The Course of Unilateral Intracranial Arteriopathy in Young Adults With Arterial Ischemic Stroke

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Background and Purpose—Unilateral intracranial focal nonprogressive arteriopathy is often found in children with arterial ischemic stroke. We aimed to investigate the course of unilateral intracranial arteriopathy in young adults.

Methods—We searched the Utrecht Stroke Database for patients between 16 and 50 years of age diagnosed with anterior circulation arterial ischemic stroke and a nonatherosclerotic, unilateral intracranial large-artery arteriopathy between 1991 and 2005. We assessed clinical features, potential causes, risk factors, extent of infarction and arteriopathy at presentation, long-term angiographic course, and clinical outcome.

Results—Of 356 patients with anterior circulation arterial ischemic stroke, 17 (5%) had a documented unilateral intracranial arteriopathy, of whom 14 could be included for follow-up investigations (median age, 34 years; range, 27–49 years). Median duration of follow-up was 8.8 years (range, 1.7–12.8 years). In 11 patients, onset of symptoms was not abrupt. The arteriopathy normalized completely in 5 and improved in 3 patients; in none of the patients did the arteriopathy worsen. Two of 14 patients had recurrent symptoms. Ten patients (71%) had a good outcome (modified Rankin Scale score ≤2).

Conclusions—In young adults, arterial ischemic stroke is rarely caused by a unilateral intracranial arteriopathy. Similar to children, onset of symptoms in young adults is often not abrupt and the arteriopathy may improve over time. Late recurrences were rare. Possibly, a monophasic inflammatory process, as has been suggested for childhood intracranial focal nonprogressive arteriopathies, also occurs in young adults. (Stroke. 2012;43:1890-1896.)

Key Words: etiology ■ intracranial stenosis ■ stroke in young adults

In young adults the proportion of patients in whom the cause of arterial ischemic stroke (AIS) can be determined has increased during the last decades mainly as a result of improvements in diagnostic investigations.1 Improved availability and quality of noninvasive imaging of the extracranial and intracranial arteries has led to an increased frequency of patients with stroke diagnosed with arteriopathies, including dissection, moyamoya, angiitis, fibromuscular dysplasia, and postradiation vasculopathy.2,3 In children, intracranial arteriopathies are found in approximately 53% of patients with AIS.4 The recently published classification of childhood AIS, based on the childhood AIS standardized classification and diagnostic evaluation criteria, describes focal cerebral arteriopathy as a separate entity.5 Transient cerebral arteriopathy (TCA) is a subset of focal cerebral arteriopathy accounting for up to one third of anterior circulation strokes in previously healthy children.6,7 Typically, these children present with a non abrupt onset of neurological deficits caused by a predominantly lenticulostriate infarction. Angiography shows unilateral arterial abnormalities of the distal internal carotid artery, proximal middle cerebral artery (MCA) or anterior cerebral artery, that stabilize or improve over time.3,6,7 TCA is presumed to be caused by monophasic arterial wall inflammation. In 31% to 44% of these children the arteriopathy is preceded by a varicella zoster virus infection.6–8 Infections with Enterovirus,9 Borrelia burgdorferi,10 or HIV11 have also been associated with TCA in children. Varicella zoster virus associated vasculopathy can also lead to progressive arterial inflammation, severe neurological disease, and death. Treatment with acyclovir and steroids has therefore been recommended for varicella zoster virus-associated vasculopathy.12,13 Intracranial inflammatory arteriopathy has also been described in adults after herpes zoster ophthalmicus.13 Whether inflammatory arteriopathies also occur in adults in the absence of varicella zoster virus infection is unknown.

The aim of our study was to investigate the frequency, presentation, long-term radiological and clinical outcome, and the presumed cause of unilateral intracranial large-artery arteriopathy in young adults with AIS.

Methods
We searched the prospective Utrecht Stroke Database for patients aged 16 to 50 years with AIS admitted to the Department of...
Neurology at the University Medical Center Utrecht or investigated at the outpatient clinic between January 1, 1991, and December 31, 2005. Patients were approached for follow-up investigation if: (1) they had had signs or symptoms attributable to anterior circulation AIS; (2) vascular imaging of the intracranial arteries performed within 3 months after stroke was available for review and showed a unilateral arteriopathy of the distal internal carotid artery, proximal anterior cerebral artery, or MCA; and (3) a cardiac source of thromboembolism had been excluded.

