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РОССИЙСКОЕ КАРДИОЛОГИЧЕСКОЕ ОБЩЕСТВО

ORIGINAL RESEARCH

Diagnostic performance of the 2019 ESC pre–test probability and Coronary Artery Disease consortium models in estimating obstructive coronary artery disease

Hoang Truong Huy[1,2]*, Do Dan Van Buu[2], Nguyen Thao Le Phuong[2], V. V. Maiskov[3], Z. D.Kobalava[3]

[1]Pham Ngoc Thach University of Medicine, Ho Chi Minh City, Vietnam
[2]Tam Duc Heart Hospital, Ho Chi Minh City, Vietnam
[3]RUDN University, Moscow, Russia

Aim. To evaluate and compare the diagnostic performance of the 2019 European Society of Cardiology pre-test probability (PTP) model and the coronary artery disease (CAD) consortium basic and clinical models in predicting obstructive CAD in patients with stable angina.
Material and methods. This cross-sectional study included 366 patients (mean age 64.8 years, 62.6% male) with suspected stable angina who underwent coronary computed tomography angiography. Obstructive CAD was defined as the presence of ≥50% stenosis in epicardial coronary artery segments with a diameter of ≥2.5 mm. We assessed clinical characteristics and cardiovascular risk factors. The PTP values from the three models were calculated, and their diagnostic performance was evaluated using area under the receiver operating characteristic curves and the Hosmer–Lemeshow test for calibration. Sensitivity, specificity, and predictive values were also analyzed.
Results. Obstructive CAD was detected in 270 (73.8%) patients. Patients with obstructive CAD had higher rates of male sex, hypertension, dyslipidemia, smoking, and typical and atypical angina (all $p<0.05$). The CAD consortium clinical model provided the most accurate estimate of obstructive CAD prevalence in high-risk patients (76.6% expected *vs* 84.4% observed), while the 2019 ESC PTP model was more accurate in low-risk patients (2.5% expected vs 0.4% observed). The CAD consortium clinical model demonstrated the best diagnostic performance with an area under the curve (AUC) of 0.760 and good calibration (Hosmer–Lemeshow test, $p = 0.823$). This was followed by the CAD consortium basic model (AUC = 0.755), and the 2019 ESC PTP model, which had the lowest performance (AUC = 0.701, poor calibration, $p = 0.001$). The CAD consortium clinical model, with a cut-off value >33%, had a sensitivity of 66.7%, specificity of 79.2%, a positive predictive value of 90%, and a negative predictive value of 45.8% in predicting obstructive CAD.
Conclusion. The CAD consortium clinical model showed superior accuracy in predicting obstructive CAD in stable angina patients, especially in high-risk groups, compared to the 2019 ESC PTP and CAD consortium basic models. Its strong diagnostic performance and reliable calibration make it a better tool for CAD risk assessment.

Keywords: CAD consortium, coronary artery disease, coronary computed tomography angiography, chronic coronary syndrome, non-invasive testing, pre-test probability, risk assessment, risk factor, stable angina.

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*Corresponding Author: truonghh@pnt.edu.vn

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Introduction

Coronary artery disease (CAD) is one of the leading causes of mortality and morbidity globally [1], accounting for an estimated 9.1 million deaths annually [2]. A common clinical manifestation of stable CAD is angina pectoris [3]. In the evaluation of patients with suspected CAD, determining the pre-test probability (PTP) is a critical step in selecting appropriate diagnostic strategies [4–6]. For decades, the Diamond–Forrester model has been widely used for this purpose and is recommended by both the American College of Cardiology (ACC)/American Heart Association (AHA) and the European Society of Cardiology (ESC) [6, 7]. This model, based on three simple factors: age, sex, and chest pain characteristics, offers an accessible means of estimating CAD risk. However, recent studies in Europe have shown that the Diamond–Forrester model often overestimates CAD probability, particularly in women and low-risk patients [8, 9], leading to the unnecessary use of invasive diagnostic tests.

To address these limitations, the 2019 ESC guidelines on the diagnosis and management of chronic coronary syndromes proposed an updated PTP model (2019 ESC PTP), which includes dyspnea as a symptom alongside age, sex, and chest pain characteristics [10]. In parallel, the updated version of the CAD consortium model, based on pooled data from large cohort studies, was also incorporated into the ESC 2019 guidelines [10, 11]. This model is presented in two versions: a basic version, which considers age, sex, and typical characteristics of chest pain but does not include dyspnea, and a clinical version, which additionally accounts for traditional cardiovascular risk factors such as hypertension, diabetes mellitus, dyslipidemia, and smoking.

