ORIGINAL RESEARCH

Hemodynamic Tandem Intracranial Lesions on Magnetic Resonance Angiography in Patients Undergoing Carotid Endarterectomy

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***Background*—**Hemodynamic tandem intracranial lesions (TILs) on intracranial magnetic resonance angiography, which develop flow dependently, have been overlooked clinically in patients undergoing carotid endarterectomy. As they represent severe baseline hemodynamic compromise at the segment, they may be associated with distinctive clinical outcomes.

***Methods and Results*—**We assessed 304 consecutive carotid endarterectomy cases treated over 3 years. Included cases had both preoperative and postoperative intracranial 3-dimensional time-of-flight magnetic resonance angiography, of which signal intensities are flow dependent, and postoperative diffusion-weighted imaging (≤3 days following carotid endarterectomy). Preoperative TILs in the ipsilateral intracranial arteries were evaluated by the presence of nonexclusive components: focal stenosis (>50%), diffuse stenosis (>50%), and decreased signal intensities (>50%). The components showing postoperative normalization were considered hemodynamic. TILs with hemodynamic components were defined as hemodynamic TILs, while others as consistent TILs. Baseline characteristics and postoperative outcomes were analyzed among 3 groups: no TILs, consistent TILs, and hemodynamic TILs. Preoperative TILs were identified in 104 (34.2%) cases; 54 (17.8%) had hemodynamic components. Diffuse stenosis and decreased signal intensities were usually reversed postoperatively. Patients with hemodynamic TILs tended to have severe proximal carotid stenosis and recent strokes (≤14 days). For the outcome, hemodynamic TILs were independently associated with the advent of postoperative ischemic lesions on diffusion-weighted imaging (odds ratio: 2.50; 95% CI, 1.20–5.20).

***Conclusions*—**In patients undergoing carotid endarterectomy, a significant number of preoperative TILs demonstrated hemodynamic components, which were reversed postoperatively. The presence of such components was distinctively associated with the postoperative incidence of new ischemic lesions. **(*J Am Heart Assoc*. 2016;5:e004153 doi: 10.1161/JAHA.116.004153)**

Key Words: carotid endarterectomy • complication • intracranial stenosis • magnetic resonance angiography

Carotid endarterectomy (CEA) is beneficial in patients who have severe symptomatic internal carotid artery stenosis.[1,2] After a stroke, such patients usually undergo angiographic evaluation of cerebral arteries, including magnetic resonance angiography (MRA).[3] Results often show tandem intracranial lesions (TILs), which raise concerns over the safety of CEA.[4–18]

Some components of TILs may develop flow dependently, and they would be reversible as intracranial blood flow is increased by carotid revascularization.[19,20] These hemodynamic components in intracranial arteries may be best detected by 3-dimensional time-of-flight (TOF) MRA, which uses a flow-related enhancement phenomenon to visualize vessels.[21] In particular, signal voids or decreased signal intensities (indicating decreased flow velocity in the segment)[22,23] and/or collapsed vessels shown as stenosis may be improved after surgery.

Hemodynamic TILs on intracranial TOF-MRA in patients undergoing CEA have rarely been investigated; clinical implications thereof are as yet unknown. As often regarded, hemodynamic TILs may merely represent an artifact arising secondarily from severe proximal carotid stenosis,[21] lacking any clinical significance. However, hemodynamic TILs may represent severe baseline hemodynamic compromise at the segment. As arteries with significantly slow blood flow may have impaired endothelial cell function,[24] reopening/recovery process of those arterial segments may be associated with distinctive clinical outcomes of carotid revascularization.

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Thus, in this prospective study, we aimed to investigate the prevalence, characteristics, and clinical implications of hemodynamic components of TILs, which are reversible postoperatively, in patients undergoing CEA. To determine the postoperative reversibility, we evaluated both preoperative and postoperative TOF-MRA.

Methods

Subjects and Preoperative Evaluation

All patients undergoing CEA were registered at Asan Medical Center, Seoul, Korea. This registration included patient baseline characteristics, risk factors, blood tests, results of carotid Doppler and transthoracic echocardiography, and surgery information. Starting in November 2011, patients scheduled to undergo CEA have been routinely evaluated by preoperative MRA (mostly ≤1 month before surgery) and postoperative MRA including diffusion-weighted imaging (within ≤3 days of after surgery). Patients undergoing CEA of both internal carotid arteries sequentially were evaluated by postoperative MRA after each CEA. Thus, ipsilateral TILs could be evaluated with respect to preoperative status and postoperative reversibility for each CEA side. Patients undergoing just a single postoperative MRA after bilateral CEA because of short intervals between the 2 procedures were evaluated by preoperative TILs on the side of their most recent CEA, ≤3 days before the postoperative MRA.

