Stroke after coronary artery bypass grafting: Preoperative predictive accuracies of CHADS₂ and CHA₂DS₂VASc stroke risk stratification schemes

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Objective: Neurologic events after coronary artery bypass grafting are an infrequent but devastating complication. This study analyzed the preoperative predictive abilities of the CHADS₂ and CHA₂DS₂VASc stroke scores in patients undergoing isolated coronary artery bypass grafting.

Methods: Included in the study were 2910 patients who underwent isolated coronary artery bypass grafting during a 19-year period. CHADS₂ and CHA₂DS₂VASc scores were computed for all patients, and outcomes were evaluated in terms of perioperative stroke and compared with 2 specific models for predicting surgical coronary artery bypass grafting stroke (Northern New England Cardiovascular Disease Study Group and Multicenter Study of Perioperative Ischemia Research Group). Perioperative stroke discrimination was quantified by computing the area under the receiver operating characteristic curve.

Results: Overall, 62 (2.1%) had perioperative strokes. Areas under the curve were 0.71 (95% confidence interval, 0.64-0.78) for CHADS₂, 0.72 (95% confidence interval, 0.65-0.79) for CHA₂DS₂VASc, 0.69 (95% confidence interval, 0.61-0.76) for Northern New England Cardiovascular Disease Study Group, and 0.73 (95% confidence interval, 0.67-0.80) for Multicenter Study of Perioperative Ischemia Research Group scores. Northern New England Cardiovascular Disease Study Group and CHA₂DS₂VASc scores were better at discriminating patients with particularly low or high risk of stroke.

Conclusions: CHADS₂ and CHA₂DS₂VASc scores predicted perioperative coronary artery bypass grafting strokes with discriminatory abilities similar to those of specific predictive surgical coronary artery bypass grafting stroke models. All schemes tested showed similar limitations in discriminating patients with high postoperative stroke risk, with a high proportion being classified as having intermediate stroke risk. (*J Thorac Cardiovasc Surg* 2012;144:1428-35)

Stroke remains a devastating complication after surgical coronary artery bypass grafting (CABG), with an incidence of between 1% to 5.6% remaining despite the continuous modification of operative procedures and improvement in intraoperative and postoperative care.¹⁻⁵ The ability to predict perioperative stroke is crucial, and many relevant prognostic tools have been developed to discriminate patients at high risk, such as the Northern New England Cardiovascular Disease Study Group (NNECDSG) and the Multicenter Study of Perioperative Ischemia Research Group (McSPI) scores.^{4,5} Neither of the aforementioned methods, however, has been extensively applied in routine clinical practice.

The CHADS₂ (congestive heart failure, hypertension, age ≥ 75 years, diabetes mellitus, previous stroke or transient ischemic attack [TIA]) and CHA₂DS₂VASc (congestive heart failure, hypertension, age ≥ 75 years doubled, diabetes mellitus, previous stroke or TIA, vascular disease, age 64-74 years, and sex category female) are simple risk scoring methods for stroke risk stratification in nonvalvular atrial fibrillation populations. They have been widely applied in clinical practice as guidelines for antithrombotic therapy but never used before to predict preoperative stroke risk in patients undergoing isolated CABG.^{6,7} These scores use similar variables (i.e., advanced age, female sex, hypertension, diabetes, heart failure, history of cerebrovascular events, impaired left ventricular function, etc.) to those computed by the specific algorithms (NNECDSG and McSPI scores) designed to predict perioperative stroke in isolated CABG. As a consequence, the aim of this study was to assess how accurately and consistently the CHADS₂ and CHA₂DS₂VASc scores performed in predicting perioperative stroke among patients undergoing isolated CABG relative to NNECDSG and McSPI scores.

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Abbreviations and Acronyms

AUC	= Area under the receiver operating characteristic curve
CABG	= coronary artery bypass grafting
CI	= confidence interval
McSPI	= Multicenter Study of Perioperative Ischemia Research Group
NNECDSG	= Northern New England Cardiovascular Disease Study Group
OR	= odds ratio
TIA	= transient ischemic attack

MATERIALS AND METHODS**Patient Cohort**

The retrospective study was conducted on 3011 consecutive patients undergoing isolated CABG at General University Hospital of Valencia between May 1993 and September 2011. Patients undergoing concomitant cardiac procedures, such as valve replacement, carotid endarterectomy, and so on, were excluded. Data were entered on a daily basis from the time of patient referral until hospital discharge, including preoperative and operating room data and intensive care unit and hospital stay durations. Complete information referring to the variables used in the analysis was available for 2910 patients. Of these patients, 101 were excluded on the grounds of incomplete data, which made application of the risk score schemes impossible in these cases.