Recent studies have shown that CAD Consortium models, especially the clinical version, provide more accurate predictions of obstructive CAD, particularly when using coronary computed tomography angiography (CCTA) [12, 13]. However, direct comparative data on the effectiveness of the CAD consortium models and the 2019 ESC PTP model in clinical practice remain limited. Therefore, this study aims to: (1) evaluate the diagnostic accuracy of the CAD consortium basic and clinical models in predicting obstructive CAD, and (2) compare them with the 2019 ESC PTP model in patients with stable angina.

Methods

Study Design and Population

This was a cross-sectional descriptive study conducted at the Tam Duc Cardiology Hospital, Ho Chi Minh City, Vietnam, from December 2023 to May 2024. All patients aged 18 years or older, diagnosed with stable angina and undergoing CCTA, were included in the study. Stable angina was defined according to current clinical guidelines [10, 14], categorizing chest pain into three types: typical angina, atypical angina, and non-anginal chest pain. Patients with typical angina had all three of the following criteria: (1) a squeezing or heavy sensation in the chest with a typical duration, (2) chest pain triggered by physical exertion or emotional stress, and (3) relief of symptoms within minutes of rest or sublingual nitroglycerin use. Patients with atypical angina met two of these criteria, while those with non-anginal chest pain fulfilled one or none of the criteria. Patients were excluded if they presented with acute coronary syndrome, had a history of myocardial infarction or coronary revascularization, were suffering from acute conditions such as fever or decompensated heart failure, or had end-stage liver or renal failure. Additionally, those with psychiatric disorders that impaired their ability to respond to study questionnaires or had incomplete CCTA data were also excluded. The study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Pham Ngoc Thach University of Medicine (approval number 959/TĐHYKPNT-HĐĐĐ, dated December 19, 2023). All participants provided informed consent before enrolling in the study.

Data Collection

Upon enrollment, detailed demographic and clinical data were collected from all participants, including cardiovascular risk factors and CCTA results. The PTP of CAD was calculated using three models: the 2019 ESC PTP [10], the CAD Consortium basic model, and the CAD Consortium clinical model. The CAD Consortium models were computed using the QxMD Pre-test Probability of CAD Calculator, which incorporates both the basic clinical features and traditional cardiovascular risk factors such as hypertension, diabetes, dyslipidemia, and smoking[1]. Based on these models, the population was classified into three risk categories for obstructive CAD: low (≤5%), intermediate (5–15%), and high (>15%), following the ESC guidelines [10].

Coronary Computed Tomography Angiography

All patients underwent CCTA using a 64-slice multidetector CT scanner (Brilliance 64, Philips Medical Systems, Best, Netherlands) within 24 hours of hospital admission. Beta-blockers were administered either orally or intravenously to maintain a stable heart rate, while sublingual glyceryl trinitrate was given unless contraindicated. The contrast agent Omnipaque was used to enhance the visualization of coronary arteries. Image acquisition was performed during breath-hold at the end of inspiration, and the data were stored and analyzed on the PACS system (Carestream) using Vue Motion software. Coronary lesions were assessed using multiplanar reconstructions (MPR), maximum intensity projection (MIP), and volume rendering techniques (VRT). Two experienced specialists, including a cardiologist

[1] https://qxmd.com/calculate/calculator_287/pre-test-probability-of-cad-cad-consortium

and a radiologist, each with over five years of experience, independently evaluated the coronary lesions. Coronary artery lesions were assessed according to the guidelines of the Society of Cardiovascular Computed Tomography [15]. Each segment of the coronary artery and its branches were analyzed using both cross-sectional and longitudinal imaging, with stenosis evaluated in at least two orthogonal planes. The presence of atherosclerotic plaque was recorded, and lesions were categorized into two groups: obstructive and non-obstructive CAD. Obstructive CAD was defined as a stenosis of ≥50% in the diameter of one of the three major epicardial coronary arteries [8].

Definitions of Variables

Hypertension is defined as a systolic blood pressure ≥140 mmHg and/or a diastolic blood pressure ≥90 mmHg, or the patient is currently using antihypertensive medication [16]. Diabetes is defined as having a fasting blood glucose ≥126 mg/dL, or HbA_{1c} ≥6.5%, or the patient is using hypoglycemic medication [17]. Smoking is defined as currently smoking or having smoked in the past and having quit for no more than 5 years [18]. Dyslipidemia is defined as having total cholesterol ≥5.2 mmol/L, or triglycerides ≥2.3 mmol/L, or low-density lipoprotein cholesterol (LDL-C) ≥3.2 mmol/L, or HDL-C (high-density lipoprotein cholesterol) <0.9 mmol/L, or the patient is using medication for dyslipidemia [19, 20]. A family history of premature CAD is defined as having a first-degree relative who is male and <55 years old or female and <65 years old who has had a myocardial infarction or undergone coronary artery revascularization [21].

