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Risk Stratification Using Computed Tomography Coronary Angiography in Patients Undergoing Intermediate-Risk Noncardiac Surgery

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Objectives This study evaluated whether coronary artery calcium scores (CACS) and the degree of stenosis that were measured with computed tomography coronary angiography (CTCA) predicted post-operative cardiovascular events in patients who were undergoing intermediate-risk noncardiac surgery.

Background Cardiovascular complications are important causes of mortality and morbidity in patients undergoing major noncardiac surgeries.

Methods A total of 239 patients underwent CTCA before intermediate-risk noncardiac surgeries. We measured CACS and the degree of stenosis with CTCA and assessed clinical risk factors according to the revised cardiac risk index (RCRI) scores. Post-operative cardiovascular events were defined as cardiac death, acute coronary syndrome, pulmonary edema, ventricular arrhythmia with hemodynamic compromise, and complete heart block.

Results Nineteen patients (8%) had post-operative cardiac events. The variables that correlated with the occurrence of cardiac events were RCRI ($p < 0.001$), CACS ($p < 0.001$), the presence of significant coronary artery stenosis (diameter stenosis ≥50%) ($p = 0.01$), and multivessel coronary artery disease ($p < 0.001$). In the receiver-operating characteristic (ROC) curve analysis of CACS for prediction of cardiac events, the cutoff value was 113 (sensitivity, 0.79; specificity, 0.61; area under the curve, 0.762). When comparing ROC curves of the combination models of RCRI, high CACS (≥113), and the presence of multivessel disease, RCRI plus high CACS, RCRI plus multivessel disease, and RCRI plus high CACS plus multivessel disease were significantly more predictable of post-operative cardiovascular events than RCRI alone.

Conclusions In the pre-operative risk stratification of patients who were undergoing intermediate-risk noncardiac surgeries, CTCA evaluations showed additive value to RCRI. (J Am Coll Cardiol 2013;61:661–8) © 2013 by the American College of Cardiology Foundation

Post-operative cardiovascular events, such as cardiac death, acute coronary syndrome, pulmonary edema, and severe ventricular arrhythmia, are the most significant risks to patients undergoing noncardiac surgery (1,2). The identification of high-risk patients is needed for preventive management and prompt treatment during the perioperative period.

According to the American College of Cardiology/American Heart Association (ACC/AHA) guidelines (3), noninvasive cardiac risk evaluations are only recommended for patients with a poor or unknown functional capacity who have 1 or more clinical risk factors and are undergoing vascular or intermediate-risk surgery. A treadmill test, stress myocardial perfusion scintigraphy, or stress echocardiography are recommended as noninvasive cardiac tests for the detection of obstructive coronary artery disease.

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Computed tomography coronary angiography (CTCA) is a reliable and noninvasive method that is used for the assessment of coronary artery disease, coronary anatomy, and cardiac function (4,5). A high negative predictive value (NPV) and a high specificity for stenoses allow for effectively ruling out coronary artery disease in patients with

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Abbreviations and Acronyms

ACC/AHA = American College of Cardiology/ American Heart Association

AUC = area under the curve

AUCCCT = Appropriate Use Criteria for Cardiac Computed Tomography

CACS = coronary artery calcium scores

CHF = congestive heart failure

CI = confidence interval

CTCA = computed tomography coronary angiography

ECG = electrocardiography

IDI = integrated discrimination improvement

NPV = negative predictive value

NRI = net reclassification improvement

OR = odds ratio

PPV = positive predictive value

RCRI = revised cardiac risk index

ROC = receiver-operating characteristic

cardiac risk factors who have nondiagnostic or equivocal noninvasive cardiac stress tests. However, the Appropriate Use Criteria for Cardiac Computed Tomography (AUCCCT), which was published in 2010, recommends that there are no appropriate indications for CT as part of preoperative evaluations for noncardiac surgery (6), which is due to the lack of studies showing direct benefits of its use in the perioperative period.

Therefore, we evaluated whether coronary artery calcium scores (CACS) and the degree of stenosis that were measured with CTCA predicted post-operative cardiovascular events in patients who were undergoing intermediate-risk noncardiac surgeries.