Risk Stratification Schemes

The CHADS₂ and CHA₂DS₂VASc scores were tested in our sample for their abilities to predict perioperative stroke. Two specific predictive scores of perioperative stroke risk designed for isolated CABG, the NNECDSG score and the McSPI score, were used to validate our institutional results and also to compare the predictive accuracies of the scores derived from the CHADS₂ and CHA₂DS₂VASc schemes.⁴⁻⁷ With this aim, all patients were scored according to the 4 score algorithms, in each case following the exact procedure described in the corresponding study.⁴⁻⁷ The risk factors used to calculate the stroke risk stratification algorithms are listed in Table 1.

The CHADS₂⁶ risk stratification scheme is based on a cumulative scoring system focused on 5 major risk factors: congestive heart failure, hypertension, age at least 75 years, and diabetes mellitus, each scoring 1, and history of previous stroke or TIA, scoring 2 to reflect its increased weight. CHA₂DS₂VASc,⁷ a new and expanded version of the CHADS₂ score, includes additional factors and weighting: age of at least ≥75 years is assigned 2 points (A₂), vascular disease (previous myocardial infarction, peripheral arterial disease, aortic plaques) is assigned 1 point (V), age of 65 to 74 years is assigned 1 point (A), and female sex category (Sc) is assigned 1 point.

The NNECDSG score⁴ is a specific stroke risk algorithm that was based on 33,062 consecutive patients undergoing isolated CABG in northern New England between 1992 and 2001. The McSPI Stroke Risk Index⁵ is similarly derived from data on 2017 patients from 24 different centers in the United States. These stroke prediction models were able to discriminate between the different categories in this population, with an area under the receiver operating characteristic curve (AUC) reported in the original studies of 0.70 (95% confidence interval [CI], 0.67-0.72) for the NNECDSG score and 0.77 (95% CI, 0.73-0.81) for the McSPI stroke risk model.

The NNECDSG stroke index score⁴ is based on 7 major factors: age 55 to 59 years is assigned 1.5 points, age 60 to 64 years is assigned 2.5 points, age 65 to 69 years is assigned 3.5 points, age 70 to 74 years is assigned 4

points, age 75 to 79 years is assigned 4.5 points, and age of at least 80 years is assigned 5.5 points; being female is assigned 1 point; diabetes mellitus is assigned 1.5 points; vascular disease is assigned 2 points; renal failure is assigned 2 points; left ventricular ejection fraction less than 40% is assigned 1.5 points; urgent surgery is assigned 1.5 points; and emergency surgery is assigned 2.5 points.

The McSPI score⁵ is similarly based on 7 major factors: unstable angina falling into New York Heart Association functional class III or IV is assigned 15 points; diabetes mellitus is assigned 17 points; history of neurologic disease (previous stroke or TIA) is assigned 18 points; previous CABG is assigned 16 points; history of vascular disease is assigned 18 points; history of pulmonary disease is assigned 16 points, and age is assigned a variable amount of points (points = [age - 25] × 100/70).

Definition Preoperative Variables

The definition of diabetes mellitus was a fasting plasma glucose level of at least 7.0 mmol/L (126 mg/dL) or treatment with oral hypoglycemic agent, insulin, or both. Hypertension was assessed at a resting systolic blood pressure greater than 140 mm Hg, a resting diastolic blood pressure greater than 90 mm Hg, or both on at least 2 occasions or current antihypertensive pharmacologic treatment. The CHADS₂ scheme considers heart failure as a clinical state defined as recent exacerbation (New York Heart Association class III or IV at admission), left ventricular fractional shortening not more than 25% according to echocardiography, or left ventricular ejection fraction not more than 40% by ventriculography. CHA₂DS₂VASc introduces a history of vascular disease variable that includes coronary artery disease (previous myocardial infarction, angina pectoris, percutaneous coronary intervention, or CABG) and peripheral vascular disease (intermittent claudication, previous surgery or percutaneous intervention on the abdominal aorta or the lower extremity vessels, abdominal or thoracic surgery, arterial and venous thrombosis). Although CHA₂DS₂VASc includes coronary artery disease as a vascular disease factor, in this study this preoperative variable was not computed to avoid scoring 1 additional point in all cases.