Statistical Analysis

Data analysis was performed using SPSS version 25.0. Categorical variables were summarized as frequencies and percentages, while continuous variables were reported as mean ± standard deviation (SD) for normally distributed data, or as median and interquartile range (IQR) for non-normally distributed data. Normality was assessed using the Kolmogorov–Smirnov test. For categorical variables, comparisons were made using the Chi-square or Fisher's exact test. The Student's t-test was used for comparing continuous variables with normal distribution, whereas the Mann–Whitney U test or Kruskal–Wallis test was employed for non-normally distributed data. Logistic regression analysis was conducted to identify the factors within the PTP models that were predictive of obstructive CAD. Statistical significance was set at $p < 0.05$. Model discrimination was assessed using the area under the receiver operating characteristic (ROC) curve (AUC), which estimates how well the model differentiates between obstructive and non-obstructive CAD. Calibration, which evaluates the agreement between predicted and observed outcomes, was tested using the Hosmer–Lemeshow goodness-of-fit statistic (H–L χ^2). Differences between AUCs were compared using DeLong's method [22]. The positive predictive value (PPV) of each model was defined as the proportion of patients with obstructive CAD among those classified as high pretest probability, while the false-negative rate was the proportion of patients with obstructive CAD among those classified as low pretest probability. A p-value of <0.05 was considered statistically significant.

Results

During the study period, 366 patients were included, mean age 64.8 ± 9.1 years, 62.6% were male (Table 1). Obstructive CAD was observed in 270 (73.8%) patients. Hypertension was the most common cardiovascular risk factor, present in 83.1% of the patients, followed by dyslipidemia in 55.5%, diabetes mellitus in 38%, smoking in 36.1%, and a family history of premature CAD in 9.3%.

Table 1. Clinical and demographic characteristics of the study population

Variables	All patients (*n* = 366)	Non-obstructive CAD (*n* = 96)	Obstructive CAD (*n* = 270)	*P*
Age, M ± SD, years	64,8±9,1	64,9±11,9	64,7±7,9	0,898
Male gender, n (%)	229 (62,6)	40 (41,7)	189 (70)	**<0,001**
BMI, M± SD, kg/m2	24,0±3,0	24,4±2,7	23,8±3,0	0,100
Smoking, n (%)	132 (36,1)	15 (15,6)	117 (43,3)	**<0,001**
Hypertension, n (%)	304 (83,1)	73 (76)	231 (85,6)	**0,039**
Diabetes, n (%)	139 (38)	28 (29,2)	111 (41,1)	0,05
Dyslipidemia, n (%)	203 (55,5)	36 (37,5)	167 (61,9)	**<0,001**
Family history of premature CAD, n (%)	34 (9,3)	2 (2,1)	32 (11,9)	**0,003**
Atrial fibrillation, n (%)	17 (4,6)	6 (6,3)	11 (4,1)	0,401
PAD, n (%)	21 (5,7)	3 (3,1)	18 (6,7)	0,306
COPD, n (%)	5 (1,4)	1 (1,0)	4 (4,1)	1,0

Continuation of the Table

Variables	All patients (*n* = 366)	Non-obstructive CAD (*n* = 96)	Obstructive CAD (*n* = 270)	*P*
Typical angina, n (%)	129 (35,2)	13 (13,5)	116 (43)	**<0,001**
Atypical angina, n (%)	133 (36,3)	23 (24)	110 (40,7)	**0,003**
Nonanginal chest pain, n (%)	34 (9,3)	23 (24,0)	11 (4,1)	**<0,001**
Dyspnea, n (%)	148 (40,4)	48 (50)	100 (37)	**0,03**
Total cholesterol, Me (IQR), mmol/L	4,24 (3,64; 5,45)	4,08 (3,60; 4,71)	4,34 (3,65; 5,71)	**0,025**
HDL-C, Me (IQR), mmol/L	1,25 (1,06; 1,48)	1,39 (1,17; 1,65)	1,19 (1,03; 1,42)	**<0,001**
LDL-C, Me (IQR), mmol/L	2,40 (1,80; 3,30)	2,40 (1,82; 2,90)	2,45 (1,80; 3,50)	0,555
Triglyceride, Me (IQR), mmol/L	1,86 (1,33; 2,62)	1,79 (1,14; 2,33)	1,94 (1,35; 2,81)	**0,031**
Pretest probability models:				
2019 ESC PTP, Me (IQR), %	26 (14; 32)	14 (11; 27)	26 (16; 34)	**<0,001**
CAD consortium basic, Me (IQR), %	27 (12,7; 45)	13 (7; 23)	32 (18; 50)	**<0,001**
CAD consortium clinical, Me (IQR), %	36 (16,7; 57)	17 (8; 31,7)	41 (24,7; 64)	**<0,001**

