Characteristics of vascular lesions in patients with posterior circulation infarction according to age and region of infarct

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Abstract
Patients with posterior circulation infarction underwent CT angiography and magnetic resonance angiography. Intracranial and extracranial vasculopathy was evaluated according to age group and location of stroke. Patients aged > 60 years and < 60 years had similar rates of vertebral artery dominance and vertebrobasilar artery developmental or origin anomalies. Vertebrobasilar artery stenosis or occlusion and tortuosity occurred more frequently in patients aged > 60 years than < 60 years. The rates of vertebrobasilar artery anomalies and tortuosity were high in patients with posterior circulation infarction. Vertebrobasilar artery tortuosity occurred more frequently in patients aged > 60 years, whereas vertebrobasilar artery developmental anomalies occurred with similar frequency in patients aged < 60 years and > 60 years. Patients with infarction of the brainstem or cerebellum were more likely to have vertebral artery stenosis or occlusion, basilar artery stenosis or occlusion, vertebral artery dominance or tortuosity, and basilar artery tortuosity, and patients with infarction of the thalamus, medial temporal, or occipital lobes were more likely to have stenosis or occlusion of the vertebral or basilar arteries. Vertebrobasilar artery tortuosity, vertebral artery dominance (hypoplasia), and congenital variations of the vertebrobasilar system may lead to posterior circulation infarction at different locations in different age groups.

Key Words
vertebrobasilar artery; vertebral artery; acute cerebral infarction; artery tortuosity; magnetic resonance angiography; CT angiography; neuroimaging; neural regeneration

Research Highlights
(1) Patients with posterior circulation infarction had high rates of vertebrobasilar artery developmental anomalies and tortuosity.
(2) Vertebrobasilar artery tortuosity occurred more frequently in patients aged > 60 years whereas vertebrobasilar artery developmental anomalies occurred with similar frequency in patients aged < 60 years and > 60 years.

Abbreviations
PCI, posterior circulation infarction; MRA, magnetic resonance angiography; CTA, CT angiography; DWI, diffusion-weighted imaging.
INTRODUCTION

Posterior circulation infarction (PCI) accounts for 15–20% of all ischemic stroke\[1\]. Vessels of the anterior and posterior circulations differ in congenital variations in blood vessel diameter and distribution are more common in the posterior circulation, including anomalies of the vertebrobasilar artery\[2\]. The diagnosis and management of PCI are complicated, because of the anatomical characteristics of the vertebrobasilar vessels and the complex clinical presentation\[1\]. Magnetic resonance angiography (MRA) and CT angiography (CTA) are reliable, convenient, and minimally invasive investigations which have been extensively used to diagnose PCI.

It is important to use of advances in imaging techniques to investigate etiological factors and pathogenesis in patients with cerebral infarction. This study therefore used current vessel imaging techniques to evaluate associations between developmental anomalies and tortuosity of the posterior circulation vessels, and PCI\[3\].

Clinical studies have shown that vascular stenosis and plaque formation are associated with cerebral infarction, but the high rates of vascular tortuosity and developmental anomalies in patients with infarction have not attracted much attention from physicians who perform imaging examinations\[4\]. Numerous studies have demonstrated that vertebrobasilar artery developmental anomalies and dolichoectasia may cause hemodynamic abnormalities in the posterior circulation, accelerate atherosclerosis, and contribute to the occurrence of PCI\[4-6\]. The prevalence of vascular tortuosity increases substantially with increasing age\[7\].

This study aimed to explore the associations between vascular tortuosity and developmental anomalies, and age and region of infarction, in patients with PCI, using high-field MRI and dual-source 64-slice CT.

RESULTS

Quantitative analysis of subjects

This study recruited 117 patients with acute PCI. Of these, 21 with incomplete imaging data were excluded. A total of 96 patients were included in the final analysis, including 51 males and 45 females aged 31–92 years, with a mean age of 71.6 ± 10.4 years.

Thirty-one patients had hypertension, 24 had diabetes mellitus, 23 had coronary artery disease, 10 had a history of stroke, 16 had hypercholesterolemia, 11 had hypertriglyceridemia, 33 were smokers, and 18 were alcohol drinkers.

Diffusion-weighted MRI and MRA showed brainstem infarction in 51 patients (51/96, 53.1%), cerebellar infarction in 28 patients (28/96, 29.2%), thalamus, medial temporal lobe, or occipital lobe infarction in 11 patients (11/96, 11.5%), and combined infarction in 6 patients (6/96, 6.3%) (Figure 1).

