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BACKGROUND AND PURPOSE: **In childhood-onset moyamoya disease, the angiographic disease process of stenoocclusive lesions is progressive, and cerebral infarctions often develop as a result of ischemia. Our purpose was to determine how the severity of stenoocclusive lesions in the anterior and posterior circulations affects the distribution of cerebral infarction in patients with childhood-onset moyamoya disease.**

METHODS: **In 69 patients with childhood-onset moyamoya disease, angiograms were reviewed for stenoocclusive lesions, and CT scans, MR images, or both were reviewed for the sites and extent of cerebral infarction. The relationship between the angiographic and CT/MR findings was examined.**

RESULTS: **The prevalence and degree of stenoocclusive lesions of the posterior cerebral artery (PCA) significantly correlated with the extent of lesions around the terminal portion of the internal carotid artery (ICA). The prevalence of infarction significantly correlated with the degree of stenoocclusive changes of both the ICA and PCA. Infarctions tended to be distributed in the anterior borderzone in less-advanced cases, while in more advanced cases lesions were additionally found posteriorly in the territory of the middle cerebral artery, the posterior borderzone, and the PCA territory.**

CONCLUSION: **Our results indicate that progressive changes of the anterior and posterior circulations are associated with the distribution of cerebral infarction, culminating in a patchily disseminated or honeycomb pattern of infarction on CT and MR studies in late stages of the disease.**

Moyamoya disease is a rare cerebrovascular occlusive disorder of unknown origin (1–4). It is divided into two types according to whether the onset occurs in childhood or adulthood (5). The main features of moyamoya disease are bilateral stenoocclusive changes at and around the internal carotid artery (ICA) bifurcation along with a distribution of abnormal netlike vessels in the basal regions, called moyamoya (3). Although changes similar to those around the ICA can also be found in the posterior circulation, few reports have dealt with the posterior circulation in this disease (6, 7).

In childhood-onset moyamoya disease, progression of cerebral infarction is considered to occur with an advancing stenoocclusive process. However, no large-scale study has been undertaken to evaluate how the severity of stenoocclusive vascular lesions in the anterior and posterior cerebral circulations is related to the development of cerebral infarction.

Recent evidence indicates that the frequency of cerebral infarction positively correlates with the progression of posterior cerebral artery (PCA) lesions (7), but the relationship between the location and extent of infarction and the degree of stenoocclusive PCA changes remains to be defined.

We studied the relationship between changes in the posterior and anterior circulations on angiograms and the frequency and extent of cerebral infarction on CT scans and MR images, or both, in 69 patients with childhood-onset moyamoya disease.

Methods

Between 1961 and 1996, 216 patients seen at our institution were confirmed to have moyamoya disease at angiography. Among them, 141 patients were under 15 years of age at the onset of symptoms attributed to this disorder (childhood-onset moyamoya disease). The 72 patients whose CT or MR findings

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TABLE 1: Angiographic ICA staging of stenoocclusive lesions in patients with moyamoya disease*

ICA Stage	Angiographic Findings
I	Narrowing of the carotid bifurcation
II	Dilatation of the ACA and MCA with appearance of ICA moyamoya
III	Partial disappearance of the ACA and MCA with intensification of ICA moyamoya
IV	Advanced stenoocclusive changes in the ICA (ACA and MCA are traced very dimly or in a completely different shape) with small amount of ICA moyamoya
V	Absence of the ACA and MCA with further reduction of ICA moyamoya
VI	Blood supply only from the external carotid artery with almost complete disappearance of ICA moyamoya

Note.—ICA, ACA, MCA indicate internal carotid, anterior, and middle cerebral arteries, respectively; ICA moyamoya, moyamoya vessels at or around the terminal part of the ICA.

* Adapted from Suzuki et al (3).

TABLE 2: Angiographic PCA staging of stenoocclusive lesions in patients with moyamoya disease

PCA Stage	Angiographic Findings
1	No occlusive changes in the PCA
2	Stenosis in the PCA with or without slightly developed PCA moyamoya
3	Severe stenosis or virtually complete occlusion of the PCA with well-developed PCA moyamoya
4	Occlusion of the PCA with decreased PCA moyamoya

Note.—PCA indicates posterior cerebral artery; PCA moyamoya, moyamoya vessels from the PCA.

were unavailable were excluded from the present study; thus, the retrospective study included the remaining 69 patients with childhood-onset moyamoya disease, including those who underwent surgery and those who did not. In 57 patients, revascularization surgery was performed, and in those patients, only the angiographic and MR and/or CT studies performed before surgery were reviewed. All but one patient had bilateral disease; the remaining patient had angiographic evidence of unilateral involvement in childhood, with subsequent development of the disease on the contralateral side. For this patient, the initially involved hemisphere was included and the contralateral side was excluded from analysis.