Patients who had preoperative symptomatic strokes, as defined by the acute development of neurological symptoms and corresponding acute lesions on diffusion-weighted imaging ≤14 days of the procedure, were recorded in the registry.

This study followed the Declaration of Helsinki, and the protocol was approved by the Institutional Review Board of our center. All patients were informed in detail about the CEA procedure, preoperative and postoperative MRA, and study protocol; each participant provided informed consent for all components of the study.

Surgery

All CEAs were carried out by 2 experienced vascular surgeons (T.-W.K. and Y.-P.C.) who perform 50 to 100 CEAs annually. Details of CEA procedures performed at our center have been described previously.[25] Briefly, surgery was performed preferably with patients under general anesthesia with endotracheal intubation, whereas regional anesthesia was used in selected patients. In patients receiving general anesthesia, a Javid carotid shunt (Bard Inc, Murray Hill, NJ) was routinely used, and CEA was performed in the standard fashion with patch angioplasty using a bovine pericardium patch. All patients were managed postoperatively in an intensive care unit for at least 24 hours with antiplatelet agents and stringent control of their blood pressure.

Outcome Variables

We captured symptomatic stroke events during the postoperative period (median, 3 days; interquartile range, 3 to 4 days), and acute new ischemic lesions on diffusion-weighted imaging ≤3 days after CEA. When patients developed new neurological deficits after surgery, they were referred to neurologists, and postoperative symptomatic strokes were diagnosed if acute lesions corresponding to newly developed symptoms were present on diffusion-weighted imaging. Regardless of symptoms, all CEA patients routinely underwent diffusion-weighted imaging ≤3 days after surgery—the majority after 2 days (>90%)—to identify acute new ischemic lesions (see below). If a patient had been confirmed to have symptomatic strokes on diffusion-weighted imaging before the routine postoperative images were taken, additional imaging was not performed; symptomatic strokes were included in postoperative new ischemic lesions.

Imaging Protocol and Analysis

Preoperative and postoperative TOF-MRA were used to examine intracranial arteries. Postoperative diffusion-weighted images were routinely taken to detect new ischemic lesions. MRA was performed using 1.5-T (Siemens Avanto, Siemens Medical Solutions, Malvern, PA) and 3.0-T (Philips Achieva, Philips Medical Systems, Andover, MA) MR imaging units. MR parameters for TOF[26] and diffusion-weighted imaging[27] have been described previously.

TIL was identified in intracranial internal carotid arteries and middle cerebral arteries, ipsilateral to the CEA side, by assessing nonexclusive components: focal stenosis, diffuse stenosis, and decreased signal intensities (Figure 1). Focal stenosis was defined as a vessel narrowing to <50% diameter at a given site compared to the proximal segments of the lesion. Diffuse stenosis was defined as a diffuse narrowing (to <50% diameter) in 2 or more segments of the distal internal carotid artery[28] or stenosis in multiple segments and/or a long (>1 cm) segment in middle cerebral arteries[29] compared to the arteries on the contralateral side. Decreased signal intensity was defined as a signal intensity reduction compared to the contralateral side (qualitatively judged by clinicians), which indicated a void or significantly decreased flow (>50%).

Postoperative normalization, complete or near-complete recovery after revascularization, was determined for TIL components by comparing preoperative and postoperative TOF-MRA. When assessing the reversibility of focal stenosis, the diameter of a segment proximal to the lesion was referenced. The reversibility of diffuse stenosis and/or decreased signal intensity was determined in comparison to

