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Stroke Risk After Coronary Artery Bypass Graft Surgery and Extent of Cerebral Artery Atherosclerosis

Eun-Jae Lee, MD,* Kyoung-Hyo Choi, MD,† Ju-Seok Ryu, MD,‡ Sang-Beom Jeon, MD,* Seung-Whan Lee, MD,§ Seong-Wook Park, MD,§ Seung-Jung Park, MD,§ Jae-Won Lee, MD,‖ Suk-Jung Choo, MD,‖ Cheol-Hyun Chung, MD,‖ Sung-Ho Jung, MD,‖ Dong-Wha Kang, MD,* Jong S. Kim, MD,* Sun U. Kwon, MD*

Seoul and Seongnam, South Korea

Objectives We aimed to define the relationship between cerebral atherosclerosis and stroke after coronary artery bypass grafting (CABG).

Background Although cerebral atherosclerosis may play a crucial role in the advent of post-CABG stroke, only extracranial carotid artery disease has been extensively studied, and the effects of atherosclerosis on the mechanisms underlying post-CABG stroke remain unclear.

Methods Pre-operative magnetic resonance angiography was performed on 1,367 consecutive CABG patients to assess intracranial and extracranial cerebral atherosclerosis. Disease severity was evaluated by atherosclerosis score, as determined by the number of steno-occlusions of cerebral arteries and the degree thereof. Post-CABG strokes (within 14 days) were classified as atherosclerotic (strokes attributable to pre-defined atherosclerosis) or other (strokes caused by other mechanisms). Associations between post-CABG stroke and each type of atherosclerotic disease (extracranial carotid artery disease, intracranial, extracranial, or extracranial and/or intracranial cerebral atherosclerosis), differentiated according to the involved arteries, were analyzed.

Results Stroke occurred in 33 patients, and the atherosclerosis score was independently associated with stroke development (odds ratio: 1.35; 95% confidence interval: 1.16 to 1.56). Atherosclerotic stroke was defined in 15 (45%), and constituted >40% of both immediate (within 24 h) and delayed strokes. Intracranial, extracranial, and extracranial and/or intracranial cerebral atherosclerosis were significantly associated with stroke.

Conclusions Cerebral atherosclerosis was closely related to the occurrence of post-CABG stroke, being both an independent risk factor for and the cause of a significant proportion of strokes. Pre-operative evaluation of intracranial and extracranial cerebral arteries, apart from the extracranial carotid artery, may be useful to predict the likelihood of post-CABG stroke. (J Am Coll Cardiol 2011;57:1811–8) © 2011 by the American College of Cardiology Foundation

Stroke is one of the most severe complications after coronary artery bypass grafting (CABG) and is associated with high rates of morbidity and mortality (1–4). The incidence of post-operative stroke is greater after CABG (1.4% to 3.8%) than after general surgery (0.08% to 0.7%) (2). Neurological sequelae result in high economic costs worldwide each year for post-CABG stroke patients (1,3). Patients undergoing CABG often have atherosclerosis of multiple cerebral arteries, regarded as an important risk factor for stroke (5,6). Although extracranial carotid artery (ECCA) disease has been extensively studied and is considered a predictor of stroke after CABG (7–9), atherosclerosis of the other cerebral arteries has not been systematically investigated as a risk factor for post-CABG stroke. Only recently has intracranial cerebral atherosclerosis been reported to increase the probability of post-CABG stroke (10–12).

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The mechanisms underlying stroke after CABG are largely unknown. To define the mechanism, pre-operative angiography may be necessary because it is often difficult to determine whether steno-occlusions of arteries observed on post-stroke

From the *Department of Neurology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea; †Department of Rehabilitation Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea; ‡Department of Rehabilitation Medicine, College of Medicine, CHA University, Seongnam, South Korea; §Department of Cardiology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea; and the ‖Department of Thoracic and Cardiovascular Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, South Korea. This study was supported by a grant (A060171) from the Korea Health 21 Research and Development Project, Ministry of Health, Welfare, and Family Affairs, Republic of Korea. The authors have reported that they have no relationships to disclose.

