Features of Brain Magnetic Resonance Imaging Diffusion-Weighted Images of Aortogenic Embolic Stroke – Comparison With Cardioembolic Stroke –

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Background: The features of acute aortogenic embolic stroke on magnetic resonance diffusion-weighted imaging (DWI) have not been fully elucidated, so we compared patients with acute aortogenic embolic stroke and those with acute cardioembolic stroke.

Methods and Results: This study included 40 consecutive patients with acute aortogenic embolic stroke, and 40 age- and sex-matched patients with acute cardioembolic stroke. The diagnosis of aortogenic embolic stroke was made when patients met 5 criteria: (1) acute neurologic event lasting >24 h; (2) positive signals on DWI; (3) atherosclerotic lesions ≥3.5-mm thick at the aortic arch on transesophageal echocardiography; (4) neuroradiologic features suggesting embolic stroke, such as lesions involving the brain cortex or the re-opening phenomenon of previously occluded vessels on Magnetic Resonance Angiography (MRA); and (5) absence of other embolic sources, including heart disease and carotid stenosis. The number, site, and maximal diameter of the infarct lesions on DWI were compared between the aortogenic and cardioembolic groups. The aortogenic patients more frequently had ≥3 lesions (25.0% vs. 2.5%, P<0.01), lesions with a maximal diameter <30 mm (77.5% vs. 20.0%, P<0.001), and vertebrobasilar system lesions (55.0% vs. 10.0%, P<0.001) than the cardioembolic patients.

Conclusions: Acute aortogenic embolic stroke is characterized by multiple (≥3) and small lesions, and involvement of the vertebrobasilar system. (Circ J 2014; 78: 738–742)

Key Words: Aortic arch; Aortogenic stroke; Atheroma; Embolism; Magnetic resonance tomography

The relationship between atheroma of the aortic arch and brain infarction was first reported in 1992.1 Later, many studies reported the importance of atheroma of the aortic arch as an embolic source.2-4 In particular, atheroma of the aortic arch that is ≥4.0 mm in thickness5-8 or 3.5 mm in thickness9 has been recognized as a cause of cryptogenic ischemic stroke. In embolic stroke patients, it is important to differentiate whether the embolism is cardiogenic, artery to artery embolic, or aortogenic. A previous study has reported that multiple bilateral and unilateral ischemic lesions are associated with cardioembolism and large artery atherothrombosis, respectively.8 However, the size, site, and number of infarctions in aortogenic brain embolism have not yet been fully elucidated. Thus, the purpose of this study was to clarify the features of diffusion-weighted images (DWI) of magnetic resonance imaging (MRI) in aortogenic embolic stroke, and compare them with those of cardioembolic stroke.

Methods

Patients
We enrolled 40 consecutive patients with acute aortogenic embolic stroke, seen at a single stroke center from October 2001 through October 2008, in this retrospective, case-controlled study (40 age- and sex-matched patients with acute cardioembolic stroke from October 2001 through October 2008 served as disease controls). Acute cardioembolic strokes were identified from the medical records of the hospital. First, the patients’ baseline characteristics, such as hypertension, diabetes mellitus, dyslipidemia, smoking, ischemic heart disease, arteriosclerosis...
Brain MRI of Aortogenic Embolic Stroke

and (5) absence of other embolic sources and stenosis ≥50% of the internal carotid artery measured on carotid echocardiography.

Risk Factors
The following cerebrovascular risk factors were investigated: hypertension (defined as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg and/or having a history of using antihypertensive agents), diabetes (defined as use of oral hypoglycemic agents or insulin, 2 fasting plasma glucose levels ≥126 mg/dl, 2 2-h postprandial plasma glucose readings ≥200 mg/dl after a glucose load of 75 g, or 2 casual glucose readings ≥200 mg/dl), dyslipidemia (defined as use of antihyperlipidemic agents or a serum cholesterol level ≥220 mg/dl), ischemic heart disease (defined as a history of angina pectoris or myocardial infarction) and arteriosclerosis obliterans (defined as having a diagnosis by vascular surgeon).