AIS was defined as focal neurological deficits caused by infarction visible on CT or MRI. Vascular imaging could consist of digital subtraction angiography (DSA), MR angiography, or CT angiography. Arteriopathy was defined as a focal or segmental stenosis or occlusion with regular or irregular abnormalities of the arterial wall. An abrupt occlusion of a major cerebral artery at initial angiography without other abnormalities suggestive of arterial wall disease was not considered an arteriopathy because this may be caused by embolic occlusion.

The following baseline characteristics were collected from the medical charts: mode of onset of stroke symptoms, preceding infections or trauma, migraine before stroke, medical history, medication before and after stroke, known prothrombotic disorders, and risk factors for atherosclerotic disease (smoking, drugs, hypertension, family history of cardiovascular disease, hypercholesterolemia, diabetes mellitus). The mode of onset of stroke symptoms was classified as “abrupt” when neurological symptoms reached maximum severity within 30 minutes. Onset was “progressing” when symptoms gradually progressed and reached maximum severity in >30 minutes. Onset was classified as “stuttering” when presenting symptoms were fluctuating and the patient was not free of symptoms between episodes and as “recurring” when the patient was free of symptoms in between.14 The severity of stroke at presentation was classified according to the National Institutes of Health Stroke Scale and modified Rankin Scale.

Results of laboratory investigations for atherosclerotic risk factors and prothrombotic disorders, performed during the diagnostic evaluation of stroke, were collected (triglycerides, total cholesterol, high- and low-density lipoprotein cholesterol, homocysteine, thrombocytes, prothrombin time, fibrinogen, anti-thrombin activity, protein S antigen, protein C activity, activated protein C resistance, prothrombin mutation, factor VIII, lupus anticoagulant, anticardiolipin IgG and IgM, and lipoprotein[a]). At follow-up, 1 of the authors (M.M.M.B.) interviewed patients about recurrence of stroke, transient ischemic attacks, or other vascular events (deep venous thrombosis, pulmonary embolism, peripheral arterial disease, ischemic heart disease) and treatment and patients underwent a clinical examination. Outcome was assessed by means of the modified Rankin Scale. Investigations of triglycerides, total cholesterol, high-density lipoprotein cholesterol, and low-density lipoprotein cholesterol were repeated and prothrombotic disorders were investigated when the investigations in the past had not included all the elements as listed previously. Patients underwent MRI investigation of the brain (T1-, T2-weighted, fluid-attenuated inversion recovery) and MR angiography of the circle of Willis (3-dimensional time of flight with maximum-intensity projection reconstruction) on a 3-T MRI scanner (Achieva; Philips Medical Systems) to study the long-term course of arteriopathy and the occurrence of new ischemic strokes. In 1 patient, a CT and CT angiography scan were performed instead of MRI because the patient had a pacemaker. Based on the comparison of MR angiography with vascular imaging at presentation, the arteriopathy was classified as progressive (increase of stenosis or progression from stenosis to occlusion or new involvement of other intracranial arteries), unchanged, improved (but not normal), or normalized.

This study was approved by the institutional ethical committee and patients gave written informed consent.

Results

Of 490 patients with AIS, 356 had an anterior circulation AIS (Figure 1). In 17 (5%) of them, a unilateral intracranial large-artery arteriopathy was documented. One patient died 4 days after stroke and 2 patients refused participation in the study. Fourteen patients underwent follow-up investigations. Characteristics of the 14 patients are summarized in Table 1. Median age at the time of stroke was 34 years (range, 27–49 years) and 7 patients were male. The onset of symptoms was abrupt in 3 patients, whereas 11 patients (79%) had a nonabrupt onset with gradual progression in 2, a stuttering course in 6, and recurring symptoms in 3 patients. Two patients presented with severe headache in the week before stroke. Four patients had no risk factors for atherosclerosis, 9 were smokers, and 7 had a family member with cardio- or cerebrovascular disease. None of the patients had had a trauma before stroke.

Radiological Characteristics at the Time of Stroke

The extent of infarction and the severity of arteriopathy are summarized in Table 2. In 7 patients the infarct involved both the basal ganglia and cortex and in 1 patient the infarct was limited to the basal ganglia.