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Abbreviations and Acronyms

CABG = coronary artery bypass grafting

CI = confidence interval

CT = computed tomography

DWI = diffusion-weighted imaging

ECCA = extracranial carotid artery

MRA = magnetic resonance angiography

angiography existed before the stroke or are newly developed. To date, however, no studies have performed pre-operative angiography on every patient undergoing CABG.

We hypothesized that atherosclerosis throughout all of the cerebral arteries (from beyond the aortic arch to the circle of Willis) might be an important independent risk factor for post-CABG stroke and could play a crucial role in stroke pathogenesis. Therefore, evaluation of atherosclerosis in both intracranial and extracranial cerebral arteries might provide more information on the likelihood of post-CABG stroke than would assessment of atherosclerosis of the ECCA alone. To analyze the association between cerebral atherosclerosis and the occurrence of stroke after CABG and to elucidate the mechanism underlying post-CABG stroke, we performed pre-operative magnetic resonance angiography (MRA) on all CABG patients in the present study and investigated the relationship between pre-operative atherosclerosis and post-CABG stroke.

Methods

Subjects. All patients undergoing CABG are prospectively registered in the Asan Medical Center database (Seoul, South Korea). This registry included patient baseline characteristics, results of cardiac evaluations, detailed information on surgery, and perioperative complications. Since August 2004, patients scheduled to undergo CABG have been routinely evaluated by MRA, most within 1 month before CABG. Patients found on MRA to have multiple severe steno-occlusive lesions were informed that they may be at higher risk of post-CABG stroke. Patients with asymptomatic (>80% stenosis) (13) or symptomatic (>70% stenosis with a history of stroke in the vascular territory of a stenosed artery) severe stenosis within the ECCA, as determined by MRA, were recommended to undergo stenting of the carotid artery if a delay of at least 1 month before operation was acceptable.

All patients undergoing CABG were informed in detail about the CABG procedure, pre-operative MRA, and the nature of the present study. Each included patient provided informed consent for each component of the analysis. Consecutive CABG patients treated between August 2004 and December 2007 were considered for inclusion. During the study period, 1,551 patients underwent CABG; of these, 184 (11.9%) did not undergo complete pre-operative MRA (Online Table 1) and were excluded. Patients who underwent pre-operative carotid stenting were included in analysis. Medical records other than the CABG registry were also reviewed to evaluate significant post-operative events featuring hemodynamic impairment, including systemic hypotension (mean arterial pressure, <60 mm Hg) (14) and sudden major bleeding (i.e., a ≥3 g/dl decrease in serum hemoglobin concentration from baseline). The study was approved by the Institutional Review Board of the Asan Medical Center.

MRA. The pre-operative MRA protocol for CABG patients included diffusion-weighted imaging (DWI), 3-dimensional time-of-flight MRA for intracranial arteries, and contrast-enhanced MRA for intracranial and extracranial arteries. The MRA examinations were performed using a 1.5-T magnetic resonance imaging unit (GE Medical Systems, Milwaukee, Wisconsin) using a standard neurovascular coil.

The extent of atherosclerosis was determined by the number of cerebral arteries showing steno-occlusion and the degree thereof (15). The extent of atherosclerosis was visually graded according to the following criteria: 0 indicating <50% stenosis; 1 indicating 50% to 99% stenosis, and 2 indicating occlusion. Assessment included the intracranial (middle cerebral, anterior cerebral, posterior cerebral, basilar, intracranial carotid, and intracranial vertebral arteries) and extracranial cerebral arteries (extracranial carotid, extracranial vertebral, innominate, and subclavian arteries). Stenosis of an intracranial artery was considered significant when both intracranial 3-dimensional time-of-flight and contrast-enhanced MRA analyses revealed consistent findings. Vertebral artery hypoplasia was not considered to reflect stenosis. The atherosclerosis score was defined as the sum of the score for each artery. An alternative method for calculating an atherosclerosis score was devised to determine whether assessment of atherosclerosis using a different scoring system would also be useful (Online Tables 2 and 3). The extent of atherosclerosis was determined by consensus between 2 reviewers blinded to patient stroke history, and a third reviewer's opinion was obtained in instances of disagreement.