The NNECDSG⁴ proposed a scheme that combined a history of vascular disease (cerebrovascular disease including previous stroke, previous TIA, previous carotid surgery, carotid stenosis or bruit; lower extremity disease including claudication, amputation, previous lower extremity bypass, absent pedal pulses, or lower extremity ulcers), renal failure (requiring dialysis, preoperative serum creatinine ≥2 mg/dL, glomerular filtration rate <30 mL/min/1.73m²), preoperative left ventricular ejection fraction less than 40%, and priority of surgery assessed as urgent (operation required within 24 hours to minimize the chance of further clinical deterioration) or emergency (cases in which there should be no delay in providing operative intervention).

McSPI⁵ proposed a scheme that collected unstable angina (angina in the presence of myocardial ischemia that requires hospitalization in an intensive care unit and the use of intravenous medications for control), a history of vascular disease (at least 1 of peripheral vascular disease, carotid stenosis >50%, cerebrovascular surgery, aortic disease), and a history of pulmonary disease (requiring pharmacologic therapy for the treatment of chronic pulmonary compromise, or forced expiratory volume in 1 second <75% of predicted value).

Perioperative stroke was defined as any new (temporary or permanent, focal or global) neurologic deficit, in accordance with the published guidelines, within 30 days from operation or later than 30 days for patients still in the hospital.⁸ Temporary stroke included TIA, defined as fully reversible neurologic deficits lasting less than 24 hours, and prolonged reversible ischemic neurologic deficits, defined as events lasting longer than 24 hours but less than 3 weeks. All stroke outcomes in this study were diagnosed by a neurologist and in most cases were localized by imaging studies, either head computed tomography or magnetic resonance imaging. The study excluded cases with diffuse postoperative brain encephalopathy, presenting as delirium, confusion, coma, seizures, prolonged alteration in mental

TABLE 1. Proportion of risk factors in 2910 isolated coronary artery bypass grafting procedures and variables included in the original stroke risk-stratification algorithms

	Variable (n = 2910)	CHADS ₂ ⁶	CHA ₂ DS ₂ VASc ⁷	NNECDSG ⁴	McSPI ⁵
Age (y, mean ± SD)	64.73 ± 9.741	Yes	Yes	Yes	Yes
Female	561/2910 (19.28%)		Yes	Yes	
Diabetes mellitus	1218/2910 (41.86%)	Yes	Yes	Yes	Yes
Hypertension	1665/2910 (57.22%)	Yes	Yes		
Previous MI or CAD	313/2910 (10.76%)		Yes	Yes	
Previous stroke or TIA	187/2910 (6.43%)	Yes	Yes	Yes	Yes
Carotid artery disease	121/2910 (4.16%)		Yes	Yes	Yes
Congestive heart failure	717/2910 (24.64%)	Yes	Yes	Yes	
Peripheral vascular disease	331/2910 (11.37%)		Yes	Yes	Yes
Renal failure	390/2910 (13.40%)			Yes	
EF <40%	317/2910 (10.89%)			Yes	
EF ≤40%	386/2910 (13.26%)		Yes		
Revascularization presentation					
Emergency	102/2910 (3.51%)			Yes	
Urgent	466/2910 (16.01%)			Yes	
Elective	2342/2910 (80.48%)				
Previous CABG	171/2910 (5.88%)				Yes
Unstable angina	541/2910 (18.59%)				Yes
COPD	376/2910 (12.92%)				Yes
Off-pump CABG	1263/2910 (43.40%)				
Body mass index (kg/m ² , mean ± SD)	28.51 ± 7.174				
Body surface area (m ² , mean ± SD)	1.87 ± 0.176				

Data represent numbers and percentages of patients except as marked. CABG, Coronary artery bypass grafting; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; EF, ejection fraction; McSPI, Multicenter Study of Perioperative Ischemia Research Group; MI, myocardial infarction; NNECDSG, Northern New England Cardiovascular Disease Study Group; TIA, transient ischemic attack.

status, combativeness, and agitation in the immediate postoperative period, which had a significant relationship with circulatory bypass time and may also reflect a longer exposure to anesthesia.⁹