Twenty-three patients were male and 46 female; all patients were under 15 years of age (mean, 6 ± 3 years [SD]) at the onset of symptoms. Angiography was performed when the patients were between 1 and 38 years of age (mean, 11 ± 7 years). The average interval from the onset of symptoms to angiography was 5 years. None of the 69 patients had any other underlying disease, consistent with a diagnosis of idiopathic moyamoya disease. The initial manifestations of disease were transient ischemic attack or cerebral infarction in 66 patients; the other three patients presented with intraventricular hemorrhage at the age of 6 years, thalamic hemorrhage at the age of 6 years, and putaminal hemorrhage at the age of 10 years, respectively.

All 69 patients underwent cerebral angiography, including bilateral internal and external or common carotid arteriography, and unilateral or bilateral vertebral arteriography. All 69 patients were examined by CT (n = 69), and 47 additionally underwent MR imaging. All CT and MR studies analyzed were performed within 1 month of cerebral angiography. CT was performed with a matrix of either 320 × 320 or 512 × 512 and a section thickness of 8 to 10 mm, with the scanning plane approximately parallel to the orbitomeatal line. MR imaging included axial spin-echo T1-weighted images (360–500/15–20/1–2 [TR/TE/excitations]), axial proton density--weighted images (2500/20/1), and axial spin-echo (2500/90/1) or fast spin- echo (3000–3500/90–100/1) T2-weighted images. Axial fluid-attenuated inversion-recovery (FLAIR) (8000/119/1) images were additionally obtained in 15 patients. The field of view was 20 to 25 cm and the matrix was 256 × 256 with a 5- to 8-mm section thickness and a 1- to 2-mm intersection gap.

To evaluate the angiographic findings for all 137 hemispheres in the 69 patients, we applied two angiographic staging systems for the anterior and posterior circulations. We classified stenoocclusive changes of the supraclinoid ICA into six angiographic stages as defined by Suzuki et al (3): stage I, narrowing of the carotid bifurcation only; stage II, dilatation of the main cerebral arteries with appearance of moyamoya vessels at or around the terminal part of the ICA (ICA moyamoya); stage III, partial disappearance of the middle (MCA) and anterior (ACA) cerebral arteries with intensification of ICA moyamoya at the base of the brain; stage IV, advanced stenoocclusive changes in the ICA (ACA and MCA are traced very dimly or in a completely different shape through the mist of the ICA moyamoya) with a small amount of ICA moyamoya; stage V, absence of the ACA and MCA with further reduction of the ICA moyamoya; and stage VI, blood supply only from the external carotid artery and almost complete disappearance of ICA moyamoya (Table 1).

We classified the stenoocclusive lesions in the PCA into four stages (Table 2 and Figs 1–4): stage 1 (Fig 1B), no occlusive changes in the PCA, with normal visualization of the cortical branches of the PCA; stage 2 (Fig 2B), stenosis in the PCA with relatively good visualization of the distal cortical branches with or without slight moyamoya from the PCA (PCA moyamoya); stage 3 (Fig 3B), severe stenosis or virtually complete occlusion of the PCA with well-developed PCA moyamoya frequently showing anastomoses with the medullary arteries (a few cortical PCA branches being opacified through the PCA moyamoya); and stage 4 (Fig 4B), occlusion of the PCA without any apparent cortical branches opacified (the PCA moyamoya is small and limited to the area of the proximal PCA in this stage).

The leptomeningeal collateral circulation frequently develops from the cortical branches of the PCA and from the posterior pericallosal arteries. The leptomeningeal collateral circulation from the PCA was subjectively classified into one of the following four grades according to its extent: good, cortical branches in all three frontal, parietal, and temporal lobes being more or less opacified; moderate, cortical branches in two of the three lobes opacified; poor, cortical branches in either the parietal or the temporal lobe opacified; none, no substantial collateral circulation.

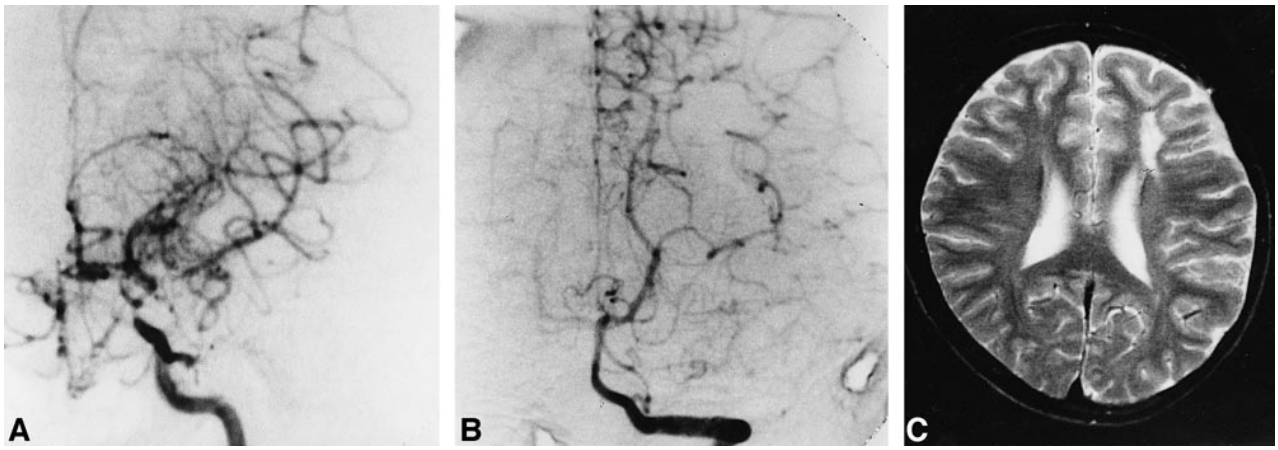

FIG 1. 12-year-old girl with an initial manifestation of transient motor weakness in right upper and lower extremities.