BMI – body mass index. CAD – coronary artery disease. COPD – chronic obstructive pulmonary disease. ESC – European Society of Cardiology. HDL-C – high-density lipoprotein cholesterol. IQR – interquartile range. LDL-C – low-density lipoprotein cholesterol. M – mean, Me – median. PAD – Peripheral arterial disease, PTP – pre-test probability, SD – standard deviation

Compared to the non-obstructive CAD group, the obstructive CAD group had a significantly higher proportion of males (70% *vs.* 41.6%; $p < 0.001$), as well as a higher prevalence of hypertension (85.6% vs. 76%; $p = 0.039$), dyslipidemia (61.9% *vs.* 37.5%; $p < 0.001$), smoking (43.3% *vs.* 15.6%; $p < 0.001$), and a family history of premature CAD (11.9% *vs.* 2.1%; $p = 0.003$). There were no statistically significant differences between the two groups in terms of age, peripheral artery disease, or chronic obstructive pulmonary disease.

Patients with obstructive CAD had higher rates of both typical and atypical angina, while non-specific chest pain and dyspnea were more prevalent in the non-obstructive CAD group. The PTP of CAD was significantly elevated in the obstructive CAD group across all three models (all p-values <0.001). Additionally, patients with obstructive CAD had higher levels of total cholesterol, triglycerides, and lower levels of HDL-C.

The distribution of patients according to PTP value groups and the observed prevalence of obstructive CAD for each group across the three models is shown in Figure 1. Using the 2019 ESC PTP model, 9 patients (2.5%) were classified as having very low probability (PTP ≤5%), and 96 patients (26.2%) fell into the intermediate probability group (PTP 5–15%). In contrast, the CAD consortium basic model categorized 26 patients (7.1%) into the low probability group and 90 patients (24.6%) into the intermediate probability group. Lastly, the CAD consortium clinical model classified 24 patients (6.6%) as low probability and 65 patients (17.8%) as intermediate probability. Among the three models, the 2019 ESC PTP provided the best estimate of obstructive CAD prevalence in the low-risk group, while the CAD consortium clinical model was the most accurate in estimating the prevalence of obstructive CAD in the high-risk group.

Multivariate regression analysis of factors in each predictive model for obstructive CAD is presented in Table 2. Based on this analysis, typical and atypical angina were strong independent predictors of obstructive CAD across all three predictive models (all $p < 0.001$). Male gender was an independent predictor in both the 2019 ESC PTP and CAD Consortium basic models ($p < 0.001$). In the CAD Consortium clinical model, smoking and dyslipidemia were independent predictors of CAD obstruction, with respective p-values of 0.004 and 0.007.

The ROC curve analysis demonstrated that the CAD consortium clinical model had the highest AUC for predicting obstructive CAD (AUC 0.760, 95% CI 0.704–0.816; p<0.001), followed by the CAD consortium basic model (AUC 0.755, 95% CI 0.698–0.811; p<0.001) and the 2019 ESC PTP model (AUC 0.701, 95% CI 0.640–0.761; p<0.001).

The diagnostic performance and accuracy of the models for predicting obstructive CAD are shown in Table 3. Model fit testing indicated that the CAD consortium clinical and basic models had the best fit, with p-values in the Hosmer–Lemeshow test of 0.823 and 0.057, respectively. The 2019 ESC PTP model showed the poorest fit, with a p-value of 0.001.

The CAD consortium clinical model demonstrated strong predictive capability for obstructive CAD, with the highest PPV of 90%, a sensitivity of 66.7%, specificity of 79.2%, and a cut-off point of >33%. The basic CAD consortium model had a PPV of 88.2%, sensitivity of 69.3%, specificity of 74%, and a cut-off point of >22%.