In 4 patients, only DSA was performed at the time of stroke; in 5 patients only MR angiography time of flight and 5 patients underwent both DSA and MR angiography. In 13 patients, the MCA was abnormal. The other patient had arterial disease in the distal internal carotid artery only. In 1 of the 13 patients with MCA involvement, the ipsilateral anterior cerebral artery was affected as well, and in 4, the arteriopathy involved distal internal carotid artery, MCA, and anterior cerebral artery. Eight patients (57%) had a tapering occlusion of ≥1 affected intracranial arteries.

Radiological Characteristics at Follow-Up

The median duration of follow-up was 8.8 years (range, 1.7–12.8 years). Imaging of the brain revealed a new infarction in 1 patient (Patient 9). In none of the patients did repeated vascular imaging reveal progression of arteriopathy. In 8 patients (57%) the arteriopathy had improved: complete normalization in 5 and evident but incomplete improvement in 3. In the other 6, the severity of the arteriopathy remained unchanged (Figure 2A–C).

Clinical Outcome

Two patients (14%) had recurrent ischemic symptoms from the hemisphere ipsilateral to the arteriopathy during follow-up. Patient 9 had a recurrent stroke after 4 years, which increased the severe paresis of her left arm but did not change her modified Rankin Scale of 2. Patient 6 had a transient ischemic attack that did not change his modified Rankin Scale of 1. No other vascular events were reported. Functional outcome at the time of follow-up was good (modified Rankin Scale ≤2) in 10 of 14 patients.

Presumed Cause of AIS

Normalizing Arteriopathy

Of the 5 patients with normalized vascular imaging, 1 patient (Patient 2) most likely had postpartum angiopathy. Patient 1 had herpes zoster ophthalmicus in the year before stroke on the side of the affected MCA but a connection between stroke
and herpes zoster ophthalmicus was never suspected at that
time. Lumbar puncture showed an increased cerebrospinal
fluid protein (0.87 g/L) but no other abnormalities. Investi-
gations for viral infections were not performed. In Patients 3,
4, and 5, the cause of arteriopathy could not be determined,
although an increased lipoprotein(a) (Patients 3 and 5) and an
increased factor VIII activity (Patients 3, 4, and 5) may have
contributed to their risk of stroke. In Patient 4, cerebrospinal
fluid pleocytosis was found, but the underlying cause was
never found and a lumbar puncture was not repeated. Despite
the presence of several risk factors for atherosclerosis, we
considered it unlikely that atherosclerosis caused the arte-
riopathies because then we would not have expected com-
plete normalization. Furthermore, these patients did not have
symptoms of the heart or peripheral arteries indicating gen-
eralized vascular disease during follow-up.

Improving Arteriopathy
In these 3 patients the cause remained unclear. Two had no
risk factors for atherosclerosis at all. Patient 6 had ulcerative
colitis. An increased risk of thromboembolic events and
cerebral vasculitis in patients with inflammatory bowel dis-
 ease has been described. In this patient, DSA showed
tapering occlusion of M2 branches and not abrupt occlusion
suggestive of an embolus. There were no signs of small-
vessel abnormalities consistent with small-vessel vasculitis.
A brain biopsy was not performed.

Stabilizing Arteriopathy
In 1 patient, polyarteritis nodosa had been considered in the
past but could never be confirmed. A large-artery vasculitis
was assumed to be the cause of stroke and DSA did not show
small-vessel abnormalities. He was treated with prednisone
for 6 years. A few years later, he was diagnosed with sarcoidosis.
In the other 5 patients, no definite cause of stroke
was found, although several possibly contributing factors
were identified (Table 1). In these patients, atherosclerosis as
the cause of the arteriopathy cannot be excluded, but no new
vascular events suggestive of generalized atherosclerosis
occurred during follow-up.