A, Left carotid angiogram (anteroposterior view) shows stenoocclusive changes at the terminal part of the ICA and the proximal part of the ACA and MCA. Moyamoya vessels at the base of the brain and a partial disappearance of cortical branches of the ACA and MCA are also evident (ICA stage III). A right carotid angiogram showed ICA stage III and the right PCA was also well opacified without stenoocclusive changes (PCA stage 1) (not shown).

B, Left vertebral angiogram (Towne projection) shows left PCA with no stenoocclusive changes (PCA stage 1). Good leptomeningeal collaterals to the anterior circulation are present.

C, Axial T2-weighted (3500/90/1) MR image reveals cerebral infarction in the left AWS but no abnormalities in the right.

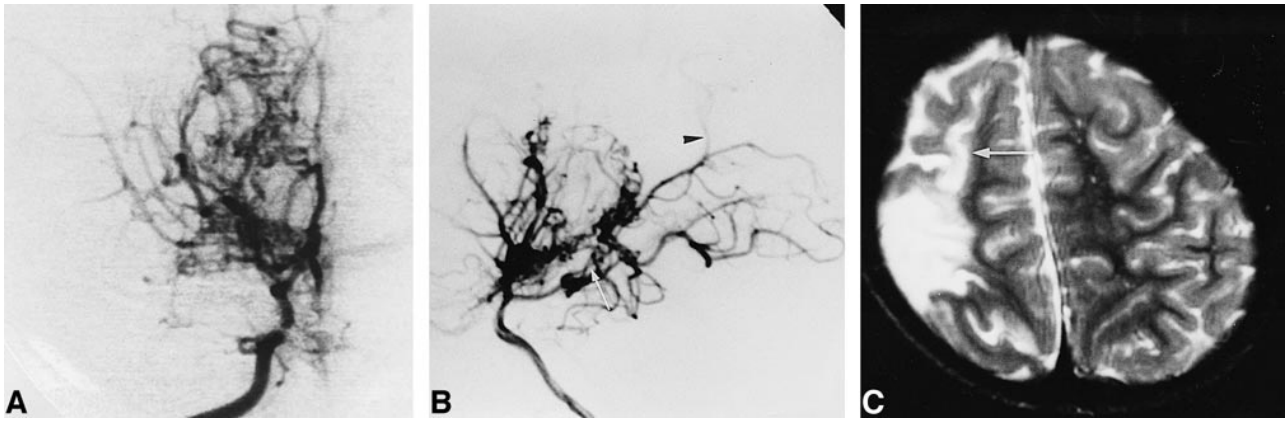

FIG 2. 3-year-old boy with an initial manifestation of transient bilateral motor weakness followed by left hemiparesis and mild right hemiparesis.

A, Anteroposterior view of a right carotid angiogram shows stenoocclusive changes at the terminal part of the ICA and the proximal part of the ACA and MCA. Well-developed moyamoya vessels around the terminal part of the ICA and a partial disappearance of cortical branches of the ACA and MCA are also evident (ICA stage III).

B, The right PCA is also opacified on lateral view of right carotid angiogram. The right PCA shows mild stenosis in its ambient segment (*arrow*) with delayed opacification of the right parietooccipital artery (*arrowhead*) (PCA stage 2). Leptomeningeal collaterals were poor at a later phase (not shown). Vertebral angiography did not fill the right PCA, and the left PCA showed no stenoocclusive changes (PCA stage 1) (not shown). A left carotid angiogram showed ICA stage II (not shown).

C, Axial T2-weighted (2500/90/1) MR image shows infarction in the right frontal (ant-MCA) (*arrow*) and parietal regions (post-MCA).

CT and MR studies were reviewed to determine the location and number of cerebral infarctions. The number of infarctions was counted according to the regions involved, as described below. One continuous lesion involving two or more adjacent zones was regarded as two or more infarctions. Zones in the hemisphere were divided into the following eight regions: the territory of the ACA; the anterior half of the territory of the MCA (ant-MCA); the posterior half of the territory of the MCA (post-MCA); the territory of the PCA; the anterior watershed area of the ACA and MCA (AWS); the posterior watershed area of the MCA and PCA (PWS); the basal ganglia; and the thalamus. The ant-MCA and post-MCA were divided at the central sulcus, and the temporal lobe was included in the post-MCA.

Angiographic findings and CT and MR images were evaluated by two radiologists blinded to the patients' identity. CT and MR images were interpreted without knowledge of the angiographic findings. When interpretations were inconsistent, the final evaluation was reached by consensus. The interobserver agreement between the two radiologists was good: 94% in the interpretation of CT scans, MR images, or both, and 84% in the interpretation of angiograms.

