Supplement

Predicting outcomes following open abdominal aortic aneurysm repair using machine learning

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eTable 1. Transparent Reporting of a Multivariable Prediction Model for Individual Prognosis or Diagnosis + Artificial Intelligence (TRIPOD+AI) checklist for prediction model development

Section/Topic	Item	Development / evaluation[1]	Checklist item	Reported on page
TITLE				
Title	1	D;E	Identify the study as developing or evaluating the performance of a multivariable prediction model, the target population, and the outcome to be predicted	1
ABSTRACT				
Abstract	2	D;E	See TRIPOD+AI for Abstracts checklist	3
INTRODUCTION				
Background	3a	D;E	Explain the healthcare context (including whether diagnostic or prognostic) and rationale for developing or evaluating the prediction model, including references to existing models	4-5
	3b	D;E	Describe the target population and the intended purpose of the prediction model in the context of the care pathway, including its intended users (e.g., healthcare professionals, patients, public)	4-5
	3c	D;E	Describe any known health inequalities between sociodemographic groups	4-5
Objectives	4	D;E	Specify the study objectives, including whether the study describes the development or validation of a prediction model (or both)	4-5
METHODS				
Data	5a	D;E	Describe the sources of data separately for the development and evaluation datasets (e.g., randomised trial, cohort, routine care or registry data), the rationale for using these data, and representativeness of the data	5-6
	5b	D;E	Specify the dates of the collected participant data, including start and end of participant accrual; and, if applicable, end of follow-up	5-6
Participants	6a	D;E	Specify key elements of the study setting (e.g., primary care, secondary care, general population) including the number and location of centres	5-6
	6b	D;E	Describe the eligibility criteria for study participants	5-6
	6c	D;E	Give details of any treatments received, and how they were handled during model development or evaluation, if relevant	5-6
Data preparation	7	D;E	Describe any data pre-processing and quality checking, including whether this was similar across relevant sociodemographic groups	5-6
Outcome	8a	D;E	Clearly define the outcome that is being predicted and the time horizon, including how and when assessed, the rationale for choosing this outcome, and whether the method of outcome assessment is consistent across sociodemographic groups	7-8
	8b	D;E	If outcome assessment requires subjective interpretation, describe the qualifications and demographic characteristics of the outcome assessors	7-8
	8c	D;E	Report any actions to blind assessment of the outcome to be predicted	7-8
Predictors	9a	D	Describe the choice of initial predictors (e.g., literature, previous models, all available predictors) and any pre-selection of predictors before model building	6-7
	9b	D;E	Clearly define all predictors, including how and when they were measured (and any actions to blind assessment of predictors for the outcome and other predictors)	6-7
	9c	D;E	If predictor measurement requires subjective interpretation, describe the qualifications and demographic characteristics of the predictor assessors	6-7
Sample size	10	D;E	Explain how the study size was arrived at (separately for development and evaluation), and justify that the study size was sufficient to answer the research question. Include details of any sample size calculation	9-10
Missing data	11	D;E	Describe how missing data were handled. Provide reasons for omitting any data	9-10
Analytical methods	12a	D	Describe how the data were used (e.g., for development and evaluation of model performance) in the analysis, including whether the data were partitioned, considering any sample size requirements	8-10
	12b	D	Depending on the type of model, describe how predictors were handled in the analyses (functional form, rescaling, transformation, or any standardisation).	8-10
	12c	D	Specify the type of model, rationale[2], all model-building steps, including any hyperparameter tuning, and method for internal validation	8-10
	12d	D;E	Describe if and how any heterogeneity in estimates of model parameter values and model performance was handled and quantified across clusters (e.g., hospitals, countries). See TRIPOD-Cluster for additional considerations[3]	8-10
	12e	D;E	Specify all measures and plots used (and their rationale) to evaluate model performance (e.g., discrimination, calibration, clinical utility) and, if relevant, to compare multiple models	8-10
	12f	E	Describe any model updating (e.g., recalibration) arising from the model evaluation, either overall or for particular sociodemographic groups or settings	8-10
	12g	E	For model evaluation, describe how the model predictions were calculated (e.g., formula, code, object, application programming interface)	8-10
Class imbalance	13	D;E	If class imbalance methods were used, state why and how this was done, and any subsequent methods to recalibrate the model or the model predictions	8-10