Methods

Study populations. From January 2007 to December 2009, 878 consecutive patients were examined with CTCA before surgery. We included only patients who were undergoing intermediate-risk noncardiac surgeries for intrathoracic, intraperitoneal, orthopedic, head and neck, and prostate disease (3). We excluded patients who were undergoing high- and low-risk operations (n = 618). In addition, we excluded patients who had recent (within 1 month) myocardial infarctions (n = 3), acute decompensated heart failure (n = 2), severe valvular disease (n = 5), or fatal cardiac arrhythmias (n = 2). Patients with immeasurable CACS due to poor image quality because of motion artifacts (n = 6) and those who were undergoing preventive coronary interventions after the CTCA evaluations (n = 3) were also excluded. Finally, in this study, a total of 239 CACS and 234 coronary artery stenosis evaluations were analyzed. We could not evaluate the coronary artery stenosis of 5 patients due to heavy calcification and motion artifacts (Fig. 1). This study was approved by the local institutional review board with waiver of individual consent.

CTCA analysis. CTCA was performed with a 64-slice system (Brilliance 64, Philips Healthcare, Best, the Netherlands). Patients with a heart rate >80 beats/min received oral propranolol given in 40-mg increments (up to 120 mg) before the CTCA scan. A low-osmolar nonionic contrast agent (90 to 100 cc Ultravist 370, Berlex, Wayne, New Jersey) was injected into the antecubital vein at flow rates between 3.5 and 4.5 ml/s. After the contrast injection, a retrospective electrocardiographic (ECG)-gated spiral scan was performed that covered the region immediately beneath the aortic arch to the apex of the left ventricle during an inspiratory breath hold of 10 to 20 ms, depending on the particular scanner. The scan parameters were gantry rotation, 330 to 420 ms, and spiral imaging with retrospective ECG gating and dose modulation (ECG pulsing), 750 to 850 mA, 120 kV, and 0.75-mm slice thickness. For all scanners, a multisegment algorithm was used to reconstruct overlapping images that were typically at 75% of the cardiac cycle. CACS was measured without contrast with semiautomated software (HeartBeat CS, Philips Medical Systems) that displayed colored spots representing calcium, which were manually marked by the operator and automatically used to calculate a summed CACS.

We classified the grades of maximal stenosis as normal or minimal stenosis (luminal diameter narrowing <30%), nonsignificant stenosis (30% ≤ luminal diameter narrowing <50%), or significant stenosis (≥50% luminal diameter narrowing). Angiographically significant disease was classified as no significant stenosis, single-vessel disease if there was significant stenosis in 1 vessel; 2-vessel disease if there was significant stenosis in 2 vessels, and 3-vessel disease if there was significant stenosis in 3 vessels.

Pre-operative risk assessments. We reviewed the medical records for clinical risk factors and laboratory findings for all patients. Body mass index (kilograms divided by meters squared), hemoglobin (grams per deciliter), glycosylated hemoglobin A_{1c} (HbA_{1c}; percentage), and the glomerular

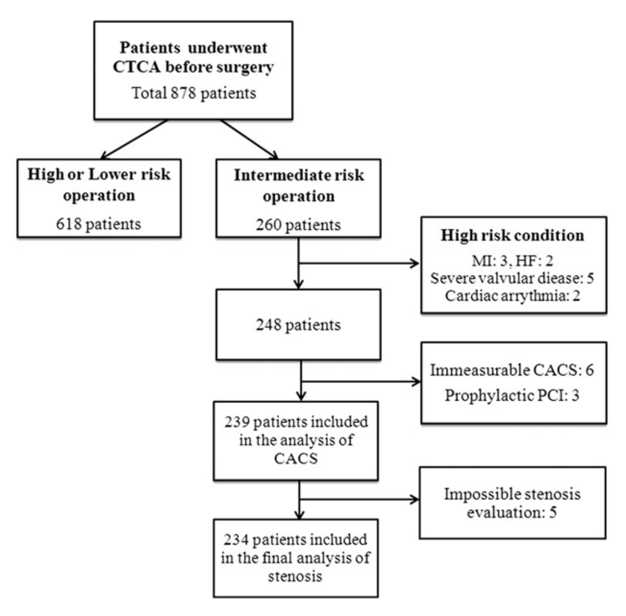

Figure 1 **Profile of Patient Enrollment**

CTCA = computed tomography coronary angiography; CACS = coronary artery calcium scores; HF = heart failure; MI = myocardial infarction; PCI = percutaneous coronary intervention.

filtration rate (milliliter per minute) were obtained at the time of the CTCA. The revised cardiac risk index (RCRI) was calculated for each patient. The RCRI relies on the presence or absence of the following 6 identifiable predictive factors: high-risk surgery (intrathoracic, intraperitoneal, or suprainguinal vascular surgery), ischemic heart disease, congestive heart failure (CHF), cerebrovascular disease, insulin therapy with diabetes mellitus, and renal dysfunction (serum creatinine level >2.0 mg/dl). Each of these predictors was assigned 1 point. According to the ACC/AHA guidelines (3), intrathoracic or intraperitoneal surgeries are classified as intermediate surgical procedures, whereas the RCRI designates these surgeries as high-risk procedures. Therefore, intrathoracic and intraperitoneal surgeries were assigned 1 point when the RCRI was calculated.