Discussion
This study shows that unilateral intracranial arteriopathy,
according to the childhood AIS standardized classification
and diagnostic evaluation criteria classified as focal cerebral
arteriopathy, is a rare cause of AIS in young adults. None of
our patients had a progressive arteriopathy and the arteriopa-
thy improved or normalized over time in 57%. In the
majority, onset of symptoms was not abrupt. Late recurrences were rare and clinical outcome was good in 71% of patients. When unilateral focal cerebral arteriopathy is diagnosed in children without risk factors for stroke, only 6% have progressive arterial disease over time, whereas in 94%, TCA can be diagnosed.6 The nonabrupt mode of onset of symptoms and the nonprogressive nature of the arteriopathies that we found in young adults are comparable to what has been observed in children with TCA.14 In children with TCA, follow-up vascular imaging shows complete normalization in 23%, stabilization in 32%, and improvement in 45%.6 Late recurrences are rare and clinical outcome is good in 41% of patients.6,7 In our small series of young adults, late recurrent stroke occurred in only 1 of the 14 patients. Based on the similarities in clinical presentation, and radiological characteristics, we suggest that TCA can cause ischemic stroke also in young adults. The design of our study does not allow a reliable estimation of the frequency of TCA in young adults with AIS. If a monophasic inflammatory process is the underlying cause of arteriopathy in at least a subset of these adult patients, as has been suggested in children with TCA, further studies are needed to determine whether immunosuppressive treatment can improve outcome. Other causes of intracranial arteriopathies that may improve over time are the "reversible cerebral vasoconstriction syndromes,"16 characterized by thunderclap headache (94%), often with seizures, a

### Table 1. Clinical Characteristics of 14 Patients With Unilateral Intracranial Large-Artery Arteriopathy

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Sex, Age, Y</th>
<th>Ischemic Event(s)</th>
<th>Onset of Symptoms</th>
<th>NIHSS</th>
<th>mRS*</th>
<th>Atherosclerotic Risk Factors</th>
<th>Relevant History</th>
<th>Relevant Laboratory Findings</th>
<th>Presumed Cause of AIS at Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M, 28</td>
<td>Minor stroke; preceding TIA</td>
<td>Recurring</td>
<td>4</td>
<td>1/0</td>
<td>None</td>
<td>HZO</td>
<td>Fibrinogen 5.7 g/L; normal at follow-up</td>
<td>HZO arteriopathy</td>
</tr>
<tr>
<td>2</td>
<td>F, 28</td>
<td>Minor stroke</td>
<td>Abrupt</td>
<td>6</td>
<td>2/1</td>
<td>Fibrinogen 5.7 g/L; normal at follow-up</td>
<td>Puerperium</td>
<td>Fibrinogen 5.7 g/L; normal at follow-up</td>
<td>Postpartum arteriopathy</td>
</tr>
<tr>
<td>3</td>
<td>F, 29</td>
<td>Major stroke</td>
<td>Stuttering</td>
<td>7</td>
<td>3/2</td>
<td>Smoking; FH; hypercholesterolemia</td>
<td>Migraine</td>
<td>Cholesterol 6.7 mmol/L; fibrinogen 6.2 g/L; factor VIII 254%; Lp(a) 834 mg/L</td>
<td>Unknown</td>
</tr>
<tr>
<td>4</td>
<td>F, 38</td>
<td>Minor stroke</td>
<td>Stuttering</td>
<td>2</td>
<td>2/1</td>
<td>Smoking; FH; hypertension</td>
<td></td>
<td>Fibrinogen 7.5 g/L; later 4.4 g/L; factor VIII 168%; Lp(a) 1040 mg/L; CSF protein 0.84 g/L</td>
<td>Vasculitis</td>
</tr>
<tr>
<td>5</td>
<td>M, 49</td>
<td>Major stroke</td>
<td>Progressing</td>
<td>15</td>
<td>4/3</td>
<td>Smoking</td>
<td></td>
<td>Fibrinogen 1.8 g/L; factor VIII 184%</td>
<td>Vasculitis</td>
</tr>
<tr>
<td>6</td>
<td>M, 27</td>
<td>Minor strokes; preceding TIA</td>
<td>Recurring</td>
<td>2</td>
<td>2/1</td>
<td>None</td>
<td>Ulcerative colitis; lacunar infarct 5 y before</td>
<td>Fibrinogen 5.3 g/L; heterozygous for factor V mutation</td>
<td>Unknown</td>
</tr>
<tr>
<td>7</td>
<td>M, 34</td>
<td>Major stroke</td>
<td>Abrupt</td>
<td>16</td>
<td>4/3</td>
<td>None</td>
<td></td>
<td>Fibrinogen 5.3 g/L; heterozygous for factor V mutation</td>
<td>Unknown</td>
</tr>
<tr>
<td>8</td>
<td>F, 36</td>
<td>Minor stroke; preceding TIA</td>
<td>Stuttering</td>
<td>2</td>
<td>2/2</td>
<td>Smoking; hypertension</td>
<td></td>
<td>Factor VIII 196%</td>
<td>Unknown</td>
</tr>
<tr>
<td>9</td>
<td>F, 30</td>
<td>Major stroke; preceding TIA</td>
<td>Stuttering</td>
<td>9</td>
<td>3/2</td>
<td>Smoking; FH; hypertension</td>
<td></td>
<td>Fibrinogen 5.0 g/L; heterozygous for factor II mutation</td>
<td>Unknown</td>
</tr>
<tr>
<td>10</td>
<td>F, 31</td>
<td>Major stroke</td>
<td>Progressing</td>
<td>5</td>
<td>3/2</td>
<td>Smoking; FH</td>
<td>Celiac trunk stenosis</td>
<td>Fibrinogen 5.0 g/L</td>
<td>Unknown</td>
</tr>
<tr>
<td>11</td>
<td>M, 34</td>
<td>Major stroke; preceding TIA</td>
<td>Abrupt</td>
<td>14</td>
<td>4/4</td>
<td>Smoking</td>
<td></td>
<td>Lp(a) 443 mg/L</td>
<td>Unknown</td>
</tr>
<tr>
<td>12</td>
<td>M, 42</td>
<td>Minor stroke; preceding TIA</td>
<td>Stuttering</td>
<td>3</td>
<td>2/1</td>
<td>Alcohol; smoking; FH; hypercholesterolemia</td>
<td></td>
<td>Cholesterol 7.7 mmol/L; ANA+; factor VIII 200%</td>
<td>Unknown</td>
</tr>
<tr>
<td>13</td>
<td>M, 46</td>
<td>Major stroke; preceding TIA</td>
<td>Recurring</td>
<td>11</td>
<td>4/3</td>
<td>None</td>
<td>PAN; lacunar infarct 2 y before</td>
<td>ANA+; protein S 45%; protein C 57%; factor VIII 192%; CSF protein 0.94 g/L</td>
<td>Vasculitis (sarcoidosis)</td>
</tr>
<tr>
<td>14</td>
<td>F, 49</td>
<td>Minor stroke</td>
<td>Stuttering</td>
<td>2</td>
<td>2/1</td>
<td>Smoking; FH; hypertension</td>
<td></td>
<td>Fibrinogen 4.4 g/L; factor VIII 180%</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

