1 unit	1.41	1.15–1.73	<0.001	2.00	1.17–3.42	0.011
EuroSCORE II, per 1% increase	1.11	1.03–1.19	0.006	1.04	0.87–1.24	0.671
High EAT	3.01	1.80–5.03	<0.001	9.05	3.45–23.77	<0.001
High NPS	1.96	1.27–3.04	0.003	1.43	0.80–2.57	0.229

Hazard ratios from the primary analysis (Original) and from the sensitivity analysis excluding 30-day perioperative events (Sensitivity). CI, confidence interval; DVI, Doppler velocity index; EAT, epicardial adipose tissue; HR, hazard ratio; NPS, Naples prognostic score; NYHA, New York Heart Association.

Supplemental Figure S1. Full follow-up ROC curves for binary MACE outcomes.



Supplemental Figure S2. Kaplan-Meier curves for MACE-free survival by high EAT group.



Supplemental Figure S3. Kaplan-Meier curves for MACE-free survival by high NPS group.