Fairness	14	D;E	Describe any approaches that were used to address model fairness and their rationale	8-10
Model output	15	D	Specify the output of the prediction model (e.g., probabilities, classification). Provide details and rationale for any classification and how the thresholds were identified	8-10
Training versus evaluation	16	D;E	Identify any differences between the development and evaluation data in healthcare setting, eligibility criteria, outcome, and predictors	8-10
Ethical approval	17	D;E	Name the institutional research board or ethics committee that approved the study and describe the participant-informed consent or the ethics committee waiver of informed consent	5
OPEN SCIENCE				
Funding	18a	D;E	Give the source of funding and the role of the funders for the present study	21
Conflicts of interest	18b	D;E	Declare any conflicts of interest and financial disclosures for all authors	21
Protocol	18c	D;E	Indicate where the study protocol can be accessed or state that a protocol was not prepared	21-23
Registration	18d	D;E	Provide registration information for the study, including register name and registration number, or state that the study was not registered	21-23
Data sharing	18e	D;E	Provide details of the availability of the study data	21-23
Code sharing	18f	D;E	Provide details of the availability of the analytical code[4]	21-23
PATIENT & PUBLIC INVOLVEMENT				
Patient & Public Involvement	19	D;E	Provide details of any patient and public involvement during the design, conduct, reporting, interpretation, or dissemination of the study or state no involvement.	21-23
RESULTS				
Participants	20a	D;E	Describe the flow of participants through the study, including the number of participants with and without the outcome and, if applicable, a summary of the follow-up time. A diagram may be helpful.	10-11
	20b	D;E	Report the characteristics overall and, where applicable, for each data source or setting, including the key dates, key predictors (including demographics), treatments received, sample size, number of outcome events, follow-up time, and amount of missing data. A table may be helpful. Report any differences across key demographic groups.	11
	20c	E	For model evaluation, show a comparison with the development data of the distribution of important predictors (demographics, predictors, and outcome).	11-12
Model development	21	D;E	Specify the number of participants and outcome events in each analysis (e.g., for model development, hyperparameter tuning, model evaluation)	10-12
Model specification	22	D	Provide details of the full prediction model (e.g., formula, code, object, application programming interface) to allow predictions in new individuals and to enable third-party evaluation and implementation, including any restrictions to access or re-use (e.g., freely available, proprietary)[5]	21-23
Model performance	23a	D;E	Report model performance estimates with confidence intervals, including for any key subgroups (e.g., sociodemographic). Consider plots to aid presentation.	11-12
	23b	D;E	If examined, report results of any heterogeneity in model performance across clusters. See TRIPOD Cluster for additional details[3].	11-12
Model updating	24	E	Report the results from any model updating, including the updated model and subsequent performance	11-12
DISCUSSION				
Interpretation	25	D;E	Give an overall interpretation of the main results, including issues of fairness in the context of the objectives and previous studies	13-19
Limitations	26	D;E	Discuss any limitations of the study (such as a non-representative sample, sample size, overfitting, missing data) and their effects on any biases, statistical uncertainty, and generalizability	19
Usability of the model in the context of current care	27a	D	Describe how poor quality or unavailable input data (e.g., predictor values) should be assessed and handled when implementing the prediction model	13-19
	27b	D	Specify whether users will be required to interact in the handling of the input data or use of the model, and what level of expertise is required of users	13-19
	27c	D;E	Discuss any next steps for future research, with a specific view to applicability and generalizability of the model	20

eTable 2. Pre-operative input features for machine learning models

Features (n = 35)	Definition based on ACS NSQIP manual
Logistics	
Operation year	Year of procedure
Admission quarter	Quarter of admission
Demographics	
Age	Age in years
Sex	Male or female
Body mass index	Weight in kg / height in m^2
Race	As per medical record or self-assigned by the patient: 1) White, 2) Black or African American, 3) American Indian or Alaskan Native, 4) Native Hawaiian or Other Pacific Islander, 5) Asian, 6) Other, 7) Unknown/not reported
Ethnicity	Hispanic or non-Hispanic
Origin status	1) Transferred from another hospital or from 2) home, 3) nursing home, 4) other facility, or 5) unknown
Comorbidities	
Hypertension	Diagnosis documented in medical record and patient requires antihypertensive medication within 30 days prior to surgery
Diabetes	Documented diagnosis; non-insulin dependent or insulin-dependent
Current smoker	Patient has smoked cigarettes at any point within the 12 months prior to surgery
Congestive heart failure	Diagnosis documented by physician or advanced provider within 30 days prior to surgery and documentation of at least 1 of the following within 30 days prior to surgery: 1) active signs or symptoms of congestive heart failure, 2) New York Heart Association Functional Classification II-IV, 3) daily prescription of disease-modifying drugs for heart failure, 4) left ventricular ejection fraction < 40% on the most recent measurement prior to surgery, 5) elevated levels of natriuretic peptides (BNP ≥100 pg/mL or NT-proBNP ≥900 pg/mL), 6) patients with one of the following devices: ventricular assist device, implantable cardioverter defibrillator, or cardiac resynchronization therapy device.
Chronic obstructive pulmonary disease	Diagnosis documented in medical record and at least 1 of the following within 30 days prior to surgery: 1) functional disability from chronic obstructive pulmonary disease, 2) requires chronic bronchodilator therapy, 3) hospitalization at any time in the past for treatment of chronic obstructive pulmonary disease, or 4) a forced expiratory volume (FEV) 1 of < 75% on any prior pulmonary function test