Surgical Procedure, Anesthesia, and Perfusion

Seven cardiac surgeons took part in the study. Although there were some individual variations in the technique, most procedures were standardized. The participating surgeons decided on the type of surgical procedure as well as on the conduits used and vessels grafted. Most of the patients underwent median sternotomy. The anesthetic technique was standardized and consisted of low- to intermediate-dose narcotics, inhalation agents, and paralytics. Assessment of the ascending aorta was performed intraoperatively by digital palpation only. Cardiopulmonary bypass (on-pump) was carried out with nonpulsatile flow (in most cases), moderate systemic hypothermia (28°C-32°C), and pump flow rates to achieve a mean arterial pressure of 60 to 80 mm Hg. Proximal anastomoses were performed with a partial occluding clamp in most patients. Only in few clinical situations (aortic calcifications in the preoperative imaging study and intraoperative palpation of aortic plaques) were other strategies used, such as single aortic crossclamp technique, change of proximal anastomosis site, total arterial graft revascularization, or the no-touch aorta strategy.^{3,10} These technical variables were not collected as part of this study. Postoperative management of all patients followed standard practice guidelines from surgery to discharge. This included admission to the intensive care unit from the operating room, with subsequent transfer to a ward.

Statistical Analysis

Continuous variables are presented as mean ± SD, and categorical variables are shown as percentages. The variables were analyzed with the Student *t* test or Mann-Whitney test (where appropriate) for continuous

variables and the χ^2 test and Fisher's exact test for categorical variables. Stepwise logistic regression was then performed, and it included predictors associated with a value of *P* < .20 from the univariate analyses. Results are reported as odds ratios (ORs) with associated 95% CIs. The discrimination assesses the score effectiveness to predict which patients are likely to have a stroke and which are not, as represented by the AUC value. The value of each stroke risk stratification scheme that provided maximum discrimination between patients who had a stroke (ie, the optimum threshold) was obtained as a trade-off decision between maximizing sensitivity and specificity by means of the receiver operating characteristic curves. This calibration evaluates the model's ability to predict both the overall perioperative stroke and the different risk groups by means of the Hosmer-Lemeshow test. We declared the classification schemes statistically significantly different if CIs did not overlap.

The predictive accuracy of the stroke risk stratification schemes was also studied by classifying their scores into 3 levels, distinguishing low (<1%), intermediate (1%-3%), and high-risk (>3%) of perioperative stroke, which would be particularly important in the decision making process. Our criteria has been arbitrary, others authors' comments have suggested similar percentages of strokes. The Statistical Package for the Social Sciences (SPSS version 19; IBM Corporation, Armonk, NY) was used for the statistical analysis. Informed consent was obtained from all subjects, and the Human Research Office of General University Hospital of Valencia approved the study.

RESULTS

Patients

Of a total of 2910 patients, 62 (2.1%) had perioperative strokes. The rate of stroke was relatively stable from 1993 to 2011 (1.6% ± 1.5%) and increased with age (0.35%

TABLE 2. Univariate and multivariate predictive power of risk factors for postoperative stroke events

Risk factor	Event rate (%)		P value		Odds ratio (95% CI)
	Without risk factor	With risk factor	Univariate	Multivariate	
All predictive factors					
Age ≥75 y	49/2460 (1.99%)	13/450 (2.89%)	.314		
Female	46/2349 (1.95%)	16/561 (2.85%)	.261		
Previous stroke or TIA	39/2723 (1.43%)	23/187 (12.29%)	<.001	<.001	1.12 (1.08-1.16)
Hypertension	22/1245 (1.77%)	40/1665 (2.40%)	.307		
Diabetes mellitus	29/1692 (1.71%)	33/1218 (2.70%)	.096	.327	1.01 (0.98-1.05)
Heart failure	32/2193 (1.46%)	30/717 (4.18%)	<.001	<.001	2.92 (1.72-4.97)
Vascular disease*	43/2579 (1.66%)	19/331 (5.74%)	<.001	.456	1.12 (0.82-1.52)
Renal failure	46/2520 (1.82%)	16/390 (4.10%)	<.008	<.001	1.94 (1.41-2.67)
Urgent surgery	46/2444 (1.88%)	16/466 (3.43%)	.058	.429	0.85 (0.58-1.25)
Emergency surgery	58/2808 (2.06%)	4/102 (3.92%)	.372		
Age by category					
<55 y	60/2446 (2.45%)	2/464 (0.43%)	.010		
55-59 y	58/2537 (2.29%)	4/373 (1.07%)	.195		
60-64 y	56/2456 (2.28%)	6/454 (1.32%)	.272		
65-69 y	45/2325 (1.94%)	17/585 (2.90%)	.208		
70-74 y	42/2326 (1.76%)	20/584 (3.59%)	.027		
75-79 y	52/2545 (2.00%)	10/365 (3.01%)	.516		
≥80 y	59/2825 (2.09%)	3/85 (3.53%)	.615		
≥75 y	49/2460 (1.99%)	13/450 (2.88%)	.314		
65-74 y	25/1741 (0.91%)	38/1169 (3.25%)	.002		