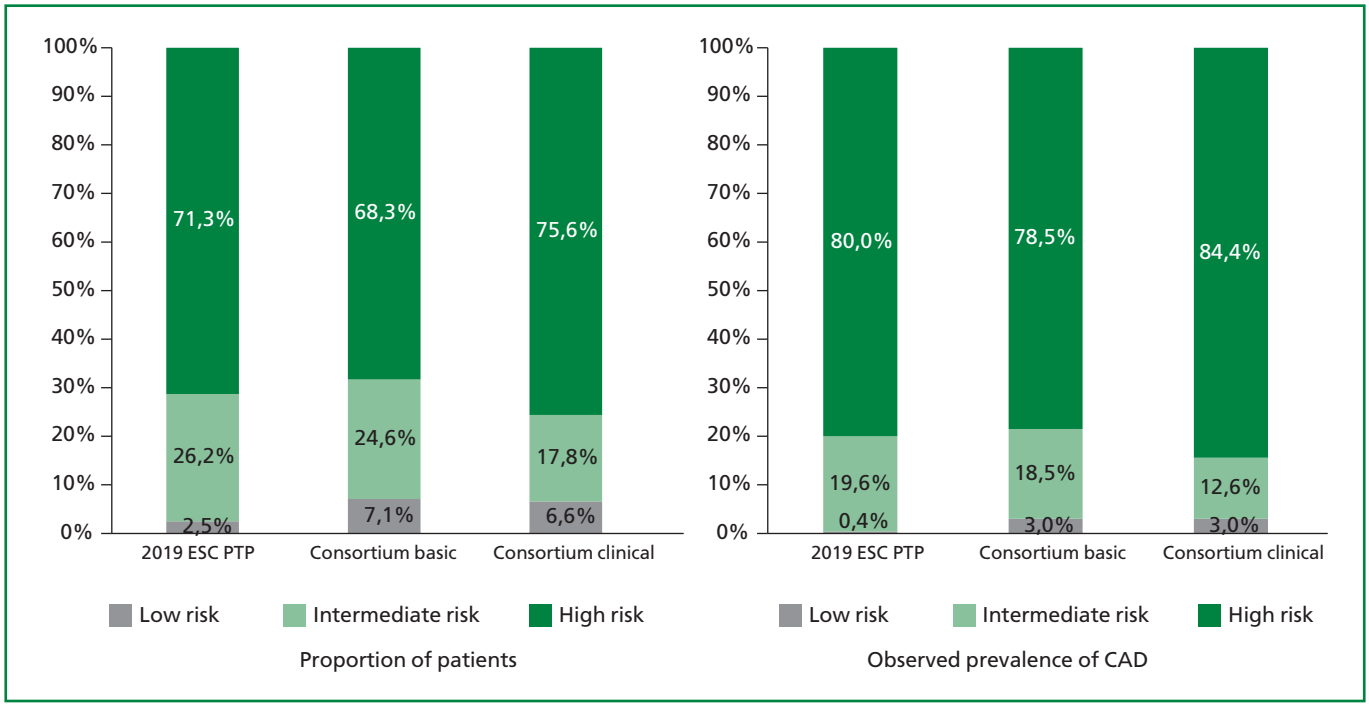

Figure 1. Distribution of patients by pre-test probability (PTP) groups and the observed prevalence of obstructive coronary artery disease (CAD) within each group, as estimated by the three models: ESC 2019 PTP, CAD consortium basic, and CAD consortium clinical.