The data were analyzed statistically by one of three methods: Spearman rank correlation, Mann-Whitney U-test, or Kruskal-Wallis rank test. Values of $P < .05$ were considered statistically significant.

Results

Stenoocclusive Lesions in the Anterior and Posterior Circulation

Of the 69 patients, 40 (58%) were found to have stenoocclusive lesions in one or both PCAs; 62

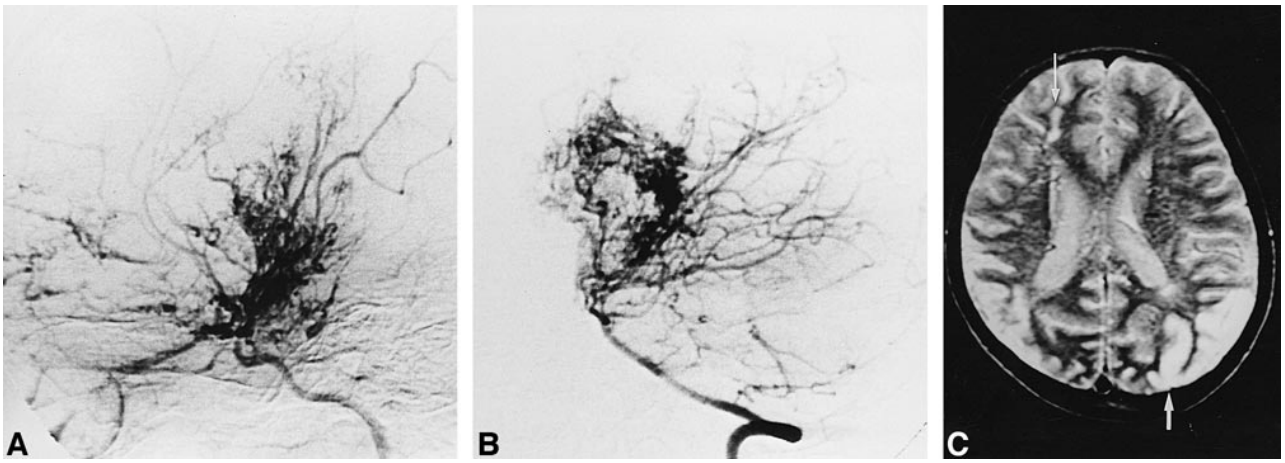

FIG 3. 8-year-old girl who initially presented with transient left-sided motor weakness. Examination revealed decreased visual acuity.

A, Lateral view of a right carotid angiogram shows partial disappearance of cortical branches of the ACA and MCA with well-developed moyamoya vessels at the base of the brain (ICA stage III). A left carotid angiogram also showed ICA stage III (not shown).

B, Lateral view of left vertebral angiogram shows advanced stenosis of bilateral PCAs with well-developed PCA moyamoya. Cortical branches of the PCA are partially opacified (PCA stage 3, bilaterally). Anastomoses between the PCA moyamoya and medullary arteries were well defined at a later phase (not shown).

C, Axial T2-weighted (2500/90/1) MR image reveals infarctions in the right AWS (*thin arrow*), bilateral post-MCAs, and left PWS (*thick arrow*). Infarctions in the right ant-MCA and the right PWS were also visible (not shown). No infarction in the PCA territory is evident on either side.