Definition of post-operative adverse events. The post-operative cardiovascular events were defined as cardiac death, acute coronary syndrome (nonfatal myocardial infarction and unstable angina), pulmonary edema, ventricular fibrillation, ventricular tachycardia with hemodynamic compromise, and complete heart block within 30 days after surgery (7).

Cardiac death was defined as sudden death or death secondary to myocardial infarction, arrhythmia, or heart failure. Myocardial infarction was defined as troponin I levels that increased to >2 times the upper limit of normal, which were associated with at least 1 of the following: new Q waves on ECG (≥30 ms in 2 continuous leads), persistent significant ST elevation or depression on the ECG, or a new regional wall motion abnormality with ECG (8). Unstable angina was defined as the appearance of reversible ischemic ST changes that accompanied clinical symptoms without increased levels of troponin I.

Statistical analysis. Statistical analysis was performed with SPSS for Windows, version 12.00 (IBM Corporation, Armonk, New York) and SAS for Window, version 9.1 (SAS Institute Inc., Cary, North Carolina). Continuous variables were expressed as medians and quartiles, and categorical data were expressed as numbers and percentages. The Mann-Whitney *U* test was used to compare continuous variables. The chi-square test or Fisher exact test was used to compare categorical variables between groups. Binary logistic regression analysis by the enter method was used to determine the independent predictors of post-operative cardiovascular events. The odds ratio (OR) and its 95% confidence interval (CI) were calculated. All p values refer to 2-tailed tests of significance. A receiver-operating characteristic (ROC) curve analysis of CACS was performed to identify the optimal cutoff value for the prediction of post-operative cardiovascular events. The optimal cutoff point of CACS was calculated by the Euclidean method. The sensitivity, specificity, positive predictive value (PPV), and NPV of the prediction of cardiovascular events were calculated. Finally, we compared 2 or more ROC curves using the area under the curve (AUC) comparison analysis method as described by DeLong et al. (9). We also calculated the integrated discrimination improvement (IDI) and the net reclassification improvement (NRI) with a category-free option among models following the methodology of Pencina et al. (10,11). Values of $p < 0.05$ were considered significant.

Results

Patient characteristics. Post-operative cardiovascular events occurred in 19 patients (8%; 11 men; age 70 ± 10 years). There were 8 cases of cardiac death, 2 cases of nonfatal myocardial infarction, 2 cases of unstable angina, 5 cases of pulmonary edema with heart failure, 1 case of ventricular tachycardia with hemodynamic compromise, and 1 case of complete atrioventricular block. Three patients died because of noncardiac causes; 1 patient had wound leakage and bleeding on the second post-operative day, and 2 patients had pneumonia on the eighth and twenty-first days after their surgeries.

The prevalences of hypertension, chronic kidney disease, angina, and the history of heart failure were higher in patients with post-operative cardiovascular events. Serum albumin levels, hemoglobin levels, and estimated glomerular filtration rates were significantly lower in patients with events. The use of calcium channel blockers was significantly higher in patients with events. The use of concomitant medications, such as insulin, beta-blockers, or 3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitors, was not related to post-operative cardiac events (Table 1).

RCRI and events. Patients were grouped into 4 RCRI classes according to 0, 1, 2, or ≥3 clinical predictors (Table 2). RCRI scores identified 105 patients (43.9%) with a score of 0 (no clinical predictors), 98 (41.0%) with a score of 1 (1 clinical predictor), 28 (11.7%) with a score of 2 (2 clinical predictors), and 8 (3.3%) with a score of 3 (3 or more clinical predictors). These patients had event rates of 5.7%, 4.1%, 14.3%, and 62.5%, respectively. In patients with RCRI scores of 0 as a reference, the OR for experiencing a post-operative event for patients with scores of 1, 2, or 3 were 0.51 (95% CI: 0.20 to 2.61, $p = 0.611$), 2.91 (95% CI: 0.79 to 9.47, $p = 0.178$), or 10.94 (95% CI: 2.73 to 43.81, $p < 0.001$), respectively (Table 2). As shown, the post-operative events rate tended to increase in patients with higher RCRI scores. However, only the group with RCRI scores of 3 had statistically significant differences.