Evaluation for intracranial and extracranial vasculopathy

Of the 96 patients, 54 underwent cranial MRA and cervical contrast enhancement MRA, and 42 underwent cranial and cervical CTA, to determine if there was intracranial or extracranial vasculopathy. Thirteen patients (13.5%) had basilar artery stenosis or occlusion, nine (9.4%) had ≥ 2-level basilar artery tortuosity, and six (6.3%) had other abnormalities including two cases of basilar artery dolichoectasia, two cases of basilar artery developmental anomalies, and two cases of basilar artery fenestration.

Forty-one patients (42.7%) had unilateral vertebral artery stenosis or occlusion, 21 (21.9%) had unilateral or bilateral vertebral artery tortuosity, 23 (23.9%) had vertebral artery dominance, and four (4.2%) had other abnormalities including one case of origin anomaly, one case of vertebral artery dissection, and two cases of bilateral vertebral artery developmental anomalies. Nine patients (9.4%) had unilateral posterior cerebral artery stenosis or occlusion and six (6.3%) had unilateral or bilateral posterior cerebral artery origin anomalies.

Five patients (5.2%) had unilateral or bilateral internal carotid artery stenosis or occlusion and four (4.2%) had severe unilateral or bilateral internal carotid artery tortuosity. No vascular lesion was found in 13 patients (13.5%).

Fifty-eight patients (60.4%) had at least two of the above-mentioned blood vessel abnormalities, including 18 patients (18.8%) with vertebral artery stenosis + vertebral artery occlusion, 14 (14.6%) with abnormal distribution of the vertebral and basilar arteries, 12 (12.5%) with vertebral artery stenosis + basilar artery stenosis, seven (7.3%) with vertebral artery dominance + basilar artery tortuosity or dolichoectasia, and seven (7.3%) with other combined abnormalities (vertebrobasilar artery developmental anomalies, and vertebrobasilar system lesion + internal carotid system lesion).
Blood vessel imaging results according to age group

Patients aged > 60 years (n = 57) and < 60 years (n = 39) had similar rates of vertebral artery dominance and vertebrobasilar artery developmental or origin anomalies (P > 0.05; Table 1).

Vertebrobasilar artery stenosis or occlusion and tortuosity occurred more frequently in patients aged > 60 years than < 60 years (P < 0.05; Table 1).

Blood vessel abnormalities according to infarct region

The rate of basilar artery abnormality was highest in patients with brainstem infarction, the rate of vertebral artery abnormality was highest in patients with cerebellar infarction, and the rate of posterior cerebral artery abnormality was highest in patients with thalamus, medial temporal lobe, or occipital lobe infarction. There were significant differences between patients with brainstem infarction and with cerebellar infarction in the rates of vertebral artery stenosis or occlusion. There were significant differences between patients with thalamus, medial temporal lobe, or occipital lobe infarction and with

Table 1  Vertebrobasilar artery abnormalities [n (%)] according to age group

| Item                                           | > 60 years | < 60 years |
|------------------------------------------------|-----------|-----------|
| n                                              | 57        | 39        |
| Vertebrobasilar artery development or origin anomalies | 8(14.0)  | 5(12.8)   |
| Vertebral artery dominance                      | 14(24.6)  | 9(23.1)   |
| Vertebrobasilar artery stenosis or occlusion    | 39(68.4)  | 15(38.5)* |
| Vertebrobasilar artery tortuosity               | 21(36.8)  | 9(23.1)*  |

n (%) = numbers of patients with abnormal vessels (percentage of the total number of patients). *P < 0.05, vs. patients aged > 60 years (chi-squared test).
combined infarction in the rates of vertebral artery stenosis or occlusion and basilar artery stenosis or occlusion ($P < 0.05$). There were no significant differences between patients with thalamus, medial temporal lobe, or occipital lobe infarction and with combined infarction in the rates of vertebral artery dominance, vertebral artery tortuosity, or basilar artery tortuosity ($P > 0.05$; Table 2).