Surgery. All CABGs were performed by experienced cardiac surgeons, each of whom performs >100 CABGs annually. Off-pump (cardiopulmonary bypass pump) or conventional CABG was performed at the discretion of the attending surgeon, with off-pump CABG usually performed when severe atherosclerosis was suspected along the aortic arch. Off-pump CABG was performed using 1 of several commercially available, suction-based, cardiac-positioning and coronary artery-stabilizing devices. Conventional CABG was performed using standard techniques that used roller-head pumps, membrane oxygenators, cardiotomy suction, arterial filters, cold antegrade and retrograde blood cardioplegia, and moderate systemic hypothermia (32°C to 34°C).

Diagnosis of stroke. All patients were post-operatively managed in the cardiac surgery intensive care unit. Post-operative stroke was suspected when a patient showed focal neurological deficits or delayed recovery of mental status after surgery. Such patients were referred to stroke neurol-

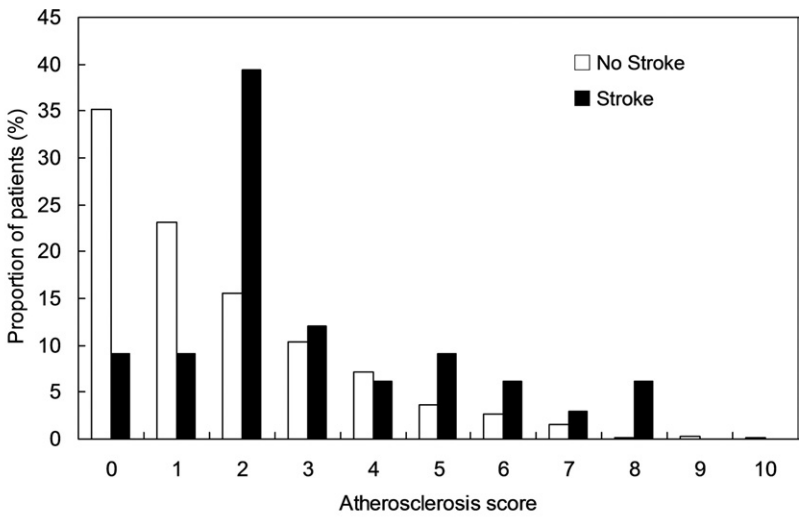
ogists and were evaluated by DWI or computed tomography (CT). Post-CABG stroke was diagnosed as: 1) newly developed neurological deficits within 14 days of CABG; and 2) high-signal lesions on post-operative DWI or low-density lesions on post-operative CT that were not observed pre-operatively. Strokes that occurred within 24 h after CABG were defined as immediate, whereas all others were considered delayed.

Mechanism of stroke. Strokes were classified as: 1) strokes attributable to pre-defined atherosclerotic lesions (atherosclerotic strokes); and 2) strokes arising from other causes (other strokes). Atherosclerotic stroke was defined as an ischemic stroke occurring in a vascular territory that had stenosis (≥50%) demonstrated on pre-operative MRA. In such patients, ischemic stroke was regarded as directly related to the underlying atherosclerotic lesion. Patients with an ischemic lesion outside the territory of a pre-existing steno-occlusive artery were defined as having other strokes.

Statistical analysis. Baseline characteristics, use of cardiopulmonary bypass, and the atherosclerosis score were compared in patients with and without post-CABG stroke. Cardiac embolic sources and post-operative hemodynamic impairments were compared in patients with post-CABG atherosclerotic and other stroke. Four atherosclerotic diseases were defined according to arteries that were considered when defining significant (≥50% steno-occlusive) atherosclerosis: ECCA disease, extracranial cerebral atherosclerosis, intracranial cerebral atherosclerosis, and extracranial and/or intracranial cerebral atherosclerosis. Associations between post-CABG stroke and each atherosclerotic disease were also compared. In univariate analysis, we used the Pearson chi-square test with the Fisher exact test to examine categorical variables and the Student *t* test or the Mann-Whitney *U* test to explore continuous variables. Multiple logistic regression analysis was performed to estimate independent contributions of variables to the development of post-CABG stroke. Variables with p values ≤0.1 by univariate analyses were candidates for inclusion in multiple logistic models. A backward elimination process was used to develop the final multivariable model, and adjusted odds ratios with 95% confidence intervals (CIs) were calculated. A 2-tailed p value <0.05 was considered statistically significant. All statistical analyses were performed using SPSS software version 14.0 (SPSS Inc., Chicago, Illinois).