Features (n = 35)	**Definition based on ACS NSQIP manual**
Dialysis	Documented peritoneal dialysis, hemodialysis, hemofiltration, hemodiafiltration, or ultrafiltration within 2 weeks prior to surgery
Functional status	1) Independent (does not require assistance for activities of daily living), 2) partially dependent (requires some assistance for activities of daily living), 3) totally dependent (requires total assistance for all activities of daily living, or 4) unknown
ASA class	1) Normal healthy patient, 2) mild systemic disease, 3) severe systemic disease, 4) severe systemic disease that is a constant threat to life, 5) moribund patient who is not expected to survive without the operation, or 6) not reported
Previous procedures	
Previous open AAA repair	Any previous documented open AAA repair
Previous endovascular AAA repair	Any previous documented endovascular AAA repair
Previous open abdominal surgery	Any previous documented open abdominal surgery
Pre-operative laboratory investigations	Collected within 90 days prior to surgery
Serum sodium	Reported in mmol/L
Blood urea nitrogen	Reported in mmol/L
Serum creatinine	Reported in umol/L
Albumin	Reported in g/L
White blood cell count	Reported in cells/mm^3
Hematocrit	Reported in %
Platelet count	Reported in 10^9/L
INR	Unitless ratio
PTT	Reported in seconds
Anatomic characteristics	
AAA diameter	Largest anterior-posterior measurement of AAA taken by CT or ultrasound prior to operation
Surgical approach	1) Transperitoneal, 2) retroperitoneal, or 3) not documented
Proximal AAA extent	Defined by the location in the aorta where the aneurysm begins on CT or MRI: 1) suprarenal (AAA begins above at least 1 main renal artery but below the celiac and superior mesenteric arteries), 2) pararenal (AAA involves the origin of the renal arteries), 3) juxtarenal (AAA does not involve the renal arteries but there is little/no normal aorta between the upper extent of the aneurysm

Features (n = 35)	Definition based on ACS NSQIP manual
	and the renal arteries, requiring clamping above the renal arteries to complete the proximal anastomosis), 4) infrarenal (AAA involves the aorta distal to the renal arteries with sufficient distance between the proximal extent of the aneurysm and the lowest renal artery to permit clamp placement), or 5) not documented
Distal AAA extent	Defined by the location where the AAA ends based on CT or MRI: 1) aorta, 2) common iliac artery, 3) internal iliac artery, 4) external iliac artery, or 5) not documented
Concomitant procedures	Procedure occurring in the same operating room setting as the index surgery
Renal revascularization	Documented reimplantation of or bypass to 1 or more renal arteries
Visceral revascularization	Documented endarterectomy or reimplantation of the celiac or superior mesenteric artery
Lower extremity revascularization	Documented bypass to or endovascular stent placement in the infrainguinal arteries

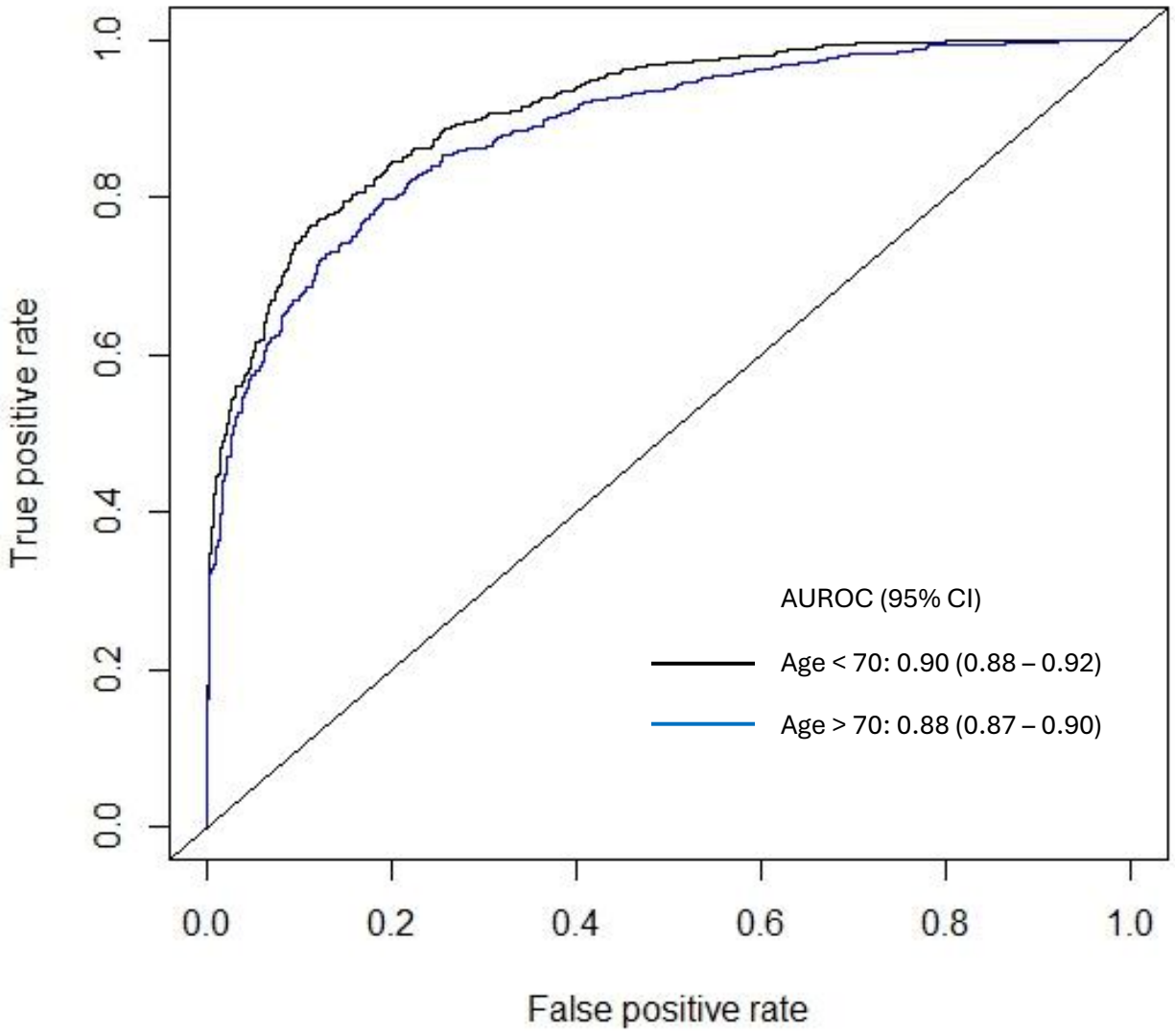
Abbreviations: ACS NSQIP (American College of Surgeons National Surgical Quality Improvement Program), BNP (brain natriuretic peptide), ASA (American Society of Anesthesiologists), AAA (abdominal aortic aneurysm), INR (international normalized ratio), PTT (partial thromboplastin time), CT (computed tomography), MRI (magnetic resonance imaging).