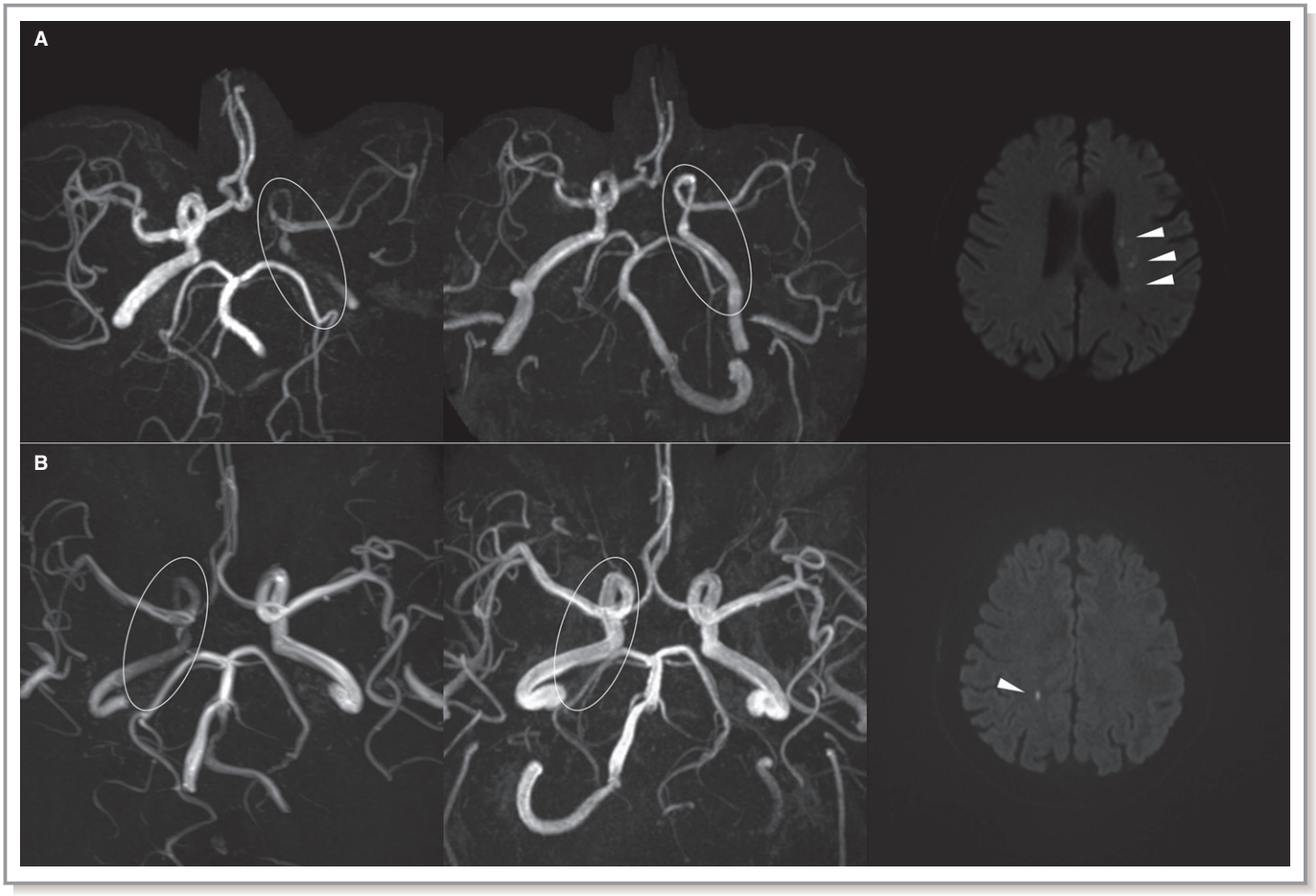

Figure 1. Components of TILs: postoperative reversal and new ischemic lesions. A, Patient with tandem TILs of diffuse stenosis and decreased signal intensities in the left distal internal carotid artery. Postoperatively, decreased signal intensities were reversed, while diffuse stenosis was partially normalized. The patient developed acute new ischemic lesions on diffusion-weighted imaging postoperatively on day 2. Left, preoperative MRA; middle, postoperative MRA; right, postoperative diffusion-weighted imaging. Circle: left distal internal carotid artery; arrowheads: new ischemic lesions. B, Patient with TILs of diffuse stenosis and decreased signal intensities in the right distal internal carotid artery. Postoperatively, all components were normalized. The patient developed acute new ischemic lesions on diffusion-weighted imaging postoperatively on day 2. Left, preoperative MRA; middle, postoperative MRA; right, postoperative diffusion-weighted imaging. Circle: right distal internal carotid artery; arrowheads: new ischemic lesions. MRA indicates magnetic resonance angiography; TILs, tandem intracranial lesions.

the diameter and/or signal intensities of contralateral or the adjacent normal arteries. TILs containing postoperatively normalized components were regarded as hemodynamic TILs, while others as consistent TILs.