Echocardiographic Study
A commercially available echocardiography system (model HDI5000; Philips Medical Systems, Amsterdam, The Netherlands) with a 4- to 7-MHz, wideband, multplane probe was used to performed the echocardiographic study in awake patients who had fasted for at least 3h before the examination. Lidocaine spray was given, and patients were placed in the left lateral decubitus position during probe insertion. The aortic arch was ob-
The 2-tailed Student’s t-test and Statistical Analysis were used to compare the mean thickness of aortic atheroma. In the aortogenic group, the mean thickness of aortic atheroma was 5.8 mm, and the frequencies of mobile plaque, ulcers, and branch atheroma were investigated (≥3 lesions). The aortogenic group tended to have small infarct lesions (P<0.001; Table 3). The aortogenic group was more likely to have a single lesion and only involving the internal carotid territory (Table 3). The aortogenic group tended to have small infarct lesions (P<0.001; Table 3); maximal diameter was 20±1.7 mm in the aortogenic group and 68±3.6 mm in the cardiogenic group (Table 4). Small lesions, defined as those having a maximal diameter <30 mm, were seen in 77.5% of the aortogenic patients and only 20% of the cardiogenic patients (P<0.001; Table 4).

### Discussion

Our study shows that the lesions of aortic embolic stroke are smaller and more frequently multiple and involving the vertebrobasilar artery territories than those in cardiogenic embolic stroke. These results help in the differentiation of aortic embolic stroke from cardiogenic embolic stroke using admission MRI findings before further invasive examination, such as transesophageal echocardiography. Previous reports have suggested that aortic embolic stroke tends to involve multiple lesions in multiple vascular territories, and our results were consistent with those.

Our findings also showed that aortic embolic stroke was frequently associated with infarction of the vertebrobasilar artery territories. These stroke lesions may be associated with the site of atheroma in the aortic arch; there was a greater likelihood of thrombus flowing into the left subclavian artery than into the innominate or the left common carotid artery, because the left subclavian artery is located in the most distal portion. Any thrombi from the aortic arch can potentially flow into the left vertebral artery through the left subclavian artery because the left subclavian artery is located in the most distal portion. Our study also showed that the lesions of aortic embolic stroke were more severe in the cardiogenic group (P<0.01; Table 4). In the cardiogenic group, 19 patients had persistent atrial fibrillation, 17 had paroxysmal atrial fibrillation, 2 had aortic valve disorders, and 2 had a patent foramen ovale. In the aortogenic group, the mean thickness of aortic atheroma was 5.8 mm, and the frequencies of mobile plaque, ulcers, and branch atheroma were investigated (≥3 lesions). In the aortogenic group, the mean thickness of aortic atheroma was 5.8 mm, and the frequencies of mobile plaque, ulcers, and branch atheroma were investigated (≥3 lesions). The aortogenic group tended to have small infarct lesions (P<0.001; Table 3). The aortogenic group was more likely to have a single lesion and only involving the internal carotid territory (Table 3). The aortogenic group tended to have small infarct lesions (P<0.001; Table 3); maximal diameter was 20±1.7 mm in the aortogenic group and 68±3.6 mm in the cardiogenic group (Table 4). Small lesions, defined as those having a maximal diameter <30 mm, were seen in 77.5% of the aortogenic patients and only 20% of the cardiogenic patients (P<0.001; Table 4).

### Results

The mean age of the 40 patients (32 males, 8 females) with aortic embolic stroke was 77.2±6.8 (±SD) years. There was no significant difference between the aortogenic and cardiogenic groups in risk factors (Table 1). However, neurologic deficits, such as the baseline NIHSS score and the mRS score at discharge, were more severe in the cardiogenic group (P<0.01; Table 1). In the cardiogenic group, 19 patients had persistent atrial fibrillation, 17 had paroxysmal atrial fibrillation, 2 had aortic valve disorders, and 2 had a patent foramen ovale. In the aortogenic group, the mean thickness of aortic atheroma was 5.8 mm, and the frequencies of mobile plaque, ulcers, and branch atheroma were investigated (≥3 lesions). In the aortogenic group, the mean thickness of aortic atheroma was 5.8 mm, and the frequencies of mobile plaque, ulcers, and branch atheroma were investigated (≥3 lesions). The aortogenic group tended to have small infarct lesions (P<0.001; Table 3). The aortogenic group was more likely to have a single lesion and only involving the internal carotid territory (Table 3). The aortogenic group tended to have small infarct lesions (P<0.001; Table 3); maximal diameter was 20±1.7 mm in the aortogenic group and 68±3.6 mm in the cardiogenic group (Table 4). Small lesions, defined as those having a maximal diameter <30 mm, were seen in 77.5% of the aortogenic patients and only 20% of the cardiogenic patients (P<0.001; Table 4).