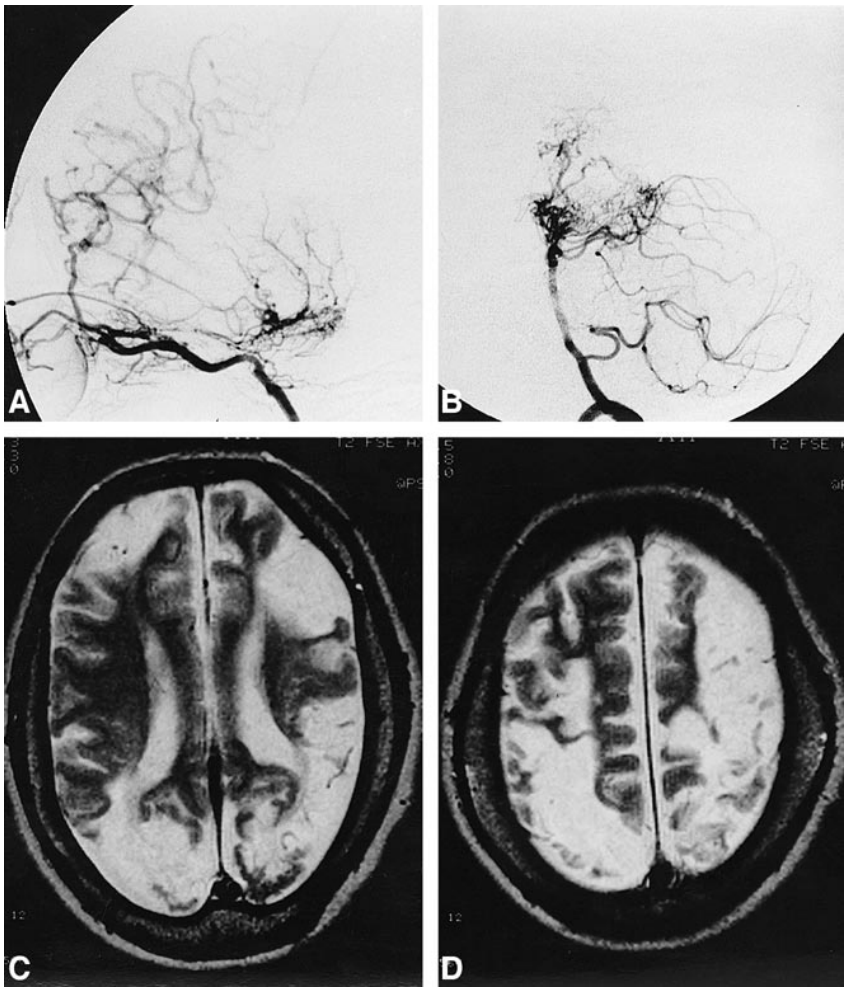

FIG 4. 35-year-old man who initially presented with right hemiparesis and speech disturbance at 3 years of age. Moyamoya disease was diagnosed at the same age on the basis of cerebral angiographic findings.

A, Lateral view of a left carotid angiogram shows complete occlusion of the ICA just distal to the origin of the ophthalmic artery (ICA stage VI). The ophthalmic artery is enlarged and provides collateral circulation mainly to the ACA distribution. The basal perforators are slightly dilated. A right carotid angiogram also showed ICA stage VI (not shown).

B, Lateral view of right vertebral angiogram discloses severe stenoocclusive changes of bilateral PCAs with no opacification of cortical branches (PCA stage 4).

C and *D,* Axial T2-weighted (3000/100/1) MR images reveal infarctions in the AWS, ant-MCA, post-MCA, PWS, and PCA territories on both sides.

TABLE 3: Relationship between angiographic ICA stage and PCA stage in patients with moyamoya disease

ICA Stage of Stenoocclusive Lesions (Sides)		PCA Stage of Stenoocclusion Lesions			
		1	2	3	4
I	(n = 6)	6	0	0	0
II	(n = 19)	16	2	1	0
III	(n = 67)	47	9	11	0
IV	(n = 26)	5	5	13	3
V	(n = 12)	1	0	9	2
VI	(n = 7)	0	0	4	3
Total	(n = 137)	75	16	38	8

Note.—Numbers indicate the number of sides according to stage.

TABLE 4: Relationship between ICA stage and degree of leptomeningeal collaterals from the PCA in patients with moyamoya disease

ICA Stage (Sides)		Degree of Leptomeningeal Collaterals from the PCA			
		Good	Moderate	Poor	None
I	(n = 6)	0 (0)	2 (33)	1 (17)	3 (50)
II	(n = 19)	8 (42)	7 (37)	4 (21)	0 (0)
III	(n = 67)	37 (55)	16 (24)	3 (4)	11 (16)
IV	(n = 26)	4 (15)	3 (12)	8 (31)	11 (42)
V	(n = 12)	1 (8)	3 (25)	4 (33)	4 (33)
VI	(n = 7)	0 (0)	0 (0)	1 (14)	6 (86)
Total	(n = 137)	50 (36)	31 (23)	21 (15)	35 (26)

Note.—Numbers in parentheses are percentages relative to the number of sides for each ICA stage. For descriptions of good, moderate, poor, none classifications, see Methods section.

PCAs (45%) in 137 sides showed stenoocclusive changes. The relationship between the ICA and the PCA stages of stenoocclusive lesions is summarized in Table 3. The degree of stenoocclusive PCA changes significantly correlated with ICA stage (Spearman rank correlation, $P < .0001$). Of the 19 sides with the most advanced stages involving the anterior circulation (ICA stages V or VI), 18 (95%) were found to have advanced PCA stages (PCA stages 3 or 4) as well.

Leptomeningeal Collaterals from the PCA

The relationship between the ICA stage and the grade of leptomeningeal collaterals from the PCA is shown in Table 4. Among the 137 sides, leptomeningeal collaterals from the PCA were seen in 102 sides (74%). These collaterals were scant in sides with ICA stage I and tended to be best developed in sides with ICA stage II or III. As the ICA stage advanced from III to VI, the degree of leptomeningeal collaterals from the PCA decreased significantly (Spearman rank correlation, $P < .0001$). Of seven sides with ICA stage VI, representing the most advanced disease, only one (14%) had collaterals, which were very poorly developed. Also, there was a significant negative correlation between the PCA stage and the degree of leptomeningeal collaterals from the PCA (Spearman rank correlation, $P < .0001$).