Acute new ischemic lesions on diffusion-weighted imaging were defined as a hyperintense lesion on the b1000 with a corresponding hypointense region on the apparent diffusion coefficient map. Because those maps have lower resolution, small lesions on diffusion-weighted imaging (<5 mm) were accepted as new ischemic lesions even in the absence of low apparent diffusion coefficient values.[30] In patients who had had strokes in ≤14 days before surgery, new ischemic lesions were determined by slice-to-slice comparisons of preoperative and postoperative diffusion-weighted imaging.[31]

Two independent investigators (E.-J.L. and S.-H.L.) rated each preoperative and postoperative MRA and diffusion-weighted imaging; in cases of disagreement, a final decision was made by H.J.N. The MRI readers were not blinded to the study objectives to examine TILs on preoperative MRA and their reversal on postoperative MRA. However, they evaluated postoperative diffusion-weighted imaging separately, blinded to the results of MRA findings. Initial Cohen's kappa values were 0.84 for the presence of TILs and 0.69 for new ischemic lesions. For signal intensities, which were defined qualitatively, kappa values were 0.83 for the presence of lesions, and 0.62 for their recovery.

Statistical Analysis

Baseline characteristics and postoperative outcomes were compared among 3 groups: no TILs, consistent TILs, and hemodynamic TILs. Variables associated with the

development of new ischemic lesions on diffusion-weighted images after surgery were also evaluated. As the observations were correlated, all analyses were performed using generalized estimating equations method. For post-hoc pairwise comparisons, Tukey's multiple comparison procedures were performed. Logistic regression analysis was used to analyze the odds for postoperative ischemic lesions. Variables with P values of <0.10 in the univariate analyses were candidates for inclusion in multiple logistic regression with generalized estimating equations method; a 2-tailed P value of <0.05 considered statistically significant. Cohen's unweighted kappa statistic, which tests agreement beyond that which is expected by chance between 2 raters, was used to evaluate interrater reliability for the presence of TILs, postoperative ischemic lesions, and qualitative variables such as decreased signal intensities and their recovery. The kappa value was interpreted as following strength of agreement: moderate (0.41–0.60), good (0.61–0.80), and very good (0.81–1.00).[32] All statistical analyses were performed using SPSS version 22.0 (IBM Corp, Armonk, NY) and SAS 9.4 (SAS Institute, Cary, NC).

Results

Consecutive patients who underwent CEA between November 2011 and December 2014 were considered. During this period, 322 patients with a total of 342 CEAs were treated; of these, 30 patients with 30 CEAs (8.8%) were excluded (Figure 2). In addition, 8 cases of bilateral CEA with only a single postoperative MRA were excluded, leaving a total of 304 CEAs in 292 patients. The mean age of included patients was 69.1±7.7 years, of which 247 (84.9%) were male.

Evaluation of preoperative MRA revealed TILs in 104 (34.2%) cases, of which 41 (39.4%) showed multiple components (Table 1). For the TIL component, focal stenosis (n=70) was the most frequent, followed by decreased signal intensities (n=51) and diffuse stenosis (n=36) (Table 2). Of the decreased signal intensities, ≈80% (40/51) were combined with other components, especially diffuse stenosis. Notably, >85% of diffuse stenosis and decreased signal intensity cases reversed after surgery; yet this was the case for just 15% of focal stenosis examples. In total, more than half of the