Coronary artery stenosis and CACS in CTCA. Patients with significant coronary artery stenosis had more post-operative events compared with those with minimal stenosis and nonsignificant stenosis. With the OR of those with minimal stenosis used as a reference group, the ORs were 2.11 (95% CI: 0.39 to 11.45, $p = 0.388$) for nonsignificant stenosis and 5.69 (95% CI: 1.89 to 17.15, $p = 0.002$) for significant stenosis.

Angiographically significant disease was categorized into 4 groups ranging from no significant stenosis to 3-vessel disease. Patients with multivessel coronary artery disease (2- and 3-vessel disease) had significantly more events compared with those with no significant stenosis or single-vessel coronary artery disease. With the OR of those with no

Table 1 Baseline Characteristics

Characteristics	Total (n = 239)	No events (n = 220)	Events (n = 19)	p Value
Male	125 (52.3%)	114 (51.8%)	11 (57.9%)	0.611
Age (yrs)	69 (62–75)	69 (62–75)	72 (64–78)	0.261
Height (cm)	161.6 (153.0–168.0)	161.5 (153.0–168.0)	162.0 (150.6–167.0)	0.917
Weight (kg)	61.6 (53.7–70.0)	62.0 (54.0–72.2)	60.0 (52.0–65.0)	0.297
Body mass index (kg/m^2)	23.5 (21.4–26.4)	23.7 (21.4–26.5)	22.4 (20.8–25.4)	0.182
GFR (ml/min)	78.3 (60.8–100.0)	80.3 (61.2–100.1)	65.2 (41.0–75.8)	0.014*
Albumin (g/dl)	3.8 (3.4–4.1)	3.8 (3.4–4.2)	3.2 (2.6–3.7)	<0.001*
Hemoglobin (g/dl)	12.1 (10.8–13.5)	12.2 (11.0–13.6)	10.7 (10.2–11.7)	0.001*
HbA_{1c} (%)	6.4 (5.6–7.2)	6.4 (5.6–7.2)	6.3 (5.8–6.9)	0.940
Current smoking habits	88 (36.8%)	81 (36.8%)	7 (36.8%)	1.000
Diabetes	94 (39.3%)	83 (37.7%)	11 (57.9%)	0.084
Hypertension	172 (72.0%)	154 (70.0%)	18 (94.7%)	0.021*
Cerebrovascular accident	26 (10.9%)	23 (10.5%)	3 (15.8%)	0.474
Chronic kidney disease	21 (8.8%)	16 (7.3%)	5 (26.3%)	0.005*
Previous myocardial infarction	11 (4.6%)	9 (4.1%)	2 (10.5%)	0.199
Angina pectoris	41 (17.2%)	33 (15.0%)	8 (42.1%)	0.003*
Heart failure	8 (3.3%)	3 (1.4%)	5 (26.3%)	<0.001*
ECG abnormalities	118 (49.4%)	105 (47.7%)	13 (68.4%)	0.083
ACE inhibitors or ARB	99 (41.4%)	90 (40.9%)	9 (47.4%)	0.583
Calcium channel blockers	97 (40.7%)	85 (38.6%)	12 (63.2%)	0.037*
Beta-blockers	58 (24.3%)	52 (23.6%)	6 (31.6%)	0.438
Digoxin	14 (5.9%)	12 (5.5%)	2 (10.5%)	0.366
Antiplatelet agents	101 (42.3%)	89 (40.5%)	12 (63.2%)	0.055
Warfarin	8 (3.3%)	7 (3.2%)	1 (5.3%)	0.628
Thiazolidinediones	3 (1.3%)	2 (0.9%)	1 (5.3%)	0.102
HMG-CoA reductase inhibitors	54 (22.6%)	47 (21.4%)	7 (36.8%)	0.122
Insulin	31 (13.0%)	29 (13.2%)	2 (10.5%)	0.741

Values are n (%) or medians (25th to 75th percentiles). *Significant p values ($p < 0.05$).
ACE = angiotensin-converting enzyme; ARB = angiotensin receptor blocker; ECG,= electrocardiography; GFR = glomerular filtration rate; HbA_{1c} = glycosylated hemoglobin A_{1c}; HMG-CoA = 3-hydroxy-3-methylglutaryl coenzyme A.

significant stenosis used as a reference group, the ORs were 11.64 (95% CI: 3.38 to 40.15, $p < 0.001$) for 2-vessel disease and 8.32 (95% CI: 2.33 to 29.64, p = 0.001) for 3-vessel disease (Table 3).