eTable 3. Selection of Extreme Gradient Boosting (XGBoost) model hyperparameters using grid search and cross validation

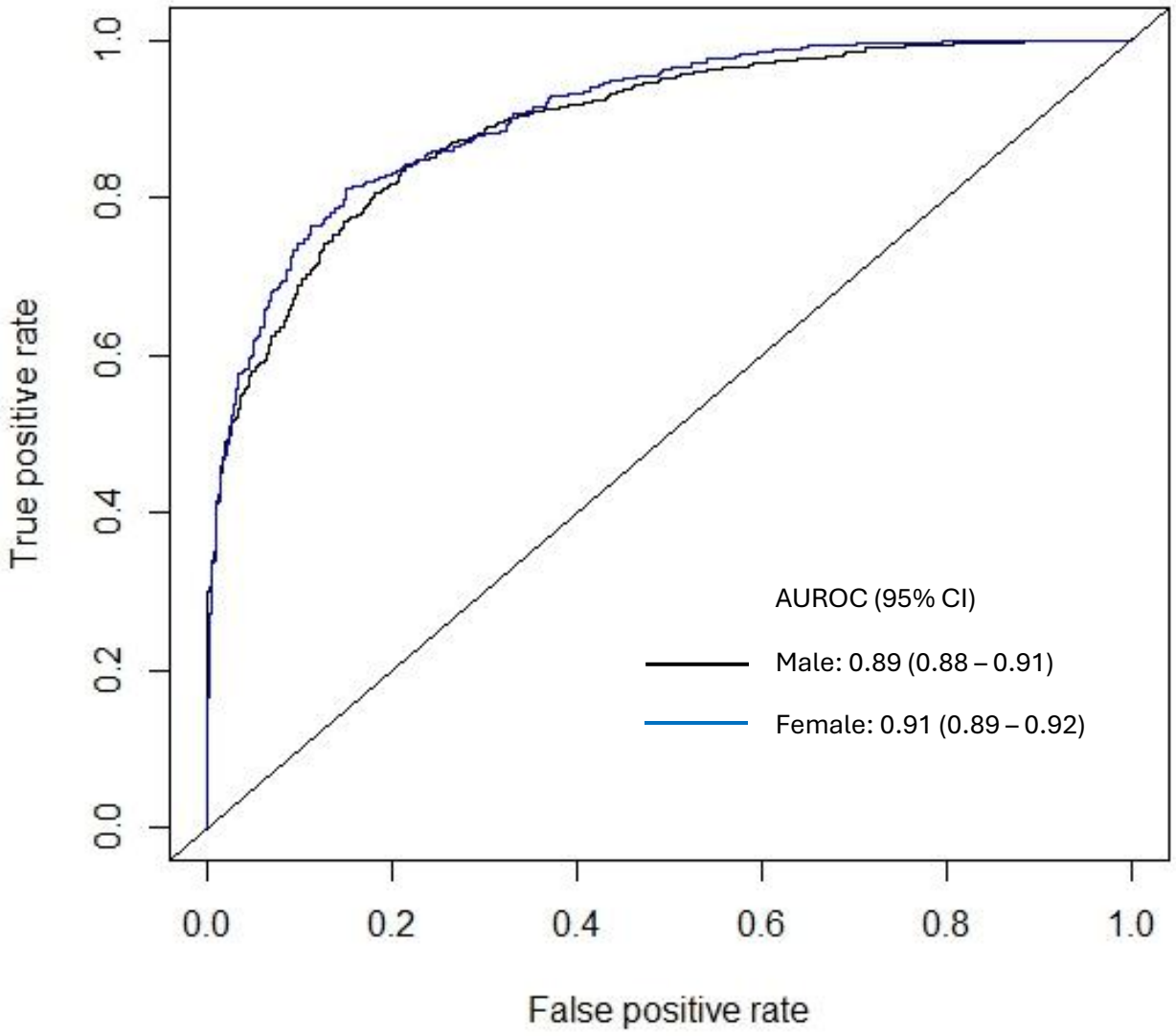
Hyperparameter	Values tested through grid search and cross validation*	Optimal value chosen to maximize AUROC
Number of rounds	50, 100, 150, 200, 250, 300, 350, 400, 450, 500	150
Maximum tree depth	2, 3, 4, 5, 6, 7, 8, 9	3
Learning rate	0.4, 0.3, 0.2, 0.1, 0.05, 0.01, 0.001	0.3
Gamma	0, 0.1, 1, 1.5, 2	0
Column sample by tree	0.5, 0.6, 0.7, 0.8, 0.9, 1	0.6
Minimum child weight	1, 3, 5, 7, 10	1
Subsample	0.5, 0.6, 0.7, 0.8, 0.9, 1	1

*Grid search and cross validation are exhaustive methods that iteratively train and evaluate models using every combination of specified hyperparameter values and selects the set of hyperparameter values that optimize model performance.