In the top portion, multivariate analysis was performed when a variable had more statistical relevance in our sample. In the bottom age is analyzed independently by categorized groups. In univariate and multivariate analyses, age is considered a dichotomous variable. CI, Confidence interval; TIA, transient ischemic attack. *Vascular disease includes coronary artery disease, peripheral vascular disease, or a previous thromboembolism other than stroke or transient ischemic attack.

for <60 years vs 3.5% for >80 years). The proportions of the risk factors in the 2910 patients are listed in Table 1. Off-pump techniques were used in 43.4% of cases. Variables found to be statistically significant and included in a logistic regression analysis to predict the development of post-CABG stroke were previous stroke or TIA (OR, 1.12; 95% CI, 1.08-1.16), heart failure (OR, 2.92; 95% CI, 1.72-4.97), and renal failure (OR, 1.94; 95% CI, 1.41-2.67; Table 2).

Predictive Accuracy of the Stroke Risk Stratification Schemes

All stroke risk stratification schemes showed a significant increasing stroke rate value between risk levels ($P < .001$), as seen in Table 3. All schemes had acceptable discriminating ability, with similar AUC values: 0.716 (95% CI, 0.64-0.78) for CHADS₂, 0.725 (95% CI 0.65-0.79) for CHA₂DS₂VASc, 0.697 (95% CI 0.61-0.76) for NNECDSG, and 0.736 (95% CI 0.67-0.80) for McSPI. The Hosmer-Lemeshow goodness-of-fit test indicated good calibration for all stroke risk models (Table 3). Mean ± SD stroke score values for perioperative stroke, sensitivity and specificity for each scheme, and the best cutoff values (optimum score threshold)s are detailed in Table 4. The best sensitivities were achieved by the McSPI (78.7%) and CHA₂DS₂VASc (74.2%) scores, and the best specificities were achieved by NNECDSG (62.4%) and McSPI (59.3%) scores.

Low and High Risks of Postoperative Stroke

CHADS₂ scores less than 2, CHA₂DS₂VASc scores less than 2, NNECDSG scores less than 3, and McSPI scores less than 71.5 represent in our study the group of patients with low risk of perioperative stroke (<1%). CHADS₂ scores of at least 3, CHA₂DS₂VASc scores of at least 4, NNECDSG scores of at least 6, and McSPI scores of at least 101.5 represent the group of patients with high risk of perioperative stroke (>3%; Table 3).

The proportion of patients assigned to individual risk categories varied widely across the schemes, as seen in Table 5. Those categorized as low risk (<1%) ranged from 22.8% (NNECDSG) to 57.6% (CHADS₂), whereas those categorized as high risk (>3%) ranged from 10.1% (McSPI) to 30% (NNECDSG). All schemes provided acceptable diagnostic accuracy, ranging from 0.67 to 0.70 in AUC, although they misclassified a considerable number of patients who had a stroke after surgery, as shown in Table 5. The NNECDSG and CHA₂DS₂VASc scores included the largest number of strokes in the high-risk group, 61.2% and 59.6%, respectively, and these were also the schemes with the fewest cases of stroke in the low-risk group, 8% and 11.3%, respectively. McSPI and CHADS₂ included the largest percentages of patients without a stroke in the low-risk group, 48.8% and 58.4%, respectively. With a score of 0, no stroke (0%) was observed only in the McSPI score, whereas the value ranged from 0.69%

TABLE 3. Perioperative stroke events in the patients in relation to the CHADS₂, CHA₂DS₂VASc, Northern New England Cardiovascular Disease Study Group, and Multicenter Study of Perioperative Ischemia Research Group scoring systems