Results

The mean age of the 1,367 included patients was 63.2 ± 8.8 years (range 35 to 88 years), with 894 patients (65.4%) having steno-occlusive lesions in the intracranial and/or extracranial cerebral arteries. Seventeen patients with severe carotid stenosis underwent pre-operative carotid stenting, followed by subsequent CABG without post-operative stroke. Forty-five patients underwent post-operative brain imaging workup (DWI in 38 patients and CT in 7 patients), with 33 patients diagnosed with post-CABG ischemic stroke (31 patients by DWI and 2 patients by CT).



No. of patients

No stroke	470	309	207	139	95	49	35	22	3	4	1
Stroke	3	3	13	4	2	3	2	1	2	0	0

Figure 1 Distribution of Atherosclerosis Score in Patients Who Did and Did Not Experience Stroke

The number of patients decreased with increased atherosclerosis score, but the proportion of patients with stroke increased along with the atherosclerosis score. No stroke means patients who did not experience stroke. Stroke means patients who experience stroke.

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Table 1 Baseline Characteristics and Atherosclerosis Scores in Patients Who Did and Did Not Experience Post-CABG Stroke

	Patients Without Stroke (n = 1,334)	Patients With Stroke (n = 33)	p Value
Pre-operative variables			
Age, yrs	63.1 ± 8.8	65.7 ± 8.1	0.095
Male	993 (74.4)	20 (60.6)	0.105
Hypertension	903 (67.7)	27 (81.8)	0.092
Diabetes mellitus	585 (43.9)	17 (51.5)	0.478
Current smoking	326 (24.5)	5 (15.2)	0.303
Hypercholesterolemia	720 (54.0)	23 (69.7)	0.079
Renal failure	94 (7.0)	2 (6.1)	>0.999
Previous stroke	111 (8.3)	6 (18.2)	0.056
Previous MI	132 (9.9)	3 (9.1)	>0.999
Peripheral artery disease	20 (1.5)	0 (0.0)	>0.999
Atrial fibrillation	53 (4.0)	4 (12.1)	0.045
LVEF, %	54.6 ± 12.0	51.6 ± 13.0	0.152
LVEF <30%	71 (5.3)	3 (9.1)	0.695
Body mass index, kg/m^2	24.5 ± 2.9	24.6 ± 2.5	0.873
Atherosclerosis score*	1.0 (1.0–3.0)	2.0 (2.0–4.5)	<0.001
Intraoperative variables			
CPB	668 (50.1)	17 (51.5)	>0.999
CPB duration, min	134.9 ± 75.0	146.8 ± 87.1	0.522

Values are mean ± SD, n (%), or median (with quartiles). *Atherosclerosis score was calculated based on cerebral atherosclerotic findings on pre-operative magnetic resonance angiography.
CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass; LVEF = left ventricular ejection fraction; MI = myocardial infarction.

Immediate stroke was observed in 15 patients (45.5%). The distribution of the atherosclerosis scores and the relationship thereof to stroke development are shown in Figure 1.

Pre-operative atrial fibrillation was significantly more frequent in patients with than those without post-CABG stroke (Table 1). In addition, patients with stroke tended to be older, hypertensive, hypercholesterolemic, and with a history of stroke, although none of these associations were statistically significant. The atherosclerosis score, based on atherosclerosis of cerebral arteries, was significantly higher in stroke than in nonstroke patients. Multiple logistic regression analysis showed that only pre-operative atrial fibrillation and the atherosclerosis score were independently associated with development of stroke (Table 2). Similar findings were observed when atherosclerosis score was calculated using an alternative method (Online Tables 2 and 3). For prediction of post-CABG stroke, the receiver-operating characteristic curve area of the atherosclerosis score was 0.702 (95% CI: 0.607 to 0.726) (Online Fig. 1). A score ≥2 was the most appropriate cutoff value to predict post-CABG stroke, with a sensitivity of 81.8% (95% CI: 64.5% to 93.0%) and a specificity of 58.4% (95% CI: 55.7% to 61.1%).