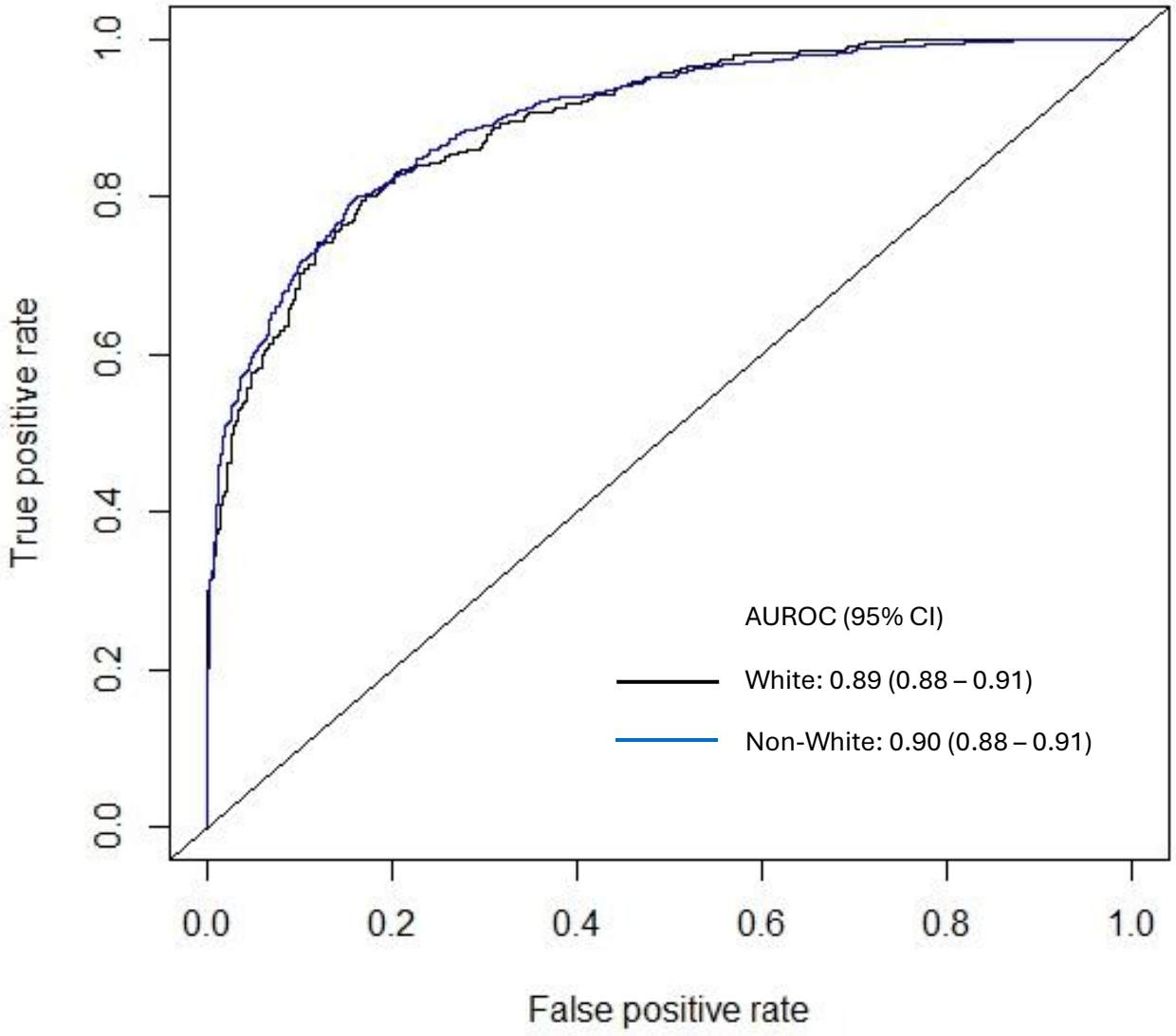
Abbreviation: AUROC (area under the receiver operating characteristic curve).