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flow and shear stress.\textsuperscript{13,17,18} Although we could not find any laterality in the ischemic lesions in the anterior circulation, some previous studies demonstrated that infarctions in the left internal carotid artery territories are more frequently seen in aortic embolic stroke than in other types of stroke.\textsuperscript{12,19} The findings of those reports may be explained by the same hypothesis that distal branch arteries are more likely to receive emboli through the aortic arch.

In the present study, infarction size seemed smaller in aortic embolic stroke than in cardioembolic stroke, and aortic embolic stroke tended to have multiple infarct lesions. We believe that white thrombus rather than red thrombus formed in the damaged segment of the blood vessel wall in the aortic arch, where the blood flow is fast. Moreover, before thrombi have increased greatly, they may be released by the fast blood flow. Thus, small lesions were frequently seen in patients with aortic brain infarction.

**Study Limitations**

First, this study was retrospective, and the sample size was relatively small. Secondly, transesophageal echocardiography was attempted in as many patients as possible, but not all patients in the cardiogenic group could undergo it, so it was actually performed in 9 of 40 patients in the cardiogenic group, and the average thickness of the aortic arch plaque was 3.3±0.7 mm (range 2.1–4.5 mm). Therefore, some of the patients in the cardiogenic group might have had atherosclerotic lesions in the aortic arch. However, stroke patients with atrial fibrillation usually show a high CHADS2 score in general,\textsuperscript{20,21} because that score contains risk factors for arteriosclerosis such as hypertension, diabetes and advanced age. Stroke patients with atrial fibrillation frequently have aortic atherosclerotic lesions and are likely to develop cardiovascular events such as brain infarction.\textsuperscript{25} In such patients, tissue factor, released from the damaged endothelium may activate the coagulation cascade, and subsequently hypercoagulable blood may contribute to large clot formation in the atrium. We assume that these mechanisms are the cause of systemic thrombosis and embolism in patients with atrial fibrillation. Therefore, the current study demonstrated an apparent difference in the size of infarct lesions between an aortogenic group and cardiogenic group. It seems reasonable that a thrombus formed in the atrium with lower blood flow is large, whereas that in the aorta with faster blood is small. In addition, it may be difficult to collect stroke patients with atrial fibrillation and without any aortic lesions as a match for stroke patients with aortic lesion and without atrial fibrillation, because atrial fibrillation patients without aortic lesions usually have a low CHADS2 score and rarely develop stroke. Third, transesophageal echocardiography may underestimate plaque in the ascending aorta and proximal aortic arch because of the interposition of the trachea.

**Conclusions**

MRI-DWI images in acute aortic embolic stroke appear to characteristically show multiple lesions (≥3), small lesions (diameter <30 mm), and lesions involving the vertebrobasilar system. These features can be feasible for diagnosing patients with acute embolic stroke on MRI.

**References**


**Table 3. Stroke Lesions In Embolic Stroke Patients**

<table>
<thead>
<tr>
<th>No. of lesion(s), n (%)</th>
<th>Aortogenic (n=40)</th>
<th>Cardiogenic (n=40)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19 (48)</td>
<td>30 (75)</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>11 (28)</td>
<td>9 (23)</td>
<td>NS</td>
</tr>
<tr>
<td>≥3</td>
<td>10 (25)</td>
<td>1 (3)</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

**Table 4. Maximal Stroke Lesion Diameter**

<table>
<thead>
<tr>
<th>Maximal diameter of lesion, mm</th>
<th>Aortogenic (n=40)</th>
<th>Cardiogenic (n=40)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>20±1.7</td>
<td>68±3.6</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Diameter of lesion &lt;30 mm, n (%)</td>
<td>31 (78)</td>
<td>8 (20)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

IC, internal carotid artery; VB, vertebrobasilar artery.