	Stroke events	N	Stroke rate	P value	AUC (95% CI)
CHADS ₂ ⁶				<.001	0.716 (0.644-0.788)
0	4	577	0.69%		
1	11	1102	0.99%		
2	17	805	2.11%		
3	16	305	5.25%		
4	9	92	9.78%		
5	4	27	14.81%		
6	1	2	50.00%		
CHA ₂ DS ₂ VASc ⁷				<.001	0.725 (0.654-0.795)
0	2	263	0.76%		
1	5	620	0.81%		
2	8	726	1.10%		
3	10	644	1.55%		
4	14	358	3.91%		
5	14	202	6.93%		
6	6	75	8.00%		
7	2	19	10.53%		
8	1	3	33.33%		
9	0	0	0%		
NNECDSG ⁴				.001	0.697 (0.611-0.762)
0	1	139	0.72%		
1	1	106	0.94%		
1.5-2.5	3	421	0.71%		
3-4	8	639	1.25%		
4.5-5.5	11	731	1.50%		
6-7	16	496	3.22%		
7.5-8.5	14	262	5.34%		
9-10	5	85	5.88%		
10.5-11.5	3	26	11.54%		
≥12	0	5	0.00%		
McSPI ⁵				<.001	0.736 (0.672-0.801)
≤25.49	0	31	0.00%		
25.5-40.49	1	184	0.54%		
40.5-55.49	4	551	0.72%		
56.5-71.49	5	635	0.79%		
71.5-86.49	18	758	2.37%		
86.5-101.49	13	455	2.86%		
101.5-117.49	12	223	5.38%		
117.5-132.49	7	63	11.11%		
≥132.5	2	10	20.00%		

Data presented as AUC, including 95% confidence intervals (CIs). The Hosmer-Lemeshow goodness-of-fit test showed good calibration in all schemes: CHADS₂, $P = .578$; $\chi^2 = 1.09$, $df = 2$; CHA₂DS₂VASc, $P = .694$, $\chi^2 = 2.22$, $df = 4$; Northern New England Cardiovascular Disease Study Group (NNECDSG), $P = .256$; $\chi^2 = 10.13$, $df = 8$; Multicenter Study of Perioperative Ischemia Research Group (McSPI), $P = .256$, $\chi^2 = 9.99$, $df = 8$. AUC, Area under receiver operating characteristic curve; CI, confidence interval.

(CHADS₂) to 0.76% (CHA₂DS₂VASc) for the other schemes. Patients with a CHADS₂ score of 1 or lower and patients with CHA₂DS₂VASc score of 2 or lower had similar incidences of postoperative strokes (0.9%). On the other hand, the stroke rate among patients with a CHADS₂ score of at least 4 was 9.7% or more, whereas with among those with a CHA₂DS₂VASc score of at least 6, it was 8% or more, consisting of groups with a very high surgical stroke risk (Table 3).

DISCUSSION

This study assessed the predictive ability of CHADS₂ and CHA₂DS₂VASc stroke risk stratification schemes for patients undergoing isolated CABG. Our results suggest that (1) CHADS₂ and CHA₂DS₂VASc schemes have demonstrated acceptable discriminatory ability (AUC >0.71) without significant deviation from the perfect fit (significant Hosmer-Lemeshow goodness-of-fit test); (2) these clinical schemes yield similar discriminatory accuracies to those of

TABLE 4. Mean score values of the stroke stratification schemes and optimum score thresholds

	With stroke	Without stroke	AUC	Optimum score threshold	Sensitivity	Specificity
CHADS ₂ ⁶	2.37 ± 1.33	1.40 ± 1.06	0.716	1.50	73.8%	58.1%
CHA ₂ DS ₂ VASc ⁷	3.68 ± 1.74	2.40 ± 1.52	0.725	2.50	74.2%	55.9%
NNECDSG ⁴	6.18 ± 2.54	4.52 ± 2.38	0.697	5.25	70.5%	62.4%
McSPI ⁵	89.69 ± 22.53	72.50 ± 22.05	0.736	76.85	78.7%	59.3%

Mean ± SD stroke score values for postoperative stroke and no postoperative stroke, with sensitivity and specificity, for each scheme. The closest point to 100% sensitivity and specificity was selected as the optimum score threshold. *P* < .001 for all schemes. *AUC*, Area under the receiver-operating-characteristic curve; *CI*, confidence interval; *McSPI*, Multicenter Study of Perioperative Ischemia Research Group; *NNECDSG*, Northern New England Cardiovascular Disease Study Group.