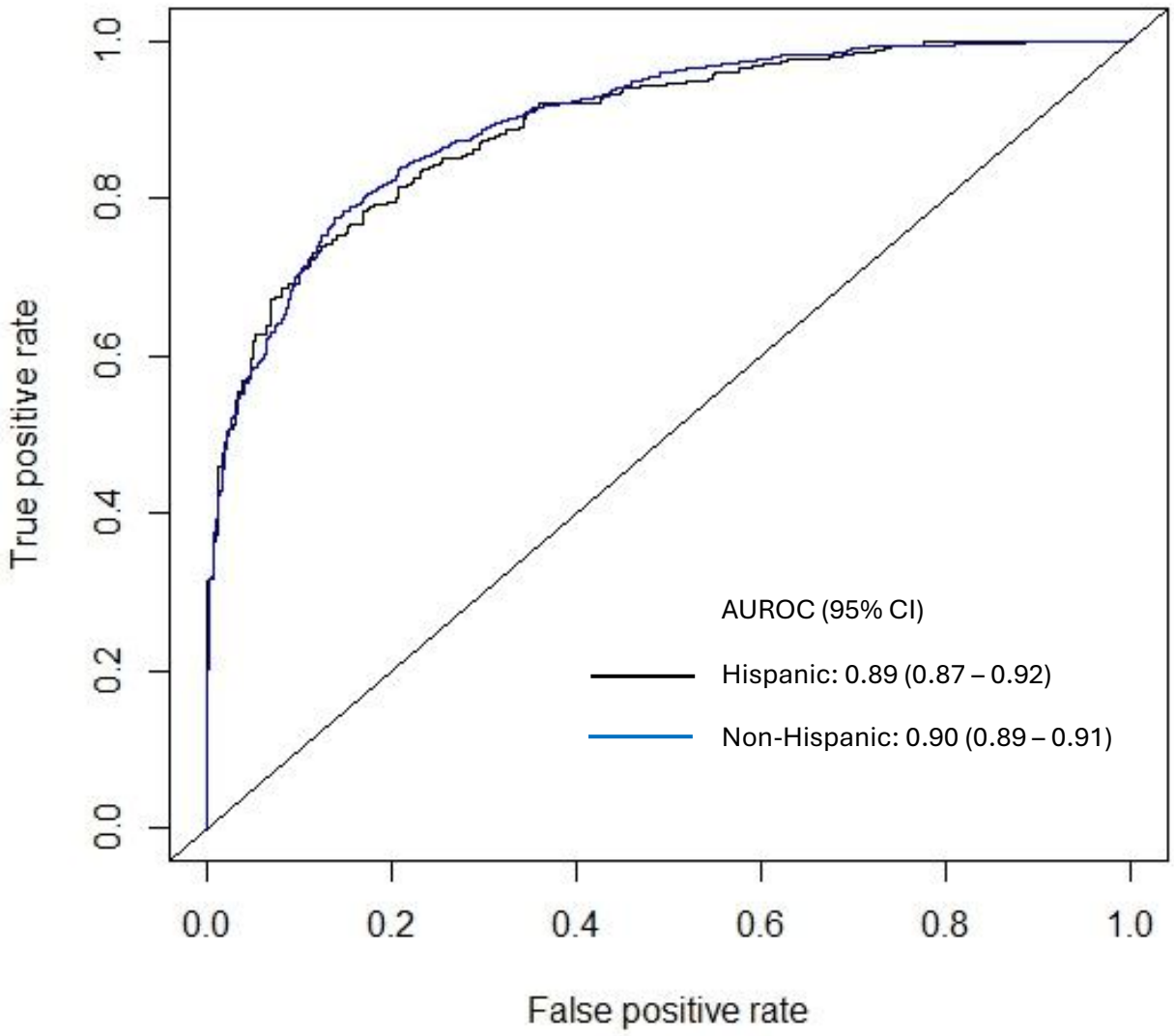
eFigure 1. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on age. AUROC (area under the receiver operating characteristic curve), CI (confidence interval).



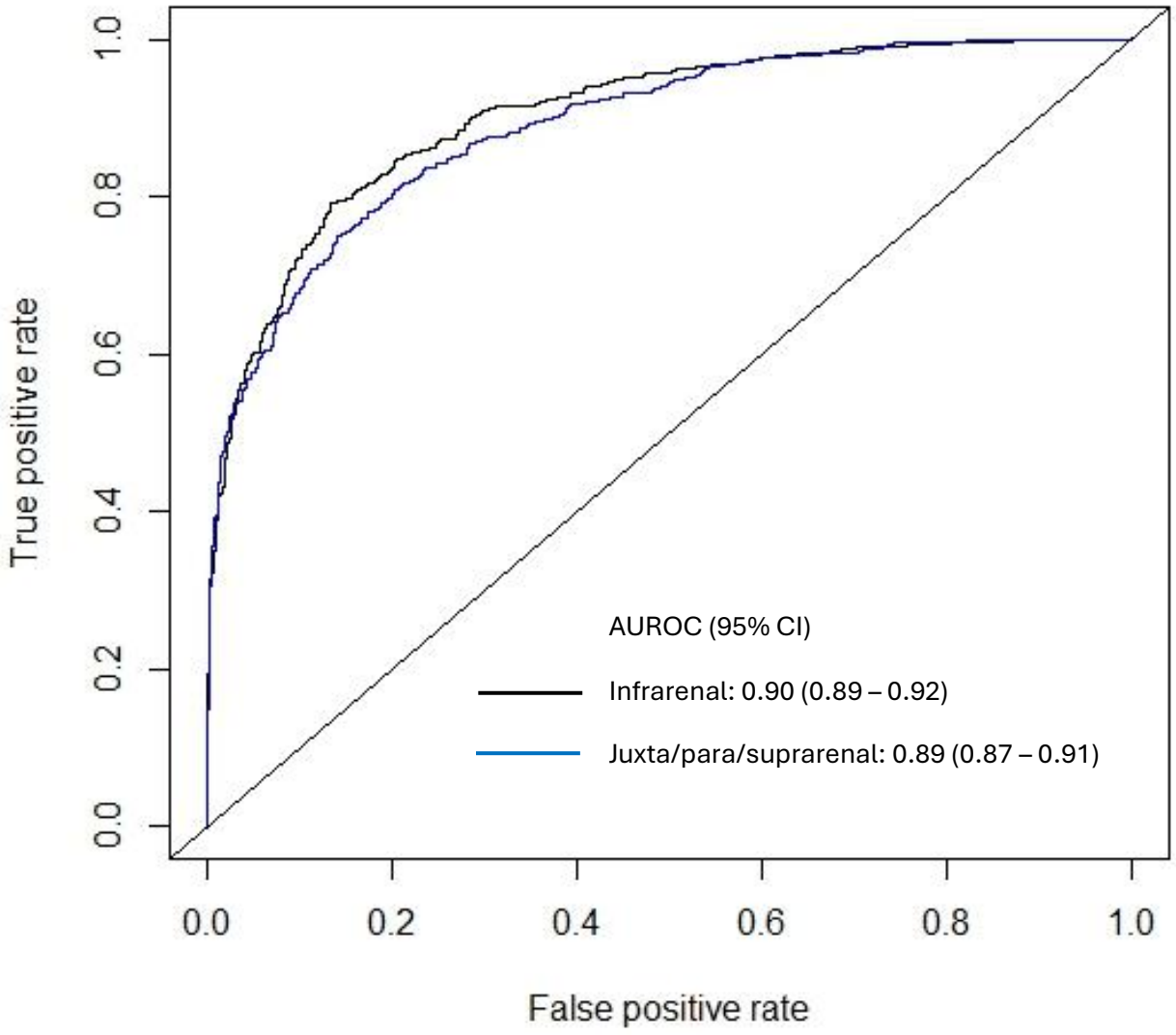
eFigure 2. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on sex. AUROC (area under the receiver operating characteristic curve), CI (confidence interval).