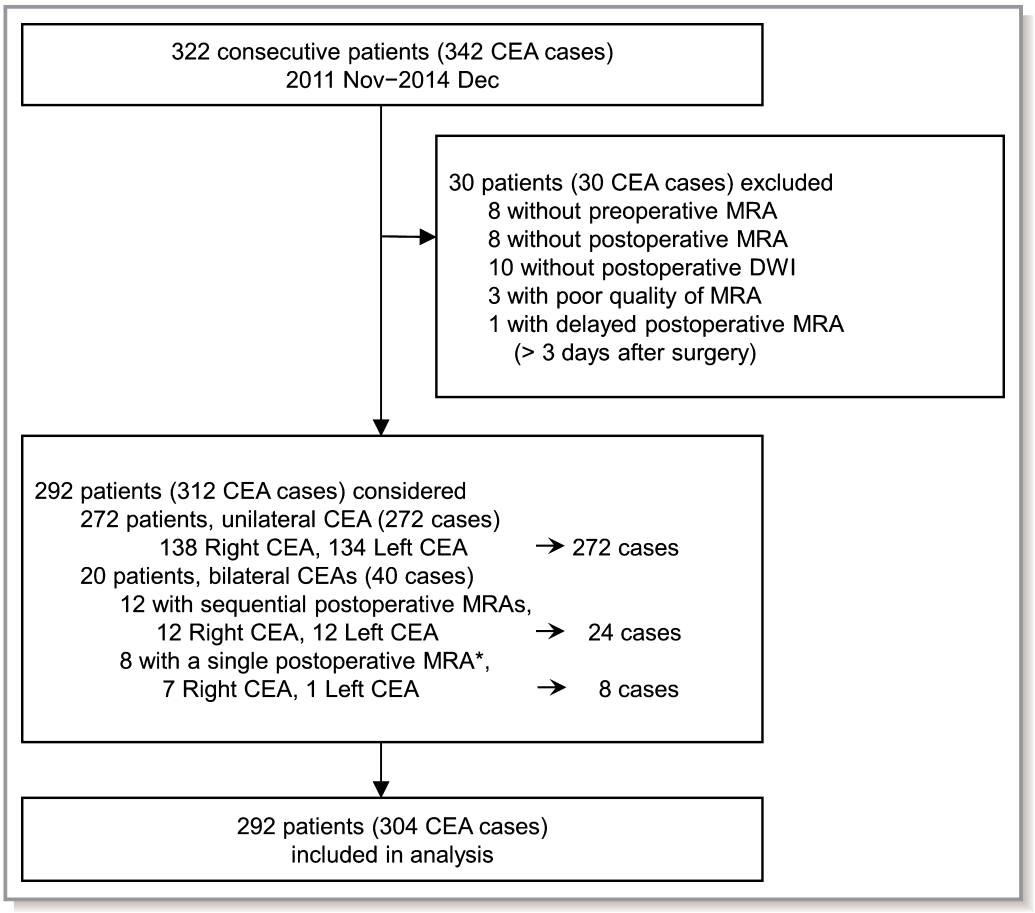

Figure 2. Study profile. *Preoperative tandem intracranial lesions on the side of the most recent CEA (within a period of 3 days before postoperative MRA) were evaluated. CEA indicates carotid endarterectomy; DWI, diffusion-weighted imaging; MRA, magnetic resonance angiography.

Table 1. Types of Tandem Intracranial Lesions (TILs)

Components	Frequency	Reversibility*
Single		
Focal stenosis only	49 (47.1)	3 (6.1)
Diffuse stenosis only	2 (1.9)	2 (100.0)
Decreased signal intensities only	11 (10.6)	10 (90.9)
Double		
Focal stenosis+diffuse stenosis	2 (1.9)	2 (100.0)
Focal stenosis+decreased signal intensities	8 (7.7)	7 (87.5)
Diffuse stenosis+decreased signal intensities	21 (20.2)	20 (95.2)
Triple		
All components	11 (10.6)	10 (90.9)
Total	104 (100.0)	54 (51.9)

Data represent n (%).
*TILs with a postoperatively normalized component were considered to have reversibility.

patients with TILs (n=54) demonstrated postoperatively normalized components.

We then compared the baseline characteristics and risk factors of patients having no TILs, consistent TILs, and hemodynamic TILs (Table 3). Conventional risk factors and age were not significantly different among the groups. However, patients with hemodynamic TILs were likely to be male and to have severe proximal carotid stenosis and preoperative strokes ≤14 days. They did not demonstrate lower levels of hemoglobin or of left ventricular ejection fraction. With regard to TIL components, diffuse stenosis and decreased signal intensities were prevalent in the hemodynamic TILs group, while focal stenosis was prevalent in the consistent TILs group.

Postoperatively, 75 cases (24.7%) and 6 (2.0%) developed new ischemic lesions on diffusion-weighted imaging and symptomatic strokes, respectively. More frequent new ischemic lesions were found in hemodynamic TILs (Table 4), whereas acute symptomatic strokes were comparable across the groups. Next, we attempted to identify other variables related to the advent of postoperative new ischemic lesions (Table 5). In univariate analysis, a high degree of carotid stenosis, high C-reactive protein levels, and preoperative stroke ≤14 days were found to be more frequent in patients who developed new ischemic lesions after surgery. Atrial fibrillation and characteristics of vulnerable carotid plaques such as intraplaque hemorrhage and plaque ulceration were not associated with the incidence of new ischemic lesions. Multiple logistic regression analysis was further conducted, and showed that TILs with hemodynamic components were independently associated with the postoperative development of new ischemic lesions (Table 6). Preoperative strokes, degree of carotid stenosis, shunt during surgery, and C-reactive protein were the other independent risk factors for new ischemic lesions on diffusion weighted-imaging.