The median CACS for the total group of 239 patients was 52.68 (interquartile range: 0.00 to 262.74). The value of CACS in patients with events (median, 359.27; interquartile range: 179.29 to 1,421.47) was significantly higher than in those without events (median, 0.00; interquartile range: 0.00 to 29.12, $p < 0.001$). In the ROC curve analysis of CACS predicting post-operative cardiac events, the AUC was 0.762 (95% CI: 0.674 to 0.849, $p < 0.001$) and the optimal CACS cutoff value was 113 (sensitivity, 79%; specificity, 61%; PPV, 15%; NPV, 97%). The OR of those with high CACS (≥ 113) was 5.84 (95% CI: 1.88 to 18.19, p = 0.001) for cardiovascular events (Table 3).

Table 2 Revised Cardiac Risk Index

Risk Factors	No. of Events/No. of Total Patients (Event Rate %)	Odds Ratio (95% CI)	p Value
None	6/105 (5.7%)	Reference group	
1	4/98 (4.1%)	0.51 (0.20–2.61)	0.611
2	4/28 (14.3%)	2.91 (0.79–9.47)	0.178
3 or more	5/8 (62.5%)	10.94 (2.73–43.81)	<0.001

Values are n/N (%).
CI = confidence interval.

To examine whether CACS and multivessel disease were independent predictors of post-operative cardiovascular events, a multivariate analysis was performed using CTCA factors and the significant risk factors of the RCRI obtained on univariate analysis (Table 4). In Model 1, which included high CACS (≥113) and the 3 clinical predictors, high CACS, CHF, and ischemic heart disease were independent significant predictors. In Model 2, which included the presence of multivessel disease, CHF and multivessel disease were independent predictors. In the final model (Model 3), which included all 3 clinical predictors and 2 CTCA parameters, only the presence of multivessel disease and CHF remained as independent predictors of cardiovascular events.

Predictive value of the RCRI score and CTCA parameters. Each RCRI score group was re-stratified based on high or low CACS (using a cutoff point of 113 on CACS) and the presence or absence of multivessel disease (Fig. 2). In the same RCRI score group, the post-operative events rate was higher in patients with CACS ≥113 than in those with CACS <113; specifically, the rates were 15.2% versus 1.4% for those with CACS ≥113 versus those with CACS <113 in the RCRI score 0 group, 4.7% versus 3.6%, respectively,

Table 3 Correlations of Computed Tomographic Findings With Post-Operative Cardiovascular Events

Characteristics	No. of Events/No. of Total Patients (Event Rate %)	Odds Ratio (95% CI)	p Value
Maximum stenosis			
Normal	5/142 (3.5%)	Reference group	
Nonsignificant CAD	2/28 (7.1%)	2.11 (0.39–11.45)	0.388
Significant CAD	11/64 (17.2%)	5.69 (1.89–17.15)	0.002
Angiographically significant disease			
No significant stenosis	7/170 (4.1%)	Reference group	
Single-vessel disease	0/27 (0%)	—	0.998
2-vessel disease	6/18 (33.3%)	11.64 (3.38–40.15)	<0.001
3-vessel disease	5/19 (26.3%)	8.32 (2.33–29.64)	0.001
Coronary artery calcium score ≥ 113	15/101 (14.1%)	5.84 (1.88–18.19)	0.001

Values are n/N (%).
CAD = coronary artery disease; CI = confidence interval.

in the RCRI score 1 group, 21.1% versus 0%, respectively, in the RCRI score 2 group, and 66.7% versus 50.0%, respectively, in the RCRI score 3 or more group (Fig. 2A). Similarly, there were more post-operative events in patients with multivessel disease than in those without multivessel disease in each RCRI group (Fig. 2B).

We conducted each ROC curve analysis of the predictive models using RCRI scores, RCRI plus CACS scores (with CACS ≥113 defined as a single independent predictive factor), RCRI plus multivessel disease (with 2- or 3-vessel disease defined as a single independent predictive factor), and RCRI plus CACS scores plus multivessel disease (Fig. 3). Based on the results of differences among the AUCs, RCRI plus CACS ≥113 score, RCRI plus multivessel disease, and RCRI plus CACS ≥113 plus multivessel disease were significantly more predictive of post-operative cardiovascular events than RCRI alone. Additionally, to estimate the incremental value of CTCA to predict cardiovascular events, we compared the probabilities of events and nonevents of models using the relative IDI and category-free NRI. The IDI of adding multivessel disease to the RCRI improved significantly (relative IDI for CACS ≥113 = 0.39, $p = 0.098$; for multivessel disease = 1.67, $p < 0.001$; and for the combined CACS ≥113 and multivessel disease = 1.78, $p < 0.001$) (Table 5). The addition of CACS ≥113 and/or multivessel disease to the RCRI resulted in a significant improvement of the category-free NRI (Table 5). The model that included 2 CTCA parameters (RCRI plus CACS ≥113 plus multivessel disease) showed the largest AUC (0.769 ± 0.062) and highest relative IDI and NRI for the prediction of cardiovascular events.