Table 2 Multiple Logistic Regression Analysis to Determine Predictors of Post-CABG Stroke (n = 33)

	Odds Ratio	95% CI	p Value
Hypercholesterolemia	2.09	0.98–4.46	0.058
Pre-operative atrial fibrillation	3.68	1.20–11.3	0.023
Atherosclerosis score	1.35	1.16–1.56	<0.001

CABG = coronary artery bypass grafting; CI = confidence interval.

Table 3 Association of Post-CABG Stroke With Types of Atherosclerotic Disease

	No Post-CABG Stroke (n = 1,334)	Post-CABG Stroke (n = 33)	p Value
ECCA disease	332 (24.9)	12 (36.4)	0.154
Extracranial cerebral atherosclerosis	595 (44.6)	21 (63.6)	0.034
Intracranial cerebral atherosclerosis	598 (44.8)	27 (81.8)	<0.001
Extracranial and/or intracranial cerebral atherosclerosis	864 (64.8)	30 (90.9)	0.001

Values are given as n (%).
CABG = coronary artery bypass grafting; ECCA = extracranial carotid artery.

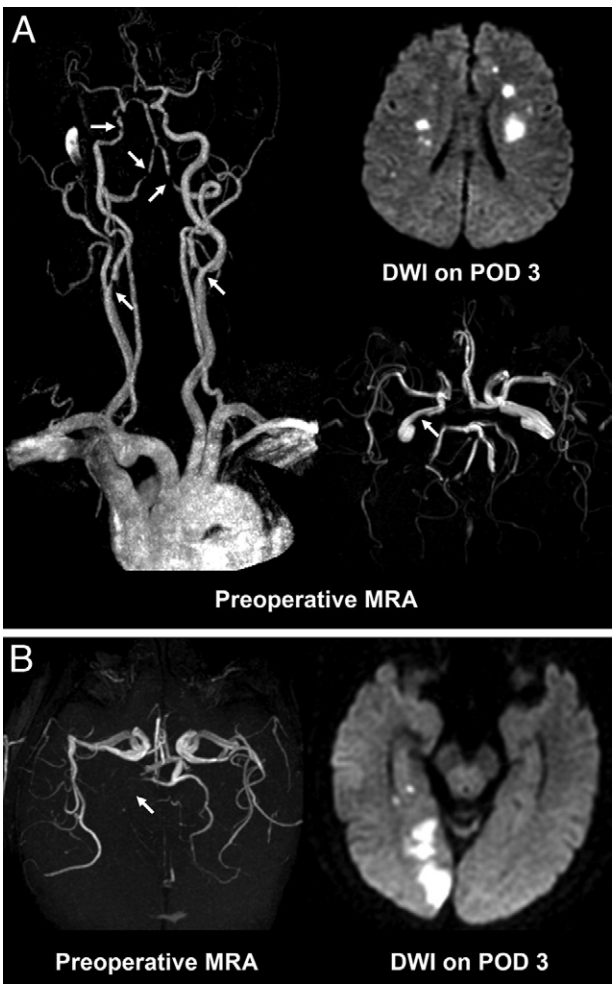

Figure 2 Atherosclerotic Stroke

(A) A 51-year-old woman in whom dysarthria and quadriparesis developed 3 days after coronary artery bypass grafting (atherosclerosis score = 5). **(B)** A 65-year-old woman who reported headache (atherosclerosis score = 1). The **bright areas** on diffusion-weighted imaging (DWI) represent the areas of stroke. **Arrows** indicate scored stenotic arteries. MRA = magnetic resonance angiography; POD = post-operative day.

We also analyzed the association between the development of post-CABG stroke and the type of atherosclerotic disease (Table 3). ECCA disease was not significantly associated with the development of stroke. However, when ECCA disease was combined with atherosclerosis of other extracranial cerebral arteries, the association was statistically significant. Extracranial and/or intracranial cerebral atherosclerosis were also significantly associated with post-CABG stroke.