Table 2. Components of Tandem Intracranial Lesions

Component	Frequency (a)	Postoperative Normalization (b)	Percent Normalization (b)/(a)
Focal stenosis	70	11	15.7%
Diffuse stenosis	36	31	86.1%
Decreased signal intensities	51	46	90.2%

Discussion

This study is the first to examine the postoperatively reversible components of TILs and their clinical implications in patients undergoing CEA using preoperative and postoperative MRA. TILs were found in more than a third of patients, approximately half of whom had reversible hemodynamic components following surgery. Hemodynamic TILs showed distinctive characteristics in terms of risk factors and postoperative outcome.

There were previous studies to evaluate the effect of tandem intracranial atherosclerosis on postoperative outcomes in patients with symptomatic internal carotid disease, although controversial results ensued. Some studies[6–12,16,17] including a substudy of the North American Symptomatic Carotid Endarterectomy Trial group insisted that tandem intracranial lesions do not increase the risk of strokes after carotid endarterectomy, while others[4,5,13,15,18] demonstrated that those lesions increase the risk of poor postoperative outcomes. Importantly, however, the cited studies evaluated intracranial arteries with conventional angiography, which may be conservative to detect hemodynamic vascular lesions. In this study, we have used TOF-MRA, of which signal intensities are flow dependent, to evaluate the hemodynamic abnormalities of TILs.

Among the TIL components, decreased signal intensities and diffuse stenosis were usually normalized after surgery, thus defined frequently as hemodynamic TILs. Signal loss beyond a stenosis on TOF-MRA can reflect decreased/slow flow or turbulence,[22,33] and diffuse stenosis may result from the collapse of arteries driven by severely decreased proximal blood flow. Proximal revascularization that improves incoming blood flow to the distal internal carotid artery is therefore likely to reverse both components. Meanwhile, focal stenosis, more frequent in consistent TILs, may suggest a true atherosclerotic stenosis.

Table 3. Preoperative Baseline Characteristics and Variables

	No TILs n=200	Consistent TILs n=50	Hemodynamic TILs n=54	*P* Value
Demographics and risk factors				
Age, y	68.7±7.7	71.4±7.7	68.5±7.6	0.371
Male	164 (82.0)	42 (84.0)	53 (98.1)*†	0.032
Body mass index, kg/m^2	24.0±3.6	24.4±3.0	23.4±3.5	0.286
Hypertension	128 (64.0)	43 (86.0)	38 (70.4)	0.176
Diabetes	72 (36.0)	29 (58.0)	18 (33.3)	0.409
Hyperlipidemia	151 (75.5)	34 (68.0)	36 (66.7)	0.326
Currently smoking	34 (17.0)	6 (12.0)	14 (25.9)	0.142
Coronary artery disease	31 (15.5)	13 (26.0)	8 (14.8)	0.187
Cardiac factors				
LV ejection fraction, %	61.4±6.3	61.9±5.4	61.4±5.1	0.949
Atrial fibrillation	6 (3.0)	0 (0.0)	1 (1.9)	NE
Carotid Doppler findings				
Carotid stenosis degree, %	73.4±7.8	72.3±6.2	80.1±9.1*†	<0.001
Intraplaque hemorrhage	22 (11.1)	7 (14.0)	11 (20.4)	0.100
Plaque ulceration	27 (13.5)	8 (16.0)	11 (20.4)	0.462
TILs components				
Focal stenosis		48 (96.0)	22 (40.7)	<0.001‡
Diffuse stenosis		2 (4.0)	34 (63.0)	<0.001‡
Decreased signal intensities		4 (8.0)	47 (87.0)	<0.001‡
Laboratory findings				
Hemoglobin, g/dL	13.5±1.5	12.5±1.5§	13.3±2.0	0.001
C-reactive protein, mg/dL	0.1 (0.1–0.3)	0.1 (0.1–0.3)	0.2 (0.1–0.9)	0.287
Preoperative stroke <14 days	22 (11.0)	4 (8.0)	16 (29.6)*†	0.001