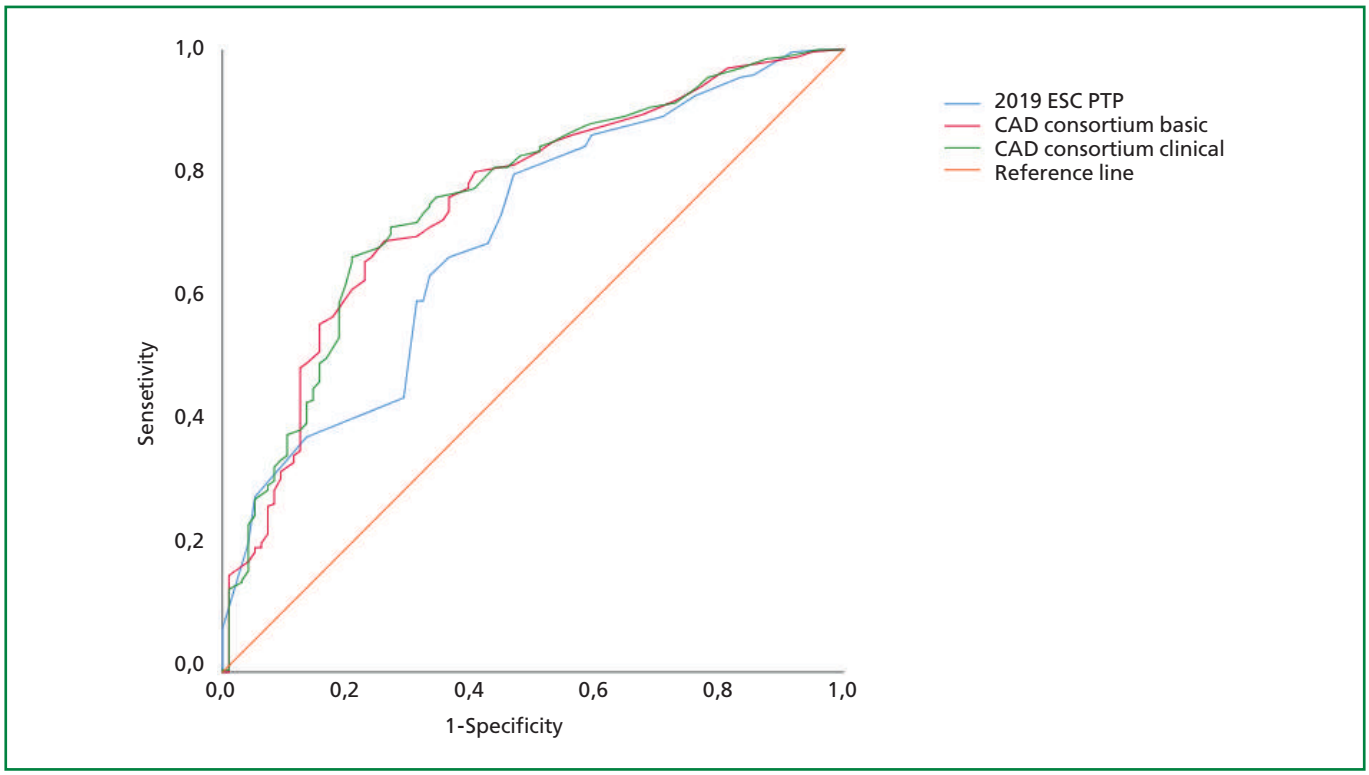

Figure 2. Comparison of ROC curves demonstrating the discriminatory ability of the 2019 ESC PTP model (blue line), the CAD consortium basic model (red line), and the CAD consortium clinical model (green line) in predicting obstructive coronary artery disease.

Table 2. Multivariate regression analysis of factors in the predictive models for obstructive coronary artery disease

Factors	2019 ESC PTP		CAD consortium basic		CAD consortium clinical	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Age (per 10 years)	0,972 (0,739–1,280)	0,842	0,969 (0,736–1,274)	0,821	0,923 (0,687–1,242)	0,788
Male gender	2,931 (1,692–5,075)	**<0,001**	2,881 (1,669–4,973)	**<0,001**	1,517 (0,795–2,894)	0,206
Typical angina	11,144 (4,487–27,677)	**<0,001**	9,437 (4,430–20,105)	**<0,001**	9,882 (4,492–21,739)	**<0,001**
Atypical angina	6,288 (2,566–15,409)	**<0,001**	5,152 (2,643–10,042)	**0,004**	4,664 (2,324–9,357)	**<0,001**
Non-anginal chest pain	0,729 (0,238–2,232)	0,580	0,581 (0,237–1,423)	0,235	0,683 (0,267–1,751)	0,428
Dyspnea	1,298 (0,602–2,797)	0,505	—	—	—	—
Hypertension	—	—	—	—	2,082 (0,977–4,440)	0,058
Diabetes	—	—	—	—	1,487 (0,812–2,724)	0,199
Smoking	—	—	—	—	3,146 (1,440–6,872)	**0,004**
Dyslipidemia	—	—	—	—	2,183 (1,243–3,835)	**0,007**

CAD – coronary artery disease, CI – confidence interval, ESC – European society of cardiology, OR – odds ratio, PTP – pre-test probability.

Table 3. Comparison of model fit and diagnostic accuracy between the 2019 ESC PTP model and the CAD Consortium basic and clinical models for predicting obstructive coronary artery disease

Parameter	2019 ESC PTP	CAD Consortium basic	CAD consortium clinical
Sensitivity, %	80	69,3	66,7
Specificity, %	53,1	74	79,2
PPV, %	82,8	88,2	90
NPV, %	48,6	46,1	45,8
Cut-off, %	>14	>22	>33
Hosmer–Lemeshow test	$\chi^2 = 27,468$; $p = 0,001$	$\chi^2 = 15,097$; $p = 0,057$	$\chi^2 = 4,364$; $p = 0,823$

CAD – coronary artery disease, ESC – European society of cardiology, NPV – negative predictive value, PPV – positive predictive value, PTP – pre-test probability.

Discussion

Our study highlights that the CAD Consortium clinical model outperforms both the CAD consortium basic and 2019 ESC PTP models in predicting obstructive CAD in patients with stable angina. With a cut-off >33%, it demonstrated the highest PPV of 90% and a sensitivity of 66.7%. The CAD clinical model also showed the best diagnostic accuracy, with an AUC of 0.760, compared to the CAD basic (AUC 0.755) and ESC PTP model (AUC 0.701). These results emphasize the importance of incorporating additional cardiovascular risk factors to improve PTP estimates.