### Table 2  Vessel abnormalities [n (%)] according to the region of infarction

| Item                        | Brain stem infarction | Cerebellar infarction | Thalamus, medial temporal lobe and occipital lobe infarction | Combined infarction |
|-----------------------------|-----------------------|-----------------------|-------------------------------------------------------------|--------------------|
| n Vertebral artery stenosis or occlusion | 6(11.8)$^a$ | 28(75.0) | 1(9.1)$^b$ | 4(66.7) |
| Basilar artery stenosis or occlusion | 10(19.6)$^a$ | 2(7.1) | 1(9.1)$^b$ | 1(16.7) |
| Vertebral artery dominance | 7(13.7)$^a$ | 13(46.4) | 1(9.1) | 2(33.3) |
| Vertebralbasilar artery tortuosity | 12(23.5)$^a$ | 15(53.6) | 1(9.1) | 2(33.3) |

*n (%) = numbers of patients with abnormal vessels (percentage of the total number of patients). $^a P < 0.05$, vs. patients with cerebellar infarction; $^b P < 0.05$, vs. patients with combined infarction (chi-squared test).

**DISCUSSION**

Vertebrobasilar artery stenosis or occlusion is considered to be the leading cause of PCI$^{[11]}$. Results from this study confirm that vessel stenosis or occlusion is the major cause of PCI, accounting for 42.7% of vertebral artery disease and 13.5% of basilar artery disease. The prognosis of PCI resulting from vertebrobasilar artery stenosis or occlusion is poor. Moufarrij et al.$^{[9]}$ reported a PCI rate of 18% within 6 years in patients with > 50% vertebrobasilar artery stenosis, of which 37% were fatal. Advancements in vessel imaging techniques have shown that vertebral artery dominance or developmental anomalies, basilar artery developmental anomalies, and congenital variations of the vertebrobasilar system are important risk factors for PCI$^{[7, 9-10]}$. Compared with the results of various previous studies$^{[7, 9-10]}$, the rate of vertebral artery abnormalities was high in the present study, which may be due to the broad criteria used for this group, including vertebral artery stenosis or occlusion, vertebral artery dominance ($n = 23$), vertebral artery tortuosity ($n = 21$), and vertebral artery developmental anomalies. These broad criteria were used to enable detailed evaluation. It is important to consider vertebral artery lesions other than stenosis and occlusion that cause hemodynamic changes and subsequent PCI$^{[11]}$.

Basilar artery dolichoectasia is a cerebrovascular disease with unclear pathogenesis and circulatory effects. This condition is characterized by significant prolongation, thickening, and tortuosity of the basilar artery. The etiological factors remain unclear (congenital, acquired, or both)$^{[12]}$. This study explored the strong association between basilar artery tortuosity and PCI. Our results indicate that basilar artery fenestration and developmental anomalies are associated with PCI, especially brainstem and cerebellar infarction. Basilar artery dolichoectasia, tortuosity, and developmental anomalies cause hemodynamic abnormalities resulting in atherosclerotic plaque formation, aneurysm formation, and vascular occlusion. Atherosclerosis promotes vascular tortuosity, and tortuous blood vessels aggravate atherosclerotic lesion formation. Basilar artery dolichoectasia results in slowing of the blood flow and formation of mural thrombus, which may become detached and block the vessel. Basilar artery tortuosity causes compression of the artery and arterioles, resulting in small vessel occlusion$^{[13]}$.

The results of this study show that vertebrobasilar artery tortuosity was significantly more common in patients aged > 60 years than < 60 years, which is consistent with the results of a previous study$^{[13]}$. Previous studies mainly focused on the association between vertebral artery dominance and development anomalies, and PCI$^{[4, 5]}$. The present study explored the strong association between vertebral artery tortuosity and PCI (brainstem and cerebellum). The recovery rate after these infarctions was high. A previous report indicated that congenital developmental anomalies of the arteries could result in multiple small infarctions. Developmental anomalies and vascular tortuosity affected blood flow and caused infarction$^{[14]}$. The prognosis of vertebrobasilar artery tortuosity-induced infarction was good, but the retrospective study did not assess neurological deficit scores or activities of daily living. It is necessary to evaluate vascular tortuosity to detect the causative vessels in patients with PCI. The precise reason for the development of vertebral artery tortuosity remains unclear. Tortuosity often occurs in middle-aged and elderly patients, and is probably associated with decreased vascular elasticity and vascular degeneration$^{[15]}$. These patients often also
have carotid artery tortuosity, aortic tortuosity, and related aneurysm formation\textsuperscript{[16]}. Folding and stenosis may occur in the initial portion of a tortuous vertebral artery\textsuperscript{[16]}. Hemodynamic changes may occur in an excessively tortuous vertebral artery, resulting in PCI\textsuperscript{[16]}. Hypertension contributes to atherosclerosis, vascular aging, and degeneration, and promotes vertebral and basilar artery tortuosity\textsuperscript{[9]}.