Among 33 stroke patients, atherosclerotic stroke (2 representative examples of which are shown in Fig. 2) was diagnosed in 15 patients (Table 4). Patients with atherosclerotic stroke had a higher atherosclerosis score. Plausible cardiac embolic sources were detected in 9 of the 18 other stroke patients (representative examples of which are shown in Figs. 3A to 3C). Of the 9 remaining patients, 1 had a lacunar infarction (Fig. 3D), whereas the other 8 patients showed multiple lesions in several vascular territories. The proportion of patients with atherosclerotic stroke was similar in those with delayed (8 of 18, 44.4%) and immediate (7 of 15, 46.7%) stroke. The characteristics and stroke mechanisms of each stroke patient are shown in Online Table 4, and data on atherosclerotic diseases in atherosclerotic stroke patients appear in Table 5. ECCA disease was present in 7 of 15 atherosclerotic stroke patients. Ischemic lesions could be explained fully by ECCA disease alone in 3 patients, whereas the other 12 atherosclerotic stroke patients had symptomatic atherosclerosis other than ECCA disease.

Discussion

This large-scale study was designed to estimate the risk of post-CABG stroke in patients pre-operatively evaluated by MRA of both intracranial and extracranial cerebral arteries. We found that the atherosclerotic burden of cerebral arteries was closely related to the risk of post-CABG stroke, with the risk of stroke increasing about 1.3-fold for every 1-point increase in the atherosclerosis score. This close relationship had been suggested but not definitively demonstrated in previous studies (7–10). Notably, whereas ECCA disease was present in a significant proportion (7 of 15, 46.7%) of atherosclerotic stroke patients, the ischemic lesions of only 3 patients could be fully explained by ECCA disease alone. Moreover, ECCA disease did not demonstrate a significant association with post-CABG stroke, in contrast to the other atherosclerotic diseases. These findings suggest that pre-operative evaluation of additional cerebral arteries may better predict the risk of post-CABG stroke than evaluation of the ECCA alone. MRA can provide better anatomical information on intracranial and extracranial cerebral arteries

Table 4 Patient Characteristics Relative to Stroke Mechanism

	Atherosclerotic Strokes (n = 15)	Other Strokes (n = 18)	p Value
Age, yrs	63.2 ± 8.0	67.2 ± 8.0	0.202
Male	9 (60.0)	11 (61.1)	>0.999
Stroke onset, post-operative day (range)	2 (0–14)	3 (0–12)	0.667
Immediate stroke (≤24 h)	7 (46.7)	8 (44.4)	>0.999
Delayed stroke (>24 h)	8 (53.3)	10 (55.6)	>0.999
Hypertension	13 (86.7)	14 (77.8)	0.665
Diabetes mellitus	8 (53.3)	9 (50.0)	>0.999
Current smoking	3 (20.0)	2 (11.1)	0.639
Hypercholesterolemia	10 (66.7)	13 (72.2)	>0.999
Renal failure	2 (13.3)	0 (0.0)	0.199
Previous stroke	4 (26.7)	2 (11.1)	0.375
Previous MI	1 (6.7)	2 (11.1)	>0.999
Peripheral artery disease	0 (0.0)	0 (0.0)	>0.999
LVEF, %	58.0 ± 8.5	46.2 ± 13.9	0.027
Body mass index, kg/m^2	25.1 ± 2.2	24.1 ± 2.7	0.202
CPB	7 (46.7)	10 (55.6)	0.732
CPB duration, min	112.6 ± 68.6	170.7 ± 93.9	0.364
Atherosclerosis score (quartiles)	4.0 (2.0–6.0)	2.0 (1.0–2.0)	0.001
Cardiac embolic source	0 (0.0)	9 (50.0)	0.001
Pre-operative atrial fibrillation	0	4	
LVEF <30%	0	3	
Thrombus at aortic arch	0	1*	
Post-operative atrial fibrillation	0	2	
Post-operative hemodynamic event	2 (13.3)	2 (11.1)	>0.999
Systemic hypotension	1†	2	
Gastrointestinal bleeding	2	0	

Values are mean ± SD, n (%), or median (with range or quartiles). *This patient also had pre-operative atrial fibrillation. †This patient also had gastrointestinal bleeding.

Abbreviations as in Table 1.

