Cerebral Blood Flow and Metabolism in Normotensive and Hypertensive Patients With Transient Neurologic Deficits

Kenichiro Fujii, MD, Seizo Sadoshima, MD, Yasushi Okada, MD, Hiroshi Yao, MD, Yasuo Kuwabara, MD, Yuichi Ichiya, MD, and Masatoshi Fujishima, MD

We used positron emission tomography to examine retrospectively the effects of blood pressure on regional cerebral blood flow and oxygen metabolism in seven normotensive and eight hypertensive patients with a history of transient neurologic deficits. In the hypertensive patients, a decrease in regional cerebral blood flow was closely related to blood pressure; these changes were most pronounced in the supratentorial structures, especially the striatum and thalamus. In contrast, the regional cerebral metabolic rate for oxygen was less related to blood pressure. Consequently, the regional oxygen extraction fraction was increased in the hypertensive patients, while regional cerebral blood volume and the regional cerebral blood flow:volume ratio were unchanged. Multivariate regression analysis confirmed that hypertension was an independent factor affecting regional cerebral blood flow. The analysis also disclosed that age, sex, hematocrit, smoking, and Paco₂ affected regional cerebral blood flow. These findings suggest that the hemodynamic reserve in hypertensive individuals is reduced, which may predispose them to cerebral ischemia and perhaps stroke, even during small decreases in cerebral perfusion pressure. (Stroke 1990;21:283–290)
TABLE 1. Clinical and Neuroradiologic Findings in Seven Normotensive and Eight Hypertensive Patients With Histories of Transient Neurologic Symptoms

<table>
<thead>
<tr>
<th>Blood pressure (mm Hg)</th>
<th>Hypertension</th>
<th>Electrocardiography</th>
<th>Antihypertensive treatment on admission</th>
<th>Neuroradiologic findings</th>
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</thead>
<tbody>
<tr>
<td>On admission</td>
<td>On PET study</td>
<td>Ocular fundi</td>
<td>LVH</td>
<td>ST-T change</td>
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</tbody>
</table>

**Normotensive**

<table>
<thead>
<tr>
<th>Pt/age/sex</th>
<th>Transient neurologic deficits</th>
<th>Duration (yr)</th>
<th>Known highest (mm Hg)</th>
<th>S/D</th>
<th>MABP</th>
<th>S/D</th>
<th>MABP</th>
<th>Ocular fundi</th>
<th>LVH</th>
<th>ST-T change</th>
<th>Type</th>
<th>Duration</th>
<th>Mean scoring points (low-density area)</th>
<th>Brain CT</th>
<th>Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/66/M</td>
<td>R numbness</td>
<td></td>
<td></td>
<td>158/70</td>
<td>99</td>
<td>158/84</td>
<td>109</td>
<td>I</td>
<td>+</td>
<td>-</td>
<td>None</td>
<td>0.75</td>
<td>L striatum</td>
<td>BICA and R VA stenosis</td>
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<tr>
<td>2/61/F</td>
<td>Amnesia</td>
<td>0.5</td>
<td>200/110</td>
<td>150/84</td>
<td>106</td>
<td>136/86</td>
<td>103</td>
<td>IIb</td>
<td>-</td>
<td>-</td>
<td>None</td>
<td>1.5</td>
<td>L cerebellum</td>
<td>RICA stenosis</td>
<td></td>
</tr>
<tr>
<td>3/59/F</td>
<td>Amnesia</td>
<td>0.8</td>
<td>200/110</td>
<td>190/84</td>
<td>119</td>
<td>174/88</td>
<td>117</td>
<td>I</td>
<td>-</td>
<td>+</td>
<td>None</td>
<td>1.5</td>
<td>L caudate</td>
<td>Not performed</td>
<td></td>
</tr>
<tr>
<td>4/58/M</td>
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<td></td>
<td></td>
<td>138/86</td>
<td>103</td>
<td>114/70</td>
<td>85</td>
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<td>-</td>
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<tr>
<td>5/62/F</td>
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<td>88</td>
<td>130/76</td>
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<td>-</td>
<td>+</td>
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<td>-</td>
<td>Arteriosclerosis</td>
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<td>104/70</td>
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<td>-</td>
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<td>0.25</td>
<td>-</td>
<td>RICA and L VA stenosis</td>
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<tr>
<td>7/52/M</td>
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<td></td>
<td></td>
<td>130/84</td>
<td>99</td>
<td>110/70</td>
<td>83</td>
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<td>None</td>
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Mean±SD 59±5