The prevalence of obstructive CAD diagnosed by CCTA in our study was 71.3%, significantly higher than predicted by the 2019 ESC PTP model across all three risk categories. In contrast, the PROMISE study [23], conducted in North America with 4,415 symptomatic outpatients without prior CAD, reported a much lower prevalence of obstructive CAD (≥50% stenosis) at just 13.9%. Interestingly, 97% of patients in PROMISE were classified as intermediate risk by the 2019 ESC PTP model, with only 3.6% in the low-risk and 0.6% in the high-risk categories. Similarly, in a sub-study of the SCOT-HEART trial [24], which included 3,755 patients with stable chest pain, the overall prevalence of obstructive CAD was 22% among the 1,613 patients who underwent CCTA. The observed prevalence of CAD in the low-, intermediate-, and high-risk groups was 13.2%, 29.2%, and 57.6%, respectively, which were all substantially lower than in our cohort. These findings suggest that the 2019 ESC PTP model is well-calibrated for detecting CAD in lower-risk populations, as evidenced by studies like PROMISE and SCOT-HEART. However, there is a lack of validation of this model in high-risk populations. External validation in such populations could lead to the development of updated ESC PTP models tailored for high-risk countries, contributing to better CAD diagnosis and management in regions with higher incidence rates. As recommended by the 2019 ESC guidelines, PTP calculation influences testing strategies for diagnosing CAD, emphasizing the need for model refinement in diverse populations.

The mean age of the study cohort was 64.8 ± 9.1 years, which was slightly higher than the findings from U.W. Lee et al. [25] in Korea (mean age 62 ± 12.7 years) and L. Baskaran et al. [12] in Singapore (mean age 58 ± 10 years) in the SCOT-HEART (Scottish COmputed Tomography of the HEART) study. Unlike these studies, no significant age differences were observed between patients with obstructive and non-obstructive CAD in this study. The male proportion (62.6%) was comparable to the 60.8% male rate reported by U.W. Lee et al. [25], but higher than that in L. Baskaran et al. [12] (56.9%) and J. Zheng et al. [26] (50.9%) in a large Chinese cohort of 11,234 patients with suspected CAD. This may reflect regional or population-specific gender differences in CAD prevalence or risk factor distribution.

Our study also showed higher rates of cardiovascular risk factors compared to other studies. Hypertension, diabetes, dyslipidemia, and smoking were present in 83.1%, 38%, 55.5%, and 36.1% of patients, respectively, which are notably higher than in L. Baskaran et al. [12] (40.6%, 14.8%, 58.4%, and 23.6%) and U.W. Lee et al. [25] (43.1%, 20%, 15.9%, and 8.9%). These findings may explain the superior performance of the CAD Consortium clinical model, which incorporates traditional risk factors like dyslipidemia and smoking into its risk estimation. The high prevalence of these risk factors in our population underscores the need for models that account for them when predicting CAD.

Patients with obstructive CAD in our study were more likely to present with typical or atypical angina, while those with non-obstructive CAD were more often reported to have non-anginal chest pain, which is partly consistent with previous research [12, 25, 27, 28]. However, our findings differ from studies like U.W. Lee et al. [25], where atypical angina was more common in non-obstructive CAD patients (50.4% *vs.* 36.6%, p<0.001). Similarly, L. Baskaran et al. [12] reported higher rates of atypical angina in non-obstructive CAD cases (26.2% vs. 20.8%, $p = 0.01$). These differences may reflect variations in study populations or clinical settings. The 2021 AHA/ACC guidelines [14] for the evaluation and diagnosis of chest pain excluded symptom categorization from the PTP estimation to address potential confusion around the term "atypical angina." The guideline now broadens the scope of symptoms considered equivalent to angina, including chest tightness, discomfort in areas such as the neck, jaw, and upper abdomen, and even symptoms like shortness of breath and fatigue. Despite these changes, the ESC inclusion of symptom typicality in their PTP model demonstrated improved accuracy in predicting CAD compared to the AHA/ACC model [10]. In the study by S. Winther et al. [29], which included 50,561 patients with angina referred for CCTA, the distribution of symptom typicality was as follows: 12% of patients presented with typical angina, 48% with atypical angina, 31% with non-anginal chest pain, and 8% reported no chest discomfort but had dyspnea as the predominant symptom. When comparing diagnostic models, the AHA/ACC PTP model had an AUC of 0.715 (95% CI, 0.707–0.722). In contrast, the inclusion of symptom typicality in the ESC guideline PTP model significantly improved CAD discrimination, with an AUC of 0.755 (95% CI, 0.747–0.763). Moreover, incorporating both symptom type and risk factors in a risk factor-weighted clinical likelihood model further enhanced the diagnostic accuracy, with an AUC of 0.777 (95% CI, 0.770–0.785). These results highlight the added value of considering both symptom presentation and risk factors in improving the diagnostic precision for coronary artery disease.