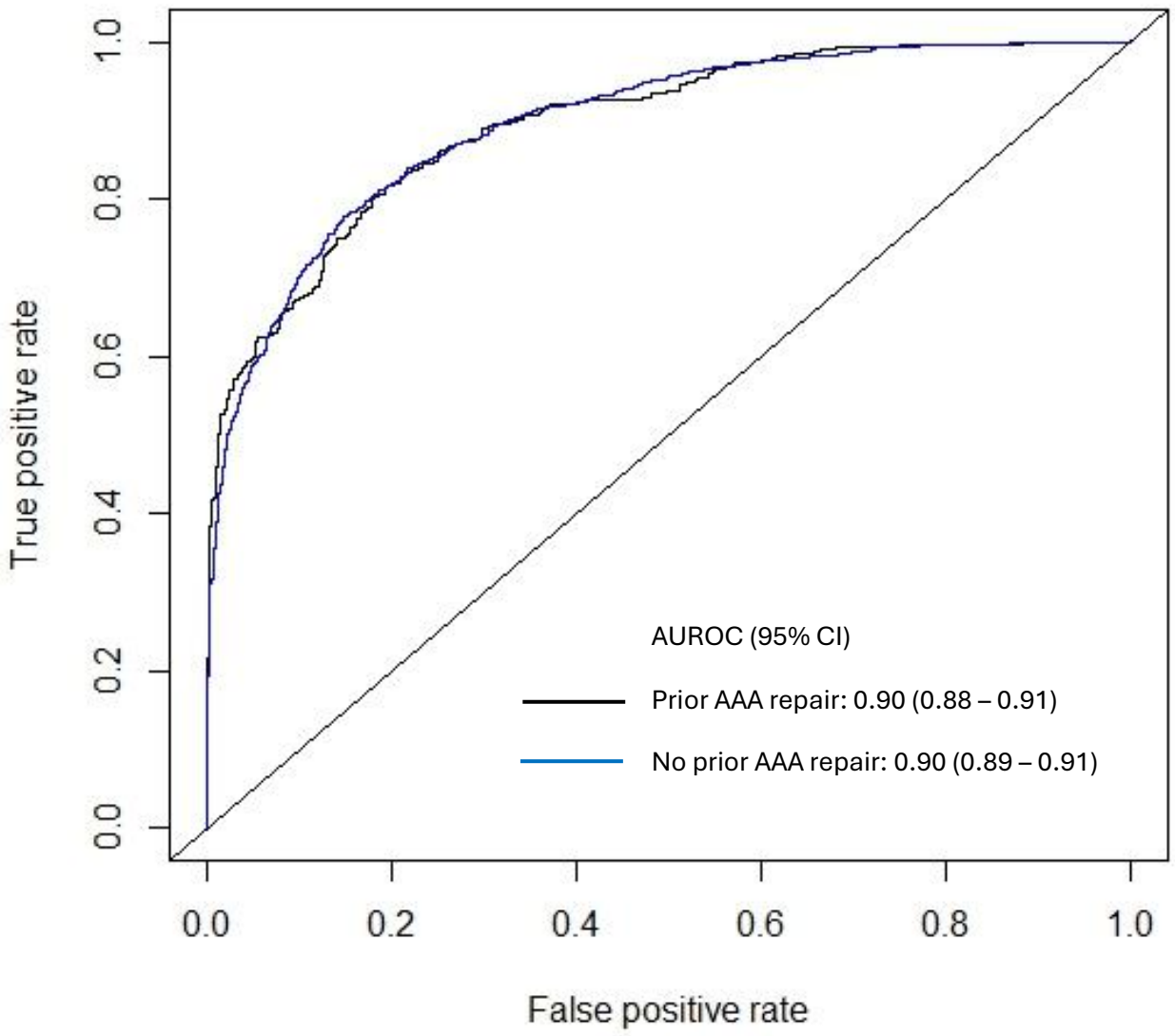
eFigure 3. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on race. AUROC (area under the receiver operating characteristic curve), CI (confidence interval).