94±8 92±11 0.32±0.31

**Hypertensive**

<table>
<thead>
<tr>
<th>Pt/age/sex</th>
<th>Transient neurologic deficits</th>
<th>Duration (yr)</th>
<th>Known highest (mm Hg)</th>
<th>S/D</th>
<th>MABP</th>
<th>S/D</th>
<th>MABP</th>
<th>Ocular fundi</th>
<th>LVH</th>
<th>ST-T change</th>
<th>Type</th>
<th>Duration</th>
<th>Mean scoring points (low-density area)</th>
<th>Brain CT</th>
<th>Angiography</th>
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<tbody>
<tr>
<td>8/64/M</td>
<td>Paraparesis</td>
<td>0.5</td>
<td>200/110</td>
<td>150/84</td>
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<td>IIb</td>
<td>-</td>
<td>-</td>
<td>None</td>
<td>1.5</td>
<td>L cerebellum</td>
<td>RICA stenosis</td>
<td></td>
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<tr>
<td>9/66/M</td>
<td>Amnesia</td>
<td>0.8</td>
<td>200/110</td>
<td>190/84</td>
<td>119</td>
<td>174/88</td>
<td>117</td>
<td>I</td>
<td>-</td>
<td>+</td>
<td>Ca 8</td>
<td>1.5</td>
<td>L caudate</td>
<td>Not performed</td>
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<tr>
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<td>I</td>
<td>-</td>
<td>+</td>
<td>Ca 8</td>
<td>1.5</td>
<td>L caudate</td>
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<tr>
<td>11/70/F</td>
<td>Dizziness, dysarthria</td>
<td>5</td>
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<td>+</td>
<td>-</td>
<td>B-B 10</td>
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<td>101</td>
<td>IIa</td>
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<td>14/61/M</td>
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<td>D 16</td>
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<tr>
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<td>180/90</td>
<td>170/90</td>
<td>117</td>
<td>130/80</td>
<td>97</td>
<td>IIa</td>
<td>-</td>
<td>-</td>
<td>None</td>
<td>1.5</td>
<td>L striatum</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Mean±SD 64±6

110±12* 102±8 1.44±0.18†

Pt, patient; S, systolic blood pressure; D, diastolic blood pressure; MABP, mean arterial blood pressure; PET, positron emission tomography; LVH, left ventricular hypertrophy; CT, computed tomography; M, male; F, female; R, right; L, left; +, presence; -, absence of abnormal findings; Ca, calcium antagonist; B-B, beta blocker; D, diuretics; AC, angiotensin-converting enzyme inhibitor; B, bilateral; ICA, internal carotid artery; VA, vertebral artery.

*tp<0.01, 0.001, respectively, different from normotensive.
events including amnesias, which were defined as transient global amnesia.

Blood pressure was measured by indirect auscultation with the patient in the supine position after at least 10 minutes of rest (Table 1). Laboratory examination included complete blood cell count and serum chemistries, electrocardiography, chest roentgenography, electroencephalography, and brain computed tomography (CT) (TCT 60A, Toshiba Inc., Tokyo, Japan) in all 15 patients. Digital subtraction angiography (Angiotron, Siemens Inc., Erlangen, FRG) of the neck and brain was taken in 14 patients. We included patients with small low-density areas on CT in our study even though these findings were not responsible for the patients' transient neurologic symptoms.