The development of a high-quality clinical prediction model should ideally allow for a straightforward and accurate estimation of individual disease probabilities, assisting in patient management. A truly effective model should be able to distinguish between those with and without disease while maintaining good calibration, meaning that predicted probabilities align closely with actual disease prevalence. Moreover, such a model would refine patient classifications, reducing the number of cases in the gray zone where management decisions are uncertain. Once validated, relevant cut-off points for guiding treatment should be established. In the study by S. Winther et al. [29], the 2019 ESC PTP model mildly overestimated the prevalence of CAD, with the CAD consortium model showing better calibration, with calibration slopes of 1.12 and 1.05, respectively. When comparing the models' ability to distinguish between obstructive and non-obstructive CAD, the 2019 ESC PTP model had a lower AUC of 0.755 (95% CI, 0.747–0.763; p<0.001) compared to the CAD consortium model, which had an AUC of 0.777 (95% CI, 0.770–0.785; p<0.001).

Our study found that the CAD Consortium clinical model provided the best discrimination, with an AUC of 0.760, consistent with previous validation [30]. This may be attributed to the inclusion of additional cardiovascular risk factors, enhancing the model's applicability across diverse populations [31]. A similar trend was observed in the research by M.S. Bittencourt et al. [13], which involved 2,274 patients (mean age, 56 ± 13 years; 57% male) undergoing CCTA at Massachusetts General Hospital or Brigham and Women's Hospital. The AUC for the basic and clinical CAD Consortium models were 0.7517 and 0.7909, respectively (all $p < 0.001$). However, in populations with higher CAD prevalence, the model's discriminatory power was reduced. J. Almeida et al. [32] studied 2,234 patients with a mean age of 63.7 years (67.5% male), of whom 66.9% had typical angina, and found obstructive CAD in 58.5%. The basic and clinical CAD Consortium models had AUCs of 0.664 (95% CI: 0.641–0.687; p<0.001) and 0.683 (95% CI: 0.661–0.706; p<0.001), respectively. Conversely, in the study by L. Baskaran et al. [12], the clinical CAD Consortium model had a lower AUC of 0.718 (95% CI: 0.668–0.767), but recalibration with updated regression coefficients improved the AUC to 0.767 (95% CI: 0.721–0.814). The Hosmer–Lemeshow test indicated poor model fit, with an overestimation of obstructive CAD rates by 13% in wom-

en and 28% in men. This pattern was also seen in U.W. Lee et al.'s study [25], where the basic and clinical CAD consortium models had AUCs of 0.736 (95% CI: 0.692–0.780) and 0.754 (95% CI: 0.711–0.797), respectively. However, both models misclassified 17% and 25% of patients with obstructive CAD, respectively.

In our study, the basic CAD Consortium model showed reasonable predictive performance for obstructive CAD, with an AUC of 0.755, slightly lower than the original T.S. Genders et al. study (AUC 0.77) but higher than the prospective study by J.M. Jensen et al. [33] on 633 angina patients, where obstructive CAD was defined as ≥50% stenosis, and the clinical CAD Consortium model had an AUC of 0.714. These findings indicate that while the clinical CAD Consortium model provides strong discrimination, its performance may vary across different populations, particularly those with higher CAD prevalence or varying risk factor profiles.

Limitations of the study

This study has several limitations. First, it was conducted in a single center, which may limit the generalizability of the findings to other populations with different healthcare systems or demographic characteristics. Second, the cross-sectional design prevents the assessment of long-term outcomes, such as the progression of CAD or the impact of treatment decisions based on the predictive models used. Third, the study population predominantly included patients with stable angina undergoing CCTA, which may not fully represent those with other forms of coronary syndromes or those at lower risk of CAD. Additionally, while the CAD Consortium models and 2019 ESC PTP model have been validated in various cohorts, their performance may vary in different ethnic or regional populations, and further validation in larger, more diverse populations is needed. Further prospective, multicenter studies are necessary to confirm the findings and assess the broader applicability of these predictive models in diverse clinical settings.

Conclusion

The CAD Consortium clinical model offers the best discrimination and higher diagnostic accuracy for predicting obstructive CAD compared to the 2019 ESC PTP model. The inclusion of additional cardiovascular risk factors enhances its performance, making it more suitable for high-risk populations. It is recommended that clinicians adopt the CAD Consortium clinical model for more accurate PTP calculations in stable angina patients, potentially reducing unnecessary testing and improving patient management. Further validation of the 2019 ESC PTP model in diverse, high-risk populations is needed to optimize its clinical utility.

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About the Authors

Hoang Truong Huy
eLibrary SPIN 5684-0275, ORCID 0000-0002-2013-2647
Do Dan Van Buu
ORCID 0009-0008-3123-4711
Nguyen Thao Le Phuong
ORCID 0009-0007-1528-9133
Victor V. Maiskov
eLibrary SPIN 7370-7545, ORCID 0009-0002-2135-2606
Zhanna D. Kobalava
eLibrary SPIN 9828-5409, ORCID 0000-0002-5873-1768