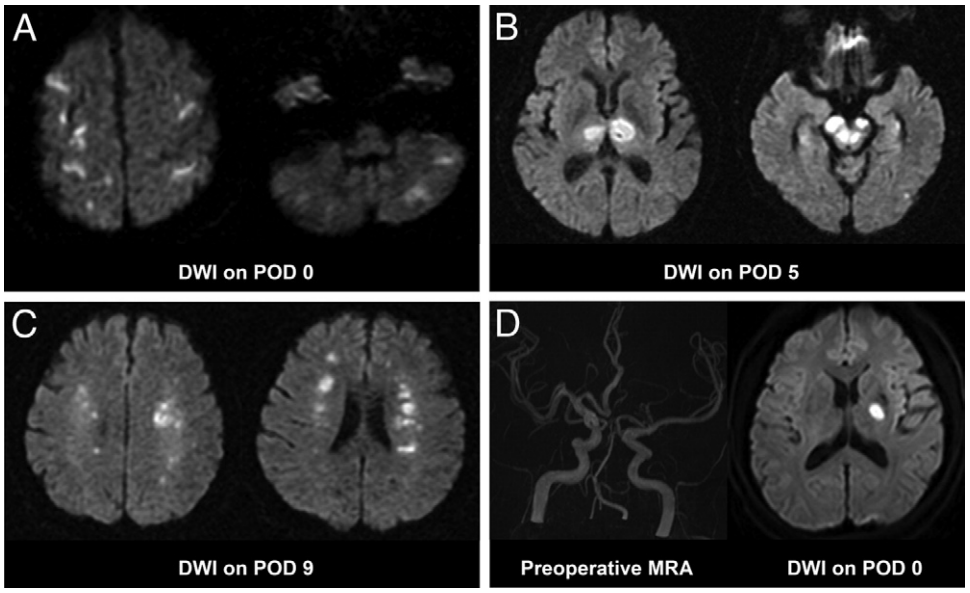

Figure 3 Other Strokes

(A) A 63-year-old man with persistent altered mental status and left hemiparesis after surgery. Despite the presence of stenoses in the basilar and left posterior cerebral arteries on pre-operative MRA (atherosclerosis score = 2), acute ischemic lesions present on DWI were not associated with stenoses. **(B)** A 68-year-old man with atrial fibrillation and a mobile thrombus in the aortic arch in whom altered mental status developed after coronary artery bypass grafting (CABG). He had no significant arterial stenotic lesions. **(C)** A 66-year-old woman with post-operative atrial fibrillation who presented with dysphagia. She had stenoses of the left intracranial and extracranial internal carotid arteries on pre-operative MRA (atherosclerosis score = 2). **(D)** A 50-year-old man who presented with dysarthria and right-side weakness. Pre-operative MRA showed no significant stenotic lesions. Abbreviations as in Figure 2.

than can transcranial or carotid Doppler imaging (16,17). Intriguingly, intracranial cerebral disease showed a closer association with stroke than did other atherosclerotic diseases. However, the predisposition to intracranial atherosclerosis in Asian populations (18) may have magnified the importance of intracranial cerebral atherosclerosis in the onset of post-CABG stroke in our patients.

We found that about one-half (45%) of strokes were classified as atherosclerotic. The proportion of post-CABG strokes associated with atherosclerosis has not been previously reported, except in a single study showing that only 1% of post-CABG strokes were thrombotic strokes (19). In the cited study, however, radiological data describing vessel status were often unobtainable, thus making it difficult to define stroke mechanisms (19). Because we performed pre-operative MRA on all enrolled CABG patients, we could determine whether the steno-occlusive lesions observed on post-stroke MRA were attributable to pre-existing atherosclerotic disease, thereby clarifying embolic sources and mechanisms. Among other stroke patients, one-half did not have cardiac embolic sources, although only a few had lacunar infarctions, suggesting that cerebral atherosclerosis may have had a hidden embolic source. Such sources may include atherosclerotic plaque at the aortic arch and mild atherosclerosis that did not manifest as significant stenosis on pre-operative MRA. Mild atherosclerotic arterial stenosis and atheroma in the aortic arch have been implicated as potential causes of cryptogenic stroke (20,21).

Post-CABG strokes are known to occur in a number of ways. Manipulation of the atherosclerotic aortic arch can cause early embolisms, thereby inducing stroke in the immediate phase after CABG (2). However, delayed embolisms have been attributed to post-operative atrial fibrillation, myocardial infarction, and coagulopathy, none of which are directly related to atherosclerosis (2). We found that 44.4% of our patients who experienced delayed stroke had atherosclerotic strokes, suggesting that atherosclerosis is not a silent condition, even for strokes occurring during the delayed period. Stresses such as physical trauma and inflammation may trigger plaque rupture or platelet aggregation in patients with severe atherosclerosis in the cervical and cranial vessels (22). Thus, stress after CABG may cause delayed embolisms in patients with severe atherosclerosis.