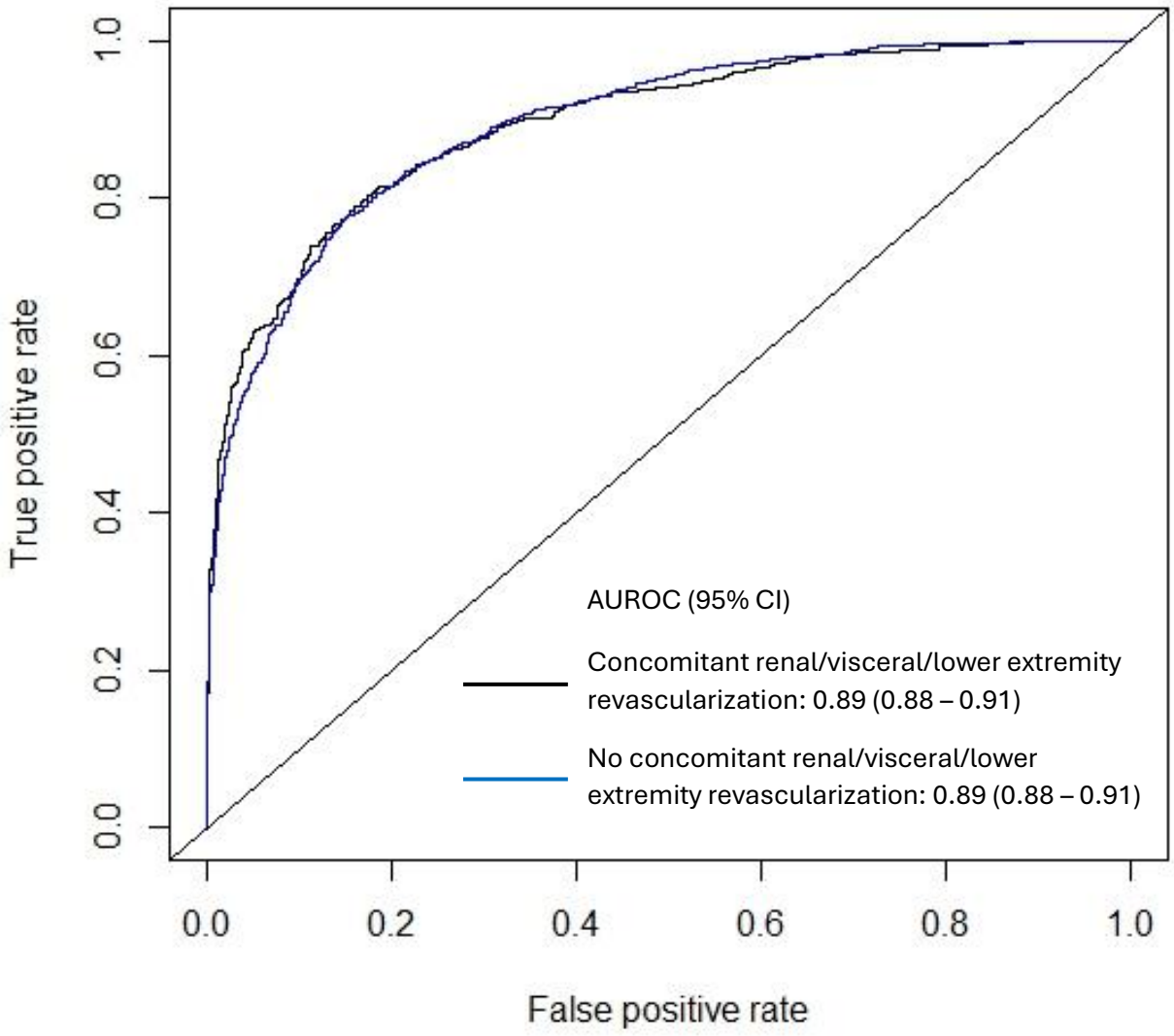
eFigure 4. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on ethnicity. AUROC (area under the receiver operating characteristic curve), CI (confidence interval).



eFigure 5. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on proximal extent of abdominal aortic aneurysm. AUROC (area under the receiver operating characteristic curve), CI (confidence interval).



eFigure 6. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on presence of previous open or endovascular abdominal aortic aneurysm repair. AAA (abdominal aortic aneurysm), AUROC (area under the receiver operating characteristic curve), CI (confidence interval).



eFigure 7. Receiver operating characteristic curve for 30-day major adverse cardiovascular events following open abdominal aortic aneurysm repair using Extreme Gradient Boosting (XGBoost) model with subgroup analysis based on need for concomitant renal, visceral, or lower extremity revascularization. AUROC (area under the receiver operating characteristic curve), CI (confidence interval).