Discussion

In this study, a higher RCRI, a high CACS (≥113), the presence of significant coronary artery stenosis (diameter stenosis ≥50%), and multivessel coronary artery disease were significantly associated with post-operative cardiovascular events. However, the RCRI alone was not sufficiently sensitive for estimating risk in patients with 2 or fewer risk predictors, because the RCRI was only significant in patients with scores of 3 or more. For each group with a different RCRI, the CTCA results stratified the post-operative risk of patients more accurately. Compared with the predictive models using the ROC curve analysis, IDI, and NRI, the combination model that added CACS ≥113 and/or multivessel disease to RCRI was more predictive than the single predictive model of RCRI only for post-operative cardiovascular events. Among combination models, the use of a 2 CTCA parameters combination was superior to a single CTCA parameter in risk prediction.

Accumulating bodies of evidence have shown that CTCA is a reliable, noninvasive method for visualization of native coronary arteries. CTCA enables direct assessment of the degree and number of significant coronary stenoses and the presence of vulnerable plaques. CTCA can be a useful tool for stress-intolerant patients or subjects who show low

Table 4 Multivariate Analysis of Post-Operative Cardiovascular Events

	Model 1		Model 2		Model 3	
Characteristics	OR (95% CI)	p Value	OR (95% CI)	p Value	OR (95% CI)	p Value
Ischemic heart disease	3.10 (1.06–9.04)	0.039*	1.81 (0.55–6.00)	0.330	1.87 (0.57–6.12)	0.302
Congestive heart failure	10.11 (1.94–52.72)	0.006*	9.61 (1.27–72.43)	0.028*	7.78 (1.16–51.90)	0.034*
Renal dysfunction†	2.59 (0.66–10.21)	0.174	1.57 (0.33–7.57)	0.574	1.81 (0.38–8.58)	0.457
CACS ≥113	4.21 (1.25–14.18)	0.020*	—	—	2.66 (0.69–10.22)	0.155
Multivessel disease	—	—	7.31 (2.25–23.69)	0.001*	4.75 (1.33–16.90)	0.016*

*Significant p values ($p < 0.05$). †Serum creatinine level > 2.0 mg/dl.
CACS = coronary artery calcium score; CI = confidence interval; OR = odds ratio.

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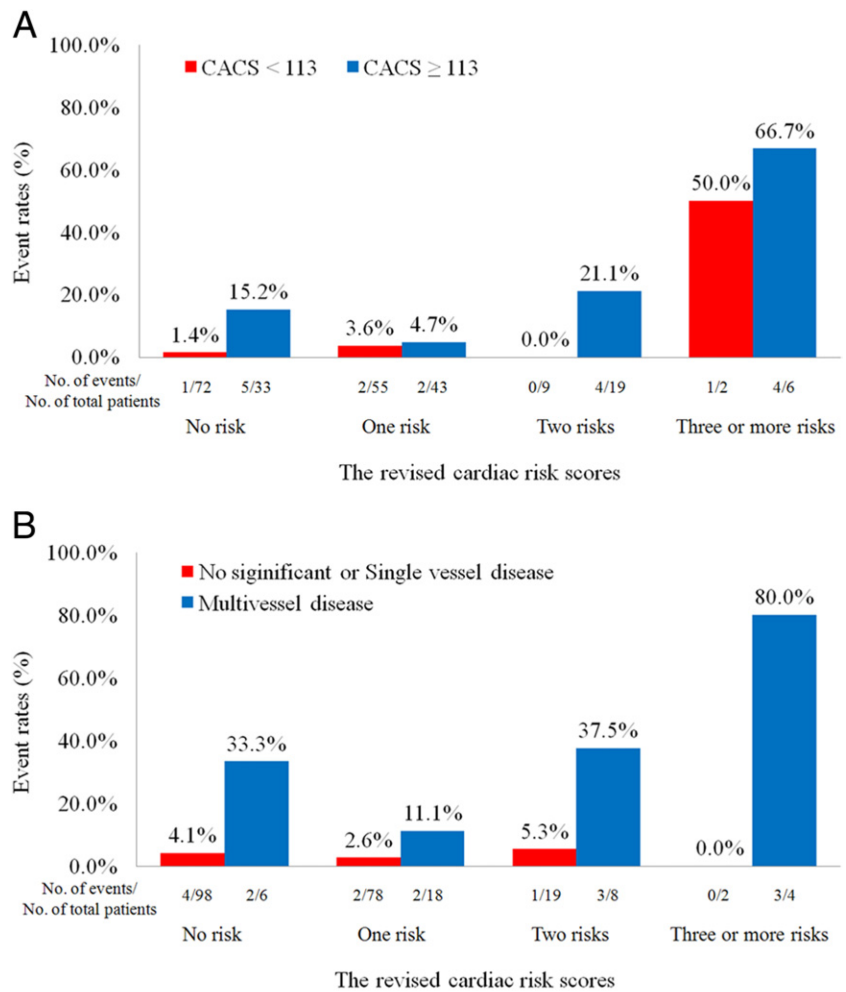