NIHSS indicates National Institutes of Health Stroke Scale; mRS, modified Rankin Scale; AIS, arterial ischemic stroke; M, male; F, female; TIA, transient ischemic attack; FH, family history of cardiovascular disease; HZO, herpes zoster ophthalmicus; PAN, polyarteritis nodosa; ANA, antinuclear antibody; CSF, cerebrospinal fluid; WBC, white blood cell count; Lp(a), lipoprotein A.

*mRS at the time of presentation/at time of follow-up.
“string of beads” appearance of cerebral arteries, and intracranial hemorrhage. Ischemic stroke is a rare complication of this syndrome (1%–31%). Postpartum angiopathy is described as part of reversible cerebral vasoconstriction syndromes. Patient 2 with postpartum angiopathy never had headache before her stroke. Patients 10 and 14 presented with severe headache in the week before stroke onset. However, both patients had a stable arteriopathy after a follow-up duration of 12 years and therefore did not have “reversible vasoconstriction.” Apart from reversible cerebral vasoconstriction syndromes, the differential diagnosis of AIS associated with unilateral intracranial arteriopathies in young adults also includes dissection, unilateral moyamoya disease, postradiation vasculopathy, fibromuscular dysplasia, primary angiitis of the central nervous system, drug-induced vasoconstriction, Sneddon syndrome, and recanalization of a thromboembolic occlusion. Although none of these conditions could be diagnosed in the described patients, we cannot exclude these with certainty because pathological studies of the vessel wall were not performed. A recent study showed that dissection of the intracranial internal carotid artery may mimic TCA. Possibly, dedicated vessel wall imaging may help to establish the underlying cause of intracranial arteriopathies in the future.