We found that pre-defined cerebral atherosclerosis was independently associated with the risk of post-CABG stroke. This association may have significant clinical implications. For example, pre-operative MRA evaluation of extracranial and intracranial cerebral arteries can provide information on the risks of post-CABG stroke, thereby allowing patients at high risk to be more carefully selected and managed. Accordingly, post-CABG stroke

Table 5 Atherosclerotic Diseases in Atherosclerotic Stroke Patients

Patient #*	ECCA Disease	Extracranial Cerebral Atherosclerosis (in Other Than the ECCA)†	Intracranial Cerebral Atherosclerosis	Symptomatic ECCA Disease‡	Symptomatic Atherosclerosis Other Than ECCA Disease§
5	+	+	+	+	+
6	+		+	+	+
8	+	+	+	+	
9	+	+	+	+	+
10	+	+		+	+
12		+	+		+
15			+		+
16		+	+		+
17			+		+
21			+		+
22	+		+	+	
23		+	+		+
26		+	+		+
31			+		+
33	+	+	+	+	

*Patient # in Online Table 4. †Atherosclerosis in the extracranial cerebral vessels other than the extracranial carotid artery (ECCA). ‡Symptomatic ECCA disease, responsible for ischemic lesions. §Symptomatic atherosclerosis in the cerebral arteries other than the ECCA, which was defined only if a patient had ischemic lesions not explained by ECCA disease alone.

developed in none of the 17 patients who had undergone pre-operative carotid stenting in our study. Previous clinical studies have also shown that modification of surgical strategy with respect to the presence of cerebral atherosclerosis may reduce the incidence of post-CABG stroke (11,12).

Study limitations. First, although we sought to evaluate all consecutive patients who underwent CABG, some patients had to be excluded because of an absence of MRA data. However, the excluded patients constituted only 12% of those who underwent CABG. Because we analyzed a large population of >1,300 patients, we assume that this bias did not materially affect our results. Second, the fact that all patients were informed of their MRA status may have influenced patients' decisions as to whether to undergo CABG or surgeons' decisions on the type of operation to be chosen. In general, patients with severe multiple atheroscleroses were told that they might be at high risk of post-CABG stroke, and some of these patients refused CABG. The fact that CABG was not performed on some patients with severe atherosclerosis may have decreased the occurrence of post-operative stroke, resulting in an underestimation of the relationship between atherosclerosis and subsequent strokes. Third, we performed carotid stenting in patients with severe ECCA disease before CABG; subsequently, none of these patients experienced any post-operative stroke. Offering pre-operative revascularization to patients with severe ECCA disease, which may have prevented post-CABG stroke, may have resulted in underestimation of the relationship between ECCA disease and related strokes. Fourth, no pre-existing standardized scoring system for evaluating atherosclerotic cerebral arteries was available. We therefore used the scoring method of a previous study (15), although that method has yet to be validated in terms of appropriateness and reproducibility. However, similar results were observed when we evaluated stenotic arteries using another method and analyzed the relationship between atherosclerosis and post-CABG stroke. In addition, our multivariate model may have been overfitted because of the small number of post-CABG stroke events. Finally, all patients were ethnically Korean and treated in a single center, thus introducing the possibilities of race- and single-center–based bias.

Conclusions

Our findings suggest that pre-operative cerebral atherosclerosis is significantly associated with the occurrence of stroke after CABG, and atherosclerotic stroke is an important mechanism. The risk of post-CABG stroke was increased as the atherosclerotic burden of the cerebral arteries increased. Notably, ECCA disease alone did not show a robust association with the occurrence of post-CABG stroke. Pre-operative evaluation of both intracranial and extracranial cerebral arteries, apart from the ECCA, may be useful to predict post-CABG stroke.

Reprint requests and correspondence: Dr. Sun U. Kwon, Asan Medical Center, Asanbyeongwon-gil 86, Songpa-gu, Seoul 138-736, South Korea. E-mail: sukwon@amc.seoul.kr.

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APPENDIX

For supplementary tables and figure, please see the online version of this article.