In summary, different patterns of blood vessel lesions were detected in PCI patients of different ages and with different infarct regions. Vertebrobasilar tortuosity occurred more frequently in elderly patients with cerebellar or brainstem infarction. Evaluation of the cervical vessels is very important in patients with PCI. Taken together, these results indicate that it is important to increase our understanding of the findings of blood vessel imaging examinations in PCI patients, to increase recognition of the corresponding vascular lesions.

SUBJECTS AND METHODS

Design
Retrospective case analysis.

Time and setting
Inpatients underwent cranial MRI and CTA at the Department of Neurology, Zhengzhou People’s Hospital, China from April 2009 to July 2011.

Subjects
We recruited 117 consecutive patients with acute PCI who were treated at the Department of Neurology, Zhengzhou People’s Hospital, China and underwent MRI using diffusion-weighted imaging. Patients were diagnosed according to the criteria for cerebrovascular disease developed by the Fourth China Cerebrovascular Conference in 1995\textsuperscript{[17]}.

Inclusion criteria
Patients who completed imaging examinations within 1 week following PCI, including cranial MRA and contrast enhanced MRA or CTA of the cranial and cervical arteries.

Exclusion criteria
Probable cardiac embolic source (atrial fibrillation, myocardial infarction within the previous 3 weeks, dilated cardiomyopathy, rheumatic heart disease, or ventricular aneurysm).

Methods

Evaluation for intracranial and extracranial vasculopathy in PCI patients using cranial imaging
MRI was performed using a GE Signa HDX 3.0 Tesla scanner (Fairfield, CT, USA). All patients were diagnosed with acute PCI. Cranial and cervical CTA were performed using dual-source 64-slice CT (Siemens, Munich, Germany). A total of 54 patients underwent cranial MRA and cervical contrast enhancement MRA, and 42 underwent CTA of the cranial and cervical arteries.

Cervical contrast enhancement MRA used gadolinium contrast medium, and CTA of the cranial and cervical arteries used iodinated contrast medium. Imaging results were used to evaluate the degree of vertebrobasilar stenosis, grade of tortuosity, dolichoectasia, and other variations; vertebral artery dominance, stenosis, abnormal distribution, dissection, and other variations; posterior cerebral artery stenosis and other variations; and internal carotid artery disease.

Assessment criteria for abnormal blood vessels
(1) Grade of vertebrobasilar stenosis (judged by a physician from the Department of Imaging) as previously described\textsuperscript{[18]}: ≤ 29% stenosis was defined as mild stenosis, 30–69% was defined as moderate stenosis, and ≥ 70% was defined as severe stenosis or occlusion. In accordance with North American Symptomatic Carotid Endarterectomy Trial method, stenosis was calculated as: (normal diameter at the distal end – narrowest diameter)/ normal diameter at the distal end × 100%.

(2) Assessment of basilar artery dolichoectasia\textsuperscript{[19]}: basilar artery length > 29.5 mm was defined as dolichoectasia. If the transverse displacement from the origin of the basilar artery to the bifurcation was > 10 mm, the basilar artery was considered to be abnormal.

(3) Tortuosity of the initial part of the vertebral artery\textsuperscript{[16]}: tortuosity was defined when cervical contrast enhancement MRA or CTA showed vertebral artery tortuosity (helical, folding, or at least two curves).

(4) Criteria for vertebral artery dominance and tortuosity\textsuperscript{[4]}: dominance was defined when there was a difference of ≥ 0.3 mm between the diameters of the right and left vertebral arteries, or when the vertebral arteries were the same diameter, the vertebral artery on one side tightly connected to the basilar artery, but one was narrow at the origin of the basilar artery. A line drawn from the confluence of the vertebral arteries to the bifurcation of the basilar artery determined the tortuosity and direction of the basilar artery. If there was no confluence of the vertebral arteries visible on MRA, an imaginary line was used to determine basilar artery tortuosity.

(5) Grade of basilar artery tortuosity using cranial MRA or
CTA: in accordance with the criteria of Giang et al., basilar artery tortuosity was divided into three grades: grade 1, doubtful deviation; grade 2, significant deviation; or grade 3, basilar artery inclining to cerebellopontine angle.

**Statistical analysis**

Numerical data were expressed as rates. All data were analyzed using SPSS 13.0 software (SPSS, Chicago, IL, USA). Intergroup differences were compared using the chi-squared test. A value of $P < 0.05$ was considered statistically significant.

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**Ethical approval:** This study was approved by the Medical Ethics Committee, Zhengzhou People’s Hospital, China.

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