Cerebral Infarctions

Cerebral infarctions were demonstrated in 71 (52%) of 137 hemispheres. There was a significant positive correlation between the ICA staging and the number of infarcted regions (Spearman rank correlation, $P < .0001$). The relationship between ICA stage and site of cerebral infarctions is shown in Table 5. The frequency of cerebral infarctions in the five regions, other than the ACA territory, significantly correlated with ICA stage (see Table 5 for *P* values). Furthermore, except for the ACA territory, the more advanced the ICA stage, the more posterior regions were involved (Kruskal-Wallis rank test, $P = .0005$). Among the 25 sides with ICA stage I or II, AWS infarctions were most frequent (n = 7; 28% of the 25 hemispheres); the PWS and the PCA territories were not involved in any case. Of the 19 sides with ICA stage V or VI, 10 (53%) had infarctions in the AWS regions, nine (47%) had infarctions in the ant-MCA, 13 (68%) had infarctions in the post-MCA, the PWS was involved in eight sides (42% of 19 hemispheres), and the PCA territory was involved in five sides (26% of 19 hemispheres).

The relationship between the PCA stage and the number of infarcted regions is shown in Table 6. The frequency of infarctions significantly correlated with PCA stage (Mann-Whitney U test, $P < .0001$): 25 (33%) of 75 hemispheres with PCA stage 1 (Fig 1), 10 (63%) of 16 hemispheres with PCA stage 2 (Fig 2), 28 (74%) of 38 hemispheres with PCA stage 3 (Fig 3), and all eight (100%) of the hemispheres with PCA stage 4 had cerebral infarctions (Fig 4). The number of infarcted regions also significantly correlated with PCA stage (Spearman rank correlation, $P < .0001$). In the PCA stage 1 group, 50 (67%) of the sides examined had no infarction and 18 (24%) had infarction in one region. In the PCA stage 4 group, however, seven (88%) of the sides had infarctions in more than four regions. In the advanced PCA stages, multiple foci of infarctions were distributed predominantly in the corticosubcortical regions, typically showing a patchy or honeycomb pattern.

The relationship between the PCA stage and the sites of cerebral infarction is shown in Table 7. The frequency of cerebral infarctions in the five regions other than the ACA territory significantly correlated with PCA stage (see Table 7 for *P* values). Furthermore, except for the ACA territory, the more advanced the PCA stage, the more posterior regions were involved (Kruskal-Wallis rank test, $P < .0001$). Among the 75 sides with PCA stage 1 (Fig 1), AWS infarctions were most frequent (29%); the PWS was involved in only one side (1%), and the PCA territory was never involved. Among the 16 sides with PCA stage 2 (Fig 2), the AWS was the

TABLE 5: Relationship between ICA stage and sites of infarction in patients with moyamoya disease

ICA Stage (Sides)		Sites of Infarction					
		ACA	AWS	ant-MCA	post-MCA	PWS	PCA
I	(n = 6)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
II	(n = 19)	1 (5)	7 (37)	4 (21)	1 (5)	0 (0)	0 (0)
III	(n = 67)	3 (4)	22 (33)	6 (9)	8 (12)	3 (4)	0 (0)
IV	(n = 26)	1 (4)	12 (46)	6 (23)	15 (58)	7 (27)	2 (8)
V	(n = 12)	0 (0)	5 (42)	4 (33)	6 (50)	3 (25)	0 (0)
VI	(n = 7)	2 (29)	5 (71)	5 (71)	7 (100)	5 (71)	5 (71)
Total	(n = 137)	7 (5)	51 (37)	25 (18)	37 (27)	18 (13)	7 (5)
P value*		NS	.0322	.0032	<.0001	<.0001	<.0001

Note.—Numbers in parentheses are percentages relative to the number of sides for each ICA stage. For definitions of ACA, AWS, ant-MCA, post-MCA, PWS, and PCA, see Methods section.

* *P* value: Mann-Whitney U-test; NS indicates not significant.

TABLE 6: Relationship between PCA stage and number of infarcted regions in patients with moyamoya disease

PCA Stage (Sides)		Number of Infarcted Regions							
		0	1	2	3	4	5	6	7
1	(n = 75)	50 (67)	18 (24)	4 (5)	2 (3)	1 (1)	0 (0)	0 (0)	0 (0)
2	(n = 16)	6 (38)	5 (31)	2 (13)	3 (19)	0 (0)	0 (0)	0 (0)	0 (0)
3	(n = 38)	10 (26)	9 (24)	7 (18)	8 (21)	4 (11)	0 (0)	0 (0)	0 (0)
4	(n = 8)	0 (0)	0 (0)	1 (13)	0 (0)	3 (38)	3 (38)	0 (0)	1 (13)
Total	(n = 137)	66 (48)	32 (23)	14 (10)	13 (9)	8 (6)	3 (2)	0 (0)	1 (1)

Note.—Numbers in parentheses are percentages relative to the number of sides for each PCA stage.