Figure 2 **Reclassification of the Revised Cardiac Risk Index Using Coronary Artery Calcium Scores**

Reclassification using coronary artery calcium scores (CACS) of 113 or more **(A)** and the presence or absence of multivessel disease **(B)**.

NPV with conventional methods (e.g., those with left bundle branch block on ECG [12]), or before undergoing severe cardiac valve surgery (13–15), or in those with dilated cardiomyopathy (16). However, for pre-operative cardiac evaluations, only a few reports have demonstrated the usefulness of CTCA in selective patients undergoing valve surgeries (13–15), liver transplantations (17), and noncoronary cardiac surgeries (18). To our knowledge, this is the first study to demonstrate that CTCA was a useful tool for predicting post-operative cardiovascular events in patients undergoing intermediate-risk noncardiac surgeries.

According to the ACC/AHA guidelines (3), noninvasive cardiac risk evaluations are only recommended for patients with poor or unknown functional capacities who have 1 or more clinical risk factors and are undergoing vascular or intermediate-risk surgery (19). Exercise ECG testing, stress myocardial perfusion scintigraphy, and dobutamine stress echocardiography are widely used. However, a considerable number of pre-operative patients cannot tolerate optimal exercise protocols, and abnormalities on resting ECG result in an inability to interpret ischemic changes. Pharmacologically-induced cardiac stress testing is also contraindicated because of safety considerations. In this regard, novel modalities are needed to evaluate perioperative cardiovascular risks and screen high-risk patients more safely and reliably. In this study, the PPV and NPV of CACS ≥ 113 for cardiac death and myocardial infarction were 9% and 98%, respectively, and the PPV and NPV of multivessel disease were 19% and 98%, respectively. These results were comparable to values of other noninvasive tests shown in the ACC/AHA guidelines (3): PPV of 2% to 20% and NPV of 97% to 100% in stress myocardial perfusion scintigraphy, and PPV of 0% to 33% and NPV of 93% to 100% in dobutamine stress echocardiography.

The ACC/AHA guidelines (3) recommend invasive coronary angiography and revascularization for patients with acute cardiac conditions and high-risk ischemia with noninvasive modalities. However, invasive modalities, including

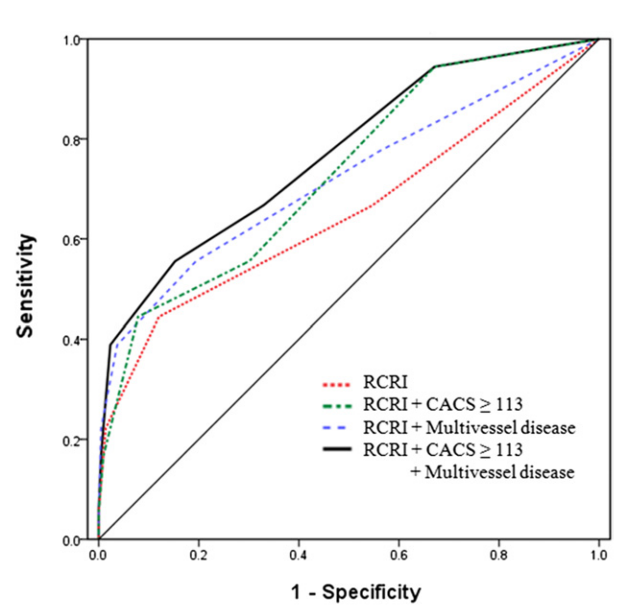

Figure 3 **Receiver-Operating Curve Comparison**

Comparison of the receiver-operating characteristic (ROC) curves of the revised cardiac risk index (RCRI) and/or the coronary artery calcium score (CACS) and the presence of multivessel disease.

revascularization, have higher procedure-related risks than CTCA. CTCA provides precise information with respect to the site and degree of coronary artery stenosis in high-risk patients. Therefore, it might preclude the unnecessary duplication of noninvasive and invasive studies for appropriate revascularization.