The strength of our study is that we were able to collect young adults with AIS from a prospective database over a

<table>
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<tr>
<th>Table 2. Radiological Characteristics of 14 Patients With Unilateral Intracranial Large-Artery Arteriopathy</th>
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<tbody>
<tr>
<td>Patient No.</td>
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<tr>
<td>---</td>
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<tr>
<td>Normalization</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<tr>
<td>3</td>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
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<tr>
<td>Improvement</td>
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<tr>
<td>6</td>
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<tr>
<td>7</td>
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<tr>
<td>8</td>
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<tr>
<td>Stabilization</td>
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<td>9</td>
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<td>10</td>
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<td>11</td>
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<td>12</td>
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<td>13</td>
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<tr>
<td>14</td>
</tr>
</tbody>
</table>

M indicates male; F, female; R, right; BG, basal ganglia; L, left; WM, white matter; MCA, middle cerebral artery; PCA, posterior cerebral artery; ACA, anterior cerebral artery; M1 and M2, M1 and M2 branches of MCA; dICA, distal internal carotid artery; VKA, vitamin K antagonist.
long period of time. In these patients we performed extensive diagnostic investigations, including vascular imaging at the time of follow-up and clinical evaluation in person to evaluate recurrence of vascular events.

Our study also has limitations. We may have missed the diagnosis of unilateral nonprogressive intracranial arteriopathy, because not in all patients in the Utrecht Stroke Database were the intracranial arteries visualized. Therefore, our study cannot reliably estimate the frequency of TCA in young adults with AIS.

Another limitation is that investigations for inflammatory causes of stroke including cerebrospinal fluid analysis were not routinely assessed in young adults with an unknown cause of stroke. Furthermore, in 4 patients, the MR angiogram at follow-up had to be compared with DSA because MR angiography was not performed at the time or presentation. However, because MR angiography may overestimate arterial stenosis compared with DSA, it is unlikely that this has affected the observation that the arteriopathy improved or stabilized in the majority of patients.

Summary and Conclusions
This study shows that in none of the described patients was unilateral intracranial arteriopathy progressive. A nonprogressive, inflammatory arteriopathy may cause AIS in young adults, similar to the entity that has been found in children, and a high index of suspicion may reveal more cases in the future. Intracranial vascular imaging should be performed in young adults with AIS when the cause of stroke is not found in the heart or the extracranial arteries. When vascular imaging shows nonatherosclerotic unilateral focal cerebral arteriopathy, the risk of late recurrences is small and clinical outcome is good in the majority of patients. It is important to search for inflammatory causes and to repeat intracranial vascular imaging, differentiating between a nonprogressive or possibly reversible arteriopathy and progressive arteriopathies as in atherosclerosis, vasculitis, or moyamoya disease.

Figure 2. A–C. Vascular imaging of 3 patients at the time of stroke and at follow-up. A, Normalization of arteriopathy. AIS in the left hemisphere of patient 3 (left panel) with stenosis of the left M1 bifurcation and M2/M3 branches (right upper panel). Follow-up vascular imaging showed normalization of arteriopathy (right lower panel). B, Improvement of arteriopathy. AIS in the right hemisphere of patient 8 (left panel) with stenosis of the M1 and M2 segments of the right MCA and A1 segment of the right ACA. The left A1 segment is hypoplastic. Right upper panel, First MRA. Follow-up vascular imaging showed improvement of arteriopathy (right lower panel). C, Stabilizing arteriopathy. AIS in the left hemisphere of Patient 10 (left upper panel) with occlusion of the left dICA. DSA (right upper panel) of the left common carotid artery showed an occlusion of the dICA, distal from the ophthalmic artery. The initial MRA is shown in the left lower panel. Follow-up imaging showed an unchanged arteriopathy (right lower panel). Filling of the left MCA is caused by blood flow from the right side through the anterior communicating artery. AIS indicates arterial ischemic stroke; MCA, middle cerebral artery; ACA, anterior cerebral artery; MRA, MR angiography; dICA, distal internal carotid artery; DSA, digital subtraction angiography.

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Disclosures
None.

References
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http://stroke.ahajournals.org/content/43/7/1890