TABLE 7: Relationship between PCA stage and sites of infarction in patients with moyamoya disease

PCA Stage (Sides)		Sites of Infarction					
		ACA	AWS	ant-MCA	post-MCA	PWS	PCA
1	(n = 75)	4 (5)	22 (29)	5 (7)	2 (3)	1 (1)	0 (0)
2	(n = 16)	1 (6)	8 (50)	4 (25)	3 (19)	0 (0)	0 (0)
3	(n = 38)	1 (3)	13 (34)	10 (26)	24 (63)	10 (26)	3 (8)
4	(n = 8)	1 (13)	8 (100)	6 (75)	8 (100)	7 (88)	4 (50)
Total	(n = 137)	7 (5)	51 (37)	25 (18)	37 (27)	18 (13)	7 (5)
P value*		NS	.0156	<.0001	<.0001	<.0001	<.0001

Note.—Numbers in parentheses are percentages relative to the number of sides for each PCA stage. For definitions of ACA, AWS, ant-MCA, post-MCA, PWS, and PCA, see Methods section.

* *P* value: Mann-Whitney U-test; NS indicates not significant.

most frequently involved (50%), and the ant-MCA and post-MCA regions were more frequently involved than in PCA stage 1. The 38 sides with PCA stage 3 (Fig 3) had high rates of involvement of the post-MCA (63%) and the PWS (26%). Among the eight sides with PCA stage 4 (Fig 4), the AWS and post-MCA regions were always involved, the ant-MCA and the PWS were involved frequently (75% and 88%, respectively), and the PCA territory was involved in half the sides.

Infarctions in the ant-MCA, the post-MCA, and the PWS were accompanied by a high frequency of stenoocclusive changes in the PCA (PCA stages 2 to 4); that is, in 20 (80%) of 25 sides, in 35 (95%) of 37 sides, and in 17 (94%) of 18 sides, respectively. Infarctions in the PCA territory were found in seven sides, and all were associated with severe stenoocclusive PCA changes (PCA stage 3 or 4).

ACA territory infarction was found in seven hemispheres, and its frequency was unrelated to the degree of PCA or ICA staging. Infarctions were seen in the basal ganglia in seven sides and in the thalamus in one side. Their frequency was also unrelated to the degree of stenoocclusive ICA and PCA changes. Brain stem and cerebellar infarctions were not evident in any patient.

Discussion

Moyamoya disease is characterized by bilateral stenoocclusive changes at or around the terminal part of the ICA, with the development of abnormal

netlike vessels, called moyamoya, at the base of the brain (3). Previous studies have focused on stenoocclusive changes of the anterior circulation, and PCA involvement is not included in the diagnostic criteria for this disease (8). Only a few studies have evaluated the posterior circulation (6, 7), even though the PCA is frequently affected in this disease. We found stenoocclusive changes of the PCAs in 58% of the 69 patients, with involvement of 62 (45%) of 137 hemispheres. The frequency is generally consistent with the findings of previous studies (6, 7).

In our series, the frequency of PCA involvement positively correlated with the ICA stage. This finding agrees with the recent work of Yamada et al (7), although the frequency of PCA involvement we observed in hemispheres with the most advanced ICA stages was quite different from theirs. ICA stages V and VI in our study correspond to ICA stage 5 in the classification used by Yamada et al. In hemispheres with such advanced ICA stages, the frequency of stenoocclusive PCA changes was 95% among our cases, in contrast to 59% in the study of Yamada et al. Although we have no obvious explanation for this large difference, it might have resulted from the difference in age of disease onset between the two studies. In our study, all patients were under 15 years of age (mean, 6 $\pm$ 3 years) at onset, whereas the study of Yamada et al included patients with adult-onset disease, resulting in a mean onset age of 10 $\pm$ 12 years; the difference in onset age between the two studies is statistically significant (Welch's *t*-test; $P = .006$). We suspect, therefore, that vascular changes might progress faster in childhood (ie, the earlier the onset of disease, the faster PCA involvement may develop). Indeed, previous serial angiographic studies of patients with childhood-onset moyamoya disease have documented that the disease progresses up to adolescence but stabilizes or progresses very slowly after adulthood, and not all patients with moyamoya disease reach ICA stage V or VI (9).

We classified stenoocclusive changes of the PCA in accordance with the classification for the anterior circulation proposed by Suzuki et al (3). Their classification was based on the relationship between stenoocclusive changes of the main trunk and the intensification of and decrease in moyamoya vessels. In brief, collaterals, including moyamoya vessels, initially develop as occlusive changes of the ICA progress, and moyamoya vessels subsequently decrease when occlusive changes of the ICA become extremely severe. Such serial changes have been documented by follow-up angiograms (3). Although our PCA staging was not based on serial angiographic findings, the close relationship between ICA and PCA stages in our study supports that disease severity progresses in the posterior circulation in a similar manner to that in the anterior circulation. With progression of disease, occlusive changes are thought to occur initially in the proximal part of the PCA, with subsequent development of the PCA moyamoya (PCA stage 2) (Fig 2B) followed by gradual progression of stenoocclusive changes in the PCA and intensification of the PCA moyamoya (PCA stage 3) (Fig 3B). Finally, when the PCA is completely occluded, cortical branches are unopacified, and the PCA moyamoya vessels decrease (PCA stage 4) (Fig 4B). The PCA moyamoya probably consists of numerous perforators from the PCA, including the thalamoperforate, thalamogeniculate, and medial and lateral posterior choroidal arteries. When PCA moyamoya develops, anastomoses between the moyamoya vessels and medullary arteries may become apparent, as is often seen in moyamoya from the ICA (10, 11).