Contrast media and radiation exposure are prerequisites for CTCA. The use of contrast media may cause allergic reactions or extravasations and is contraindicated in patients with poor renal function (20). Because CACS does not use contrast, it might be a good option for patients with a history of contrast media allergies or renal dysfunction. One of the concerns of CTCA is radiation exposure. However, radiation doses in CTCA are usually similar to those used in myocardial perfusion scintigraphy (20). Recent advancements in techniques, such as small scan volume, low tube current, and prospective ECG gating, can minimize radiation exposure. In clinical practice, the additional cost associated with CTCA is another concern. A few studies reported that CTCA for coronary artery disease is less costly overall and more effective in patients with chest pain (21,22). A cost-effectiveness analysis of the CTCA for post-operative risk stratification has not been reported. We believe that the CTCA is a valuable, cost-effective tool because intermediate-risk operations are associated with a considerable rate of death and myocardial infarction (1% to 5%); however, further studies regarding cost effectiveness are needed.

Study limitations. First, the principal methodological limitation was the retrospective use of medical records, leading to the possibility of selection bias, because we excluded patients who underwent prophylactic coronary revascularization for left main or left main–equivalent coronary artery disease; this may have resulted in an underestimation of cardiovascular events. Second, because image reconstruction artifacts that are related to radiodense materials, such as calcium or metal, can obscure the coronary artery lumen, this artifact may have led to both an under- and an overestimation of coronary stenosis and calcium scores. Third, routine collection of post-operative serial ECG and cardiac enzyme studies was not performed in all patients, which may also have led to an underestimation of cardiovascular events.

Conclusions

In patients who were undergoing intermediate-risk noncardiac surgeries, the evaluation of CACS and coronary artery stenosis with CTCA showed additive predictive value to evaluations with RCRI alone. The CTCA should be considered in patients with poor or unknown functional capacities, high RCRI score (≥3), and contraindications to noninvasive stress tests. Even if patients are deemed to have a low RCRI score, CTCA might be useful. A large sample size and prospective study is needed to further define the role of CTCA in pre-operative risk stratification for intermediate-risk noncardiac surgeries.

Table 5 **Comparisons of AUCs, IDI, and NRI for CTCA Parameters**

Models	AUC	SE	95% CI	p Value (Difference Between AUCs)	Relative IDI		Category-Free NRI			
					Values	p Value	Event	Nonevent	Total	p Value
RCRI	0.652	0.079	0.587–0.713	Reference group						
RCRI + CACS ≥113	0.731	0.063	0.669–0.786	0.032*§	0.39*	0.098*	58%*	22%*	0.798*	0.001*§
RCRI + Multivessel disease	0.719	0.074	0.656–0.775	0.048*§	1.67*	<0.001*§	22%*	76%*	0.981*	<0.001*§
				0.719†	0.833†	0.010†§	56%†	−37%†	0.185†	0.450†
RCRI + CACS ≥113 + multivessel disease	0.770	0.062	0.711–0.822	0.017*§	1.781*§	<0.001*§	44%*	55%*	0.991*	<0.001*§
				0.052†	0.911†	0.001†§	33%†	10%†	0.435†	0.076†
				0.086‡	0.042‡	0.588‡	56%‡	24%‡	0.796‡	0.001‡§

*Comparison with the ROC curves of RCRI (reference group). †Comparison with the ROC curves of RCRI plus CACS ≥ 113. ‡Comparison with the ROC curves of RCRI plus multivessel disease. §Significant p values.

AUC = area under the curve; CACS = coronary artery calcium score; CI = confidential interval; IDI = integrated discrimination improvement; NRI = net reclassification improvement; RCRI = revised cardiac risk index; ROC = receiver-operating characteristics.

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Key Words: computed tomography coronary angiography ■ coronary artery calcium score ■ intermediate risk ■ noncardiac surgery ■ preoperative cardiovascular risk.