Data represent n (%), mean±SD, or median (quartiles). LV indicates left ventricle; NE, not estimable; TILs, tandem intracranial lesions.
*No TILs vs hemodynamic TILs, $P<0.05$ using Tukey's multiple comparison procedure.
†Hemodynamic TILs vs consistent TILs, $P<0.05$ using Tukey's multiple comparison procedure.
‡Hemodynamic TILs vs consistent TILs.
§No TILs vs consistent TILs, $P<0.05$ using Tukey's multiple comparison procedure.

Severe proximal carotid stenosis was associated with the presence of flow-dependent components. However, low left ventricular ejection fraction and anemia, which may reflect hemodynamic status on a more global scale, were not. These findings suggest that hemodynamic impairment in the very proximal segment, which directly affects distal blood flow, is

Table 4. Postoperative Outcome Parameters

	No TILs n=200	Consistent TILs n=50	Hemodynamic TILs n=54	*P* Value
Imaging outcome				
New ischemic lesions	37 (18.5)	13 (26.0)	25 (46.3)*	<0.001
Clinical outcome				
Symptomatic strokes	3 (1.5)	1 (2.0)	2 (3.7)	0.568

Data represent n (%). TILs indicates tandem intracranial lesions.
*No TILs vs hemodynamic TILs, $P<0.05$ using Tukey's multiple comparison procedure.

Table 5. Baseline Characteristics and Acute New Ischemic Lesions

	No New Lesions n=229	New Lesions n=75	*P* Value
Demographics and risk factors			
Age, y	68.9±7.5	69.7±8.4	0.423
Male	35 (15.3)	10 (13.3)	0.696
Body mass index, kg/m^2	23.9±3.6	24.2±3.1	0.371
Hypertension	155 (67.7)	54 (72.0)	0.438
Diabetes	87 (38.0)	32 (42.7)	0.506
Hyperlipidemia	70 (74.5)	29 (60.4)	0.515
Currently smoking	38 (16.6)	16 (21.3)	0.388
Coronary artery disease	28 (29.8)	7 (14.6)	0.637
Cardiac factors			
LV ejection fraction, %	61.5±5.9	61.5±6.2	0.870
Atrial fibrillation	5 (2.2)	2 (2.7)	0.814
Carotid Doppler findings			
Carotid stenosis degree, %	73.4±8.4	77.6±7.2	<0.001
Intraplaque hemorrhage	32 (14.0)	8 (10.7)	0.503
Plaque ulceration	37 (16.2)	9 (12.0)	0.337
Intraoperative factors			
Shunt use	197 (86.0)	71 (94.7)	0.055
Laboratory findings			
Hemoglobin, g/dL	13.3±1.6	13.1±1.7	0.423
C-reactive proteins, mg/dL	0.1 (0.1–0.3)	0.2 (0.1–0.7)	0.005
Preoperative stroke <14 days	19 (8.3)	23 (30.7)	<0.001

Data represent n (%), mean±SD, or median (quartiles). LV indicates left ventricle.

Table 6. Factors Independently Associated With Acute New Ischemic Lesions

	Odds Ratio	95% CI	*P* Value
Male	0.79	0.33 to 1.91	0.601
Preoperative stroke (≤14 days)	3.77	1.72 to 8.22	<0.001
Degree of carotid stenosis (%, by Doppler)	1.05	1.01 to 1.09	0.009
Shunt during endarterectomy	5.55	1.89 to 16.32	0.002
Hemoglobin, g/dL	0.98	0.81 to 1.19	0.859
C-reactive protein, mg/dL	1.61	1.21 to 2.15	0.001
TILs			
No TILs (reference)			
Consistent TILs	2.10	0.92 to 4.76	0.077
Hemodynamic TILs	2.50	1.20 to 5.20	0.014

TILs indicates tandem intracranial lesions.

important. Notably, our findings are reminiscent of the previous studies using ocular pneumoplethysmography, a noninvasive tool to measure ophthalmic pressure to estimate the flow status of ipsilateral intracranial arteries.[34] Abnormalities on ocular pneumoplethysmography were shown more commonly in patients with severe carotid stenosis or occlusions, and those hemodynamic lesions were usually recovered after carotid endarterectomy[35,36]; both findings are accordant with our results.