The present study documented a changing pattern of the leptomeningeal collaterals from the PCA between ICA stages. They were scanty in ICA stage I and best developed in ICA stages II and III; they decreased with advancement in ICA (from III to VI) and PCA stages. Thus, leptomeningeal collaterals from the PCA that compensate for reduced anterior circulation decrease proportionally with the degree of severity of stenoocclusive ICA changes, which in turn are associated with PCA stage.

Several previous studies have reported that ischemic lesions most often occur in the AWS or PWS (12–14), and a recent study reported that infarctions can also occur in the MCA territory in addition to the AWS and PWS (15). In our series, we found that infarction was most frequent in the AWS, irrespective of ICA or PCA staging. The PWS tended to be preserved in PCA stages 1 and 2 (infarction rate 1%), but showed a high infarction rate (37%) in PCA stages 3 and 4. In PCA stage 1, in which the PCA had no stenoocclusive changes, the leptomeningeal collaterals from the posterior to the anterior circulation were generally well developed (except for the hemispheres in ICA stage I). Consequently, the posterior half of the hemisphere was probably sufficiently supplied by the collaterals. However, the anterior half was supplied by the affected ICA only, making the AWS most hemodynamically vulnerable to infarction. In PCA stages 2 to 4, cerebral infarctions involved the MCA territory as well as the AWS, more frequently and more extensively than in PCA stage 1. These results are concordant with those of Miyamoto et al (6), who found that MCA territory infarctions occur more frequently in hemispheres with advanced stenoocclusive PCA changes than in those with a normal or slightly involved PCA. This may be explained by a decrease in leptomeningeal collaterals from the PCA to the anterior circulation as the PCA stage advances.

The PCA territory was relatively spared until the advanced PCA stages; the territory was infarcted in 8% and 50% of the sides in PCA stages 3 and 4, respectively. In PCA stage 3 sides, cortical branches of the PCA barely supplied the PCA territory. This explains the relative sparing of the PCA

territory in PCA stage 3 sides. When the PCA was completely occluded without opacification of the PCA branches (PCA stage 4), the frequency of infarction in the PCA territory was very high.

The prevalence of cerebral infarction in the ACA territory was unrelated to either the ICA or PCA stages. This may be associated with the frequent development of collaterals from the ophthalmic artery supplying mainly the ACA territory (16, 17). Infarctions in the basal ganglia and thalamus were occasionally found in our series. Their prevalence was also not related to either ICA or PCA stage, as described previously (7).

Cerebral infarctions in the MCA territory, the PWS, or the PCA territory were closely associated with stenoocclusive changes in the PCA. Thus, when we see cerebral infarctions in the MCA territory, stenoocclusive changes in the PCA are highly likely. Stenoocclusive PCA changes are most probable, especially when the PWS and/or PCA territory are involved.

The positive correlation between the number of infarcted regions and ICA and PCA stage indicated a gradual extension of infarction in this disease. As for the pattern of distribution, cerebral infarction may involve the AWS in early stages and extend back to the ant-MCA, post-MCA, PWS, and PCA territories, in that order, although we emphasize that the present study was not based on serial imaging findings. We postulate that the progression of stenoocclusive PCA changes is closely related to such a pattern of development of cerebral infarction.

Yamada et al (7) found that the occurrence of cerebral infarction did not correlate with stenoocclusive ICA changes, but correlated with stenoocclusive PCA changes, although stenoocclusive ICA and PCA changes correlated with each other. In the present series, however, the frequency of cerebral infarction significantly correlated with the severity of both stenoocclusive ICA and PCA changes. This discrepancy between the present study and that of Yamada et al may reflect large difference in the frequency of PCA involvement in the hemispheres with the most advanced ICA stages, as noted above (95% vs 59%).

In the advanced PCA stages, foci of multiple infarctions were scattered and found predominantly in the corticosubcortical regions, typically showing a patchy or honeycomb pattern. The foci did not always follow the normal vasculature, and their distribution pattern differed from that of major cerebral infarctions encountered in routine practice (unrelated to moyamoya disease). The patchy or honeycomb pattern in moyamoya disease may represent an irregular defect in the blood supply provided by leptomeningeal collaterals from the PCA affected by stenoocclusive lesions.

Conclusion

We found that the severity of stenoocclusive lesions in the PCA correlated positively with the severity of the stenoocclusive ICA changes in childhood-onset moyamoya disease. Infarctions tended to be distributed in the anterior borderzone in the less advanced cases, while in the more advanced cases, lesions were additionally found posteriorly in the territory of the middle cerebral artery, the posterior borderzone, and the PCA territory. We postulate that the severity of stenoocclusive PCA changes is closely related to such a pattern of development of cerebral infarction. Despite the general neglect of stenoocclusive PCA changes in the literature, changes in the posterior circulation may be important factors in the development of infarcts in patients with moyamoya disease.

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