NNECDSG and McSPI risk scores (specific for isolated CABG surgery); (3) the NNECDSG and CHA₂DS₂VASc stroke risk stratification schemes are better at discriminating patients at particularly low (<1%) and high (>3%) risks; and (4) all the schemes considered as at intermediate risk the large percentage of patients who had between 27% and 50% of all perioperative strokes.

In recent decades, there have been significant changes in the population undergoing CABG surgery.^{1,11} Improvements in surgical techniques have made it possible to operate successfully on older patients with comorbid diseases, especially cerebrovascular disease, which may predispose them toward severe postoperative neurologic complications. Prevention is particularly important, because stroke patients have prolonged stays in intensive care and a markedly higher mortality.^{1,2} Several risk stratification schemes have been developed to predict perioperative stroke after isolated CABG; however none has been extensively applied in routine clinical practice. It is clear that an ideal stroke risk assessment tool that is generally applicable, simple, and widely accepted does not exist, and that each available tool has its limitations. Since their publication, the CHADS₂ and CHA₂DS₂VASc

stratification schemes have proved their worth as simple and practical schemes for the prediction of major stroke in populations with nonvalvular atrial fibrillation. These days, they are widely used in clinical practice and in some guidelines for selecting certain treatments for stroke prevention.^{6,7,12} Interestingly, these schemes use the same atherothrombotic risk factors associated with increased risk of perioperative stroke after isolated CABG surgery. This study therefore tested CHADS₂ and CHA₂DS₂VASc as stratification schemes in our population of patients undergoing isolated CABG and observed good discriminatory accuracy in predicting perioperative stroke, similar to that achieved by the NNECDSG and McSPI stroke risk scores (AUC, 0.74-0.69). These results suggest that the CHADS₂ or CHA₂DS₂VASc could be used as a complementary method of stratifying the preoperative stroke risk in isolated CABG surgery.

One of the major advantages of these schemes is their ability to classify patients into risk categories or levels. A predictive tool should be able to make accurate predictions in diverse settings across the range of both low- and high-risk patients. This study showed that McSPI and CHADS₂ schemes present the best discrimination (AUC, 0.70) in

TABLE 5. Stroke events in relation to stroke risk stratification models and predictive ability of each stroke risk scheme

	Low	Intermediate or moderate	High	AUC	95% CI	SE
CHADS ₂ ⁶				0.704	0.633-0.775	0.036
In risk category (%)	57.6%	27.6%	14.6%			
Stroke events (no.)	15 (24.2%)	17 (27.4%)	30 (48.3%)			
Mean rate of stroke (%)	0.89%	2.11%	7.04%			
CHA ₂ DS ₂ VASc ⁷				0.696	0.626-0.766	0.036
In risk category (%)	30.3%	47.0%	22.5%			
Stroke events (no.)	7 (11.3%)	18 (29%)	37 (59.6%)			
Mean rate of stroke (%)	0.79%	1.31%	5.63%			
NNECDSG ⁴				0.671	0.604-0.738	0.034
In risk category (%)	22.8%	47.0%	30.0%			
Stroke events (no.)	5 (8%)	19 (30.6%)	38 (61.2%)			
Mean rate of stroke (%)	0.75%	1.38%	4.34%			
McSPI ⁵				0.704	0.637-0.770	0.033
In risk category (%)	48.1%	41.6%	10.1%			
Stroke events (no.)	10 (16.1%)	31 (50.0%)	21 (33.8%)			
Mean rate of stroke (%)	0.71%	2.55%	7.09%			

Scores were categorized into 3 perioperative stroke risk levels: low (<1%), moderate or intermediate (1%-3%), and high risk (>3%). *P* < .0001 for all schemes. *AUC*, Area under the receiver-operating-characteristic curve; *CI*, confidence interval; *McSPI*, Multicenter Study of Perioperative Ischemia Research Group; *NNECDSG*, Northern New England Cardiovascular Disease Study Group; *SE*, standard error.

discriminating the 3 risk groups in the entire population. They also included larger percentages of stroke-free patients in their low-risk groups, 48.8% and 58.8%, respectively. Interestingly, only patients who scored 0 in the McSPI scheme had no stroke; in the other schemes, even patients with no comorbid (score 0) had a minimal stroke rate (<0.8%). In this regard it should be considered that there is probably always a minimum number of strokes related to other factors, such as preoperative atrial fibrillation or surgical technique (aortic crossclamping, cardiopulmonary bypass) that are not considered in the schemes and are therefore difficult to predict.