For the other factors, preoperative strokes <14 days were more common in those with hemodynamic TILs. Severe carotid stenosis and resultant hemodynamically significant intracranial lesions are known to increase the odds of developing subsequent strokes in patients with carotid stenosis, if not surgically treated.[16,37] In addition, being male was also associated with hemodynamic TILs. The mechanism of its association is unclear, but more severe degree of carotid stenosis in male than in female patients (74.8±8.4% versus 72.4±7.3%, *P*=0.075) may have influenced the results.

Hemodynamic TILs were independently associated with development of new ischemic lesions, together with other variables such as recent strokes, severe carotid stenosis, shunt use, and C-reactive proteins (Tables 4 and 6). New ischemic lesions are known to develop on diffusion-weighted imaging after CEA in some cases (3–34%),[38,39] but the few studies to investigate their risk factors suggest microembolism, shunt use, and ulcerative plaques are important.[38–41]

Several mechanisms can be proposed to account for the independent association of hemodynamic TILs and the development of new ischemic lesions. First, reversible components on TOF-MRA reflect severe underlying hypoperfusion.[22,33] Microemboli, known to increase during CEA,[41] are prone to induce microinfarcts because of insufficient washout.[42] Second, the reopening of collapsed vessels may contribute to the migration of preformed thromboemboli in the proximal segments, or further thrombus formation upon reperfusion because slow baseline blood flow in the collapsed distal segments may have damaged the endothelium.[24] The involvement of other factors related to new ischemic lesions is also plausible. Severe carotid stenosis may enhance the low perfusion state and slow blood flow, and intraoperative shunt use has been associated with new ischemic lesions.[38,43] Inflammation, as indicated by high levels of C-reactive protein, may trigger plaque instability or enhance procoagulant activity.[44] Finally, a recent stroke can promote the

subsequent development of new ischemic lesions during acute and subacute periods.[45]

Then, what are the clinical implications of hemodynamic TILs on TOF-MRA? Hemodynamic TILs were independently associated with the incidence of new ischemic lesions even after the adjustment for the degree of proximal carotid stenosis. Thus, they should not be merely a secondary artifact, but may have distinct roles in developing new ischemic lesions. Importantly, new ischemic lesions after acute events including carotid stenting have been implicated in prediction of future strokes and cognitive impairment.[45–47] Thus, although the clinical significance of those lesions after CEA has not been determined, it may be reasonable to cautiously manage patients with diffuse stenosis and/or decreased signal intensities on preoperative TOF-MRA.

There are a number of limitations to this study. First, we used both 1.5- and 3.0-T scanners to evaluate the presence of TILs. Using different field strengths of MRA between evaluations before and after CEA may have affected the results. When we evaluated the aforementioned outcomes only in patients with identical field strengths of preoperative and postoperative MRA (189 [62.2%] cases; 3.0 T in 171, and 1.5 T in 18 cases), similar results were identified in univariate analysis, but not in multiple logistic regression analysis (data not shown). Thus, our results should be interpreted with caution. Second, we did not perform routine diffusion-weighted imaging before surgery. The incidence of new ischemic lesions in this study (24.7%) is comparable to that reported in previous works dealing with postoperative new ischemic lesions after CEA (0–33.8%). However, we still cannot exclude the possibility that preoperative events of silent ischemic lesions have contaminated the postoperative outcome.[38,39] Third, we adopted an arbitrary system here to evaluate TIL components. In particular, decreased signal intensities were defined qualitatively, not quantitatively; thus, small postoperative differences may have been neglected. Moreover, because we regarded only those components that exhibited complete, or near-complete, reversal as being recovered, partial reversal after surgery may have been ignored. Fourth, the MRI readers were not blinded to the study objectives. Thus, TILs and their recovery may have been detected too sensitively, although 2 independent investigators participated in the evaluation. Finally, it is important that all patients were ethnically Korean; because of the high prevalence of intracranial atherosclerosis in East Asians, our results may not be more generally applicable.

Despite these limitations, our findings suggest that hemodynamic TILs on TOF-MRA, which are reversed after surgery, are frequently found in patients undergoing CEA. Clinically, hemodynamic TILs were distinctively associated with postoperative development of new ischemic lesions on diffusion-weighted imaging, warranting further studies to confirm the implication and validate whether they affect the long-term prognosis.

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Disclosures

None.

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