CHA₂DS₂VASc and NNECDSG included the highest percentages of strokes in their high-risk group, 59.6% and 61.2%, respectively. When the CHADS₂ score was 3 or greater and the CHA₂DS₂VASc was 4 or greater, the mean stroke rates were at least 7% and 5.6%, respectively. This finding has major research implications, because it enables the discrimination of patients at very high risk who need neuroprotection during surgery (ioff-pump surgery, aorta no-touch strategy, intraoperative epiaortic ultrasound examination of the ascending aorta) or who could be regarded as candidates for percutaneous coronary revascularization and possibly routine postoperative prophylactic pharmacologic treatment.

Simplicity of these schemes may lead to inadequate discrimination results, especially in patients in the intermediate (moderate) risk category. In our opinion, all the schemes had 2 important limitations in the analyzed cohort of patients undergoing isolated CABG. First, they considered a large percentage of patients as being in the intermediate risk range, from 27% (CHADS₂) to 47% (CHA₂DS₂VASc and NNECDSG). Second, all the schemes included a high number of the strokes that occurred in the intermediate-risk group, ranging from 27% to 50% of all perioperative strokes in CHADS₂ and McSPI, respectively. This inability to differentiate patients with very different risk levels of development of stroke is an important limiting factor for all 4 predictive strategies assessed in this study. This lack of ability to discriminate could be due to the homogeneity of the populations in which the models were defined. Most of them were based on low-risk CABG stroke populations and therefore by definition are not calibrated to predict outcomes in high-risk patients.^{4,5,13}

The most commonly accepted explanation for an age-associated postoperative stroke appears to be the increased presence of atherosclerosis, with occult cerebrovascular disease as well as a higher risk of embolization.¹⁴ Our patient cohort older than 70 years had a stroke rate of 3.2%, and McSPI was the best stroke risk stratification scheme at discriminating patients with low stroke risk, probably because it considered age as a continuous variable. Even though the degree and extent of occult cerebral arterial disease and their potential contribution to having a stroke are

not normally known, we believe that age should be considered preoperatively in the choice of revascularization technique.

Finally, there are some limitations to this study that need to be considered. First, it was a retrospective, observational study, and the conclusions derived are necessarily limited in application. Although we have validated the CHADS₂ and CHA₂DS₂VASc prediction schemes for the first time in the scientific literature, these findings still require confirmation from other sources. Second, the number of subjects was not large enough to give a robust validation. The results themselves were statistically robust, however, with a stable SE, and we believe they were correctly interpreted. Third, the diagnoses of stroke and diffuse brain encephalopathy were mutually exclusive, and this may potentially have underestimated the real prevalence of small perioperative strokes, even though some studies have reported diffuse brain encephalopathy to be related mainly to intraoperative factors, such as cardiopulmonary bypass time.⁹ Fourth, in our study the categorization of risk groups was completely arbitrary, with the only purpose of grouping patients into simple risk groups, but it is based on other authors' comments that suggest similar percentages of strokes. Stratification schemes for primary prevention of stroke, such as the Atrial Fibrillation Investigators, Stroke Prevention in Atrial Fibrillation, American College of Chest Physicians, CHADS₂, and Framingham schemes having thromboembolism rates in low-, moderate-, and high-risk patients during 1 year of 1.4% or less, between 1% and 3.2%, and at least 3%, respectively.¹⁵ Finally, it is also unclear how useful these tools could actually be in aiding resource management as compared to the clinician's own estimate of risk for an individual patient.

In conclusion, this study shows that CHADS₂ and CHA₂DS₂VASc scores demonstrated good accuracy in predicting perioperative post-CABG stroke, with discriminatory performances similar to those of the NNECDSG and McSPI stroke risk stratification schemes in a cohort of patients who had undergone isolated CABG surgery. Furthermore, we also believe that all the schemes tested in this study have serious limitations in discriminating high-risk patients, because a large proportion of these were classified as at intermediate risk.

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