The patients were divided into normotensive and hypertensive groups (Table 1) according to the criteria of mean scoring points.6 History of hypertension, blood pressure on admission and during hospitalization, retinopathy graded by Keith-Wagener-Keidai classification, and electrocardiographic findings were scored from 0 to 3 according to severity, and the total score in each patient was divided by the number of items scored. Patients with a mean score of >1 point were defined as hypertensive, and those with a mean score of ≤1 point were defined as normotensive. Hypertension in all patients was considered to be essential hypertension.

Informed consent was obtained from all patients before the PET study. The interval between the transient neurologic symptoms and the PET study was 1–3 months in all patients. rCBF and regional oxygen extraction fraction (rOEF) were measured by the $^{15}$O continuous infusion method and the $^{15}$O continuous inhalation method, respectively, according to the oxygen-15 steady-state technique described by Frackowiak et al.7 Regional cerebral metabolic rate for oxygen (rCMRO$_2$) was calculated as rCMRO$_2$=rCBF×rOEF×arterial oxygen content. Both rOEF and rCMRO$_2$ were corrected using regional cerebral blood volume (rCBV) measured using a single inhalation of $^{15}$O gas.8 We used a HEADTOME-III device (Shimadzu Inc., Kyoto and Akita Noken, Akita, Japan) with planar and axial resolutions of 8.2 mm full-width at half-maximum and corrected for attenuation by means of a transmission scan using an external germanium-$^{68}$-gallium-$^{68}$ ring source in each patient. During the PET study, each patient was placed in the supine position with the eyes open and the ears unplugged in a dimly lit room. One femoral artery was cannulated to sample blood for radioactive concentration and blood gases. Arterial blood gases were analyzed at the start and end of each scan.

Five slices (20, 35, 50, 65, and 80 mm above the orbitomeatal line) were obtained and imaged in each scan. Regions of interest 18×14 mm were set on the bilateral cerebral cortical areas (frontal, temporal, parietal, and occipital cortices), the bilateral white matter (centrum semiovale) and deep gray matter (striatum and thalamus), the bilateral cerebellar hemispheres, and the brainstem (Figure 1) using the brain CT image corresponding to each PET slice as a reference. Regions of interest were placed to minimize the partial volume effect and the inclusion of other structures and thus represent each anatomic structure appropriately. Brain CT images were also used to avoid placing regions of interest on either infarcted areas or on the ventricles. The values of all pixels within a region of interest were averaged to demonstrate rCBF, rOEF, rCMRO$_2$, and rCBV. In addition, the average value for all four regions of interest on the cerebral cortices was considered to be the mean value for the cortical measures.

Data are given as mean±SD. We compared average rCBF, rOEF, rCMRO$_2$, rCBV, and the rCBF:rCBV ratio in each region of interest between the normotensive and hypertensive groups using Student's small-sample $t$ test and Welch's $t$ test for unequal variances. The relations between MABP on admission or at the PET study and rCBF, rOEF, rCMRO$_2$, and rCBV were evaluated by linear regression analysis. To elucidate the clinical parameters that could influence rCBF, we performed multivariate regression analysis. Parameters were chosen for the multiple regression model by the stepwise forward selection method. We used PaCO$_2$ in our analysis.
TABLE 3. $rCBF$, $rOEF$, $rCMROj$, $rCBV$, and $rCBFrCBV$ Ratio in Six Normotensive and Seven Hypertensive Patients With Transient Neurologic Symptoms

<table>
<thead>
<tr>
<th>Region</th>
<th>Normotensive ($n=7$)</th>
<th>Hypertensive ($n=8$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cholesterol</td>
<td>$230±28$</td>
<td>$240±50$</td>
</tr>
<tr>
<td>Triglyceride</td>
<td>$150±51$</td>
<td>$138±60$</td>
</tr>
<tr>
<td>Fasting blood sugar</td>
<td>$109±28$</td>
<td>$99±10$</td>
</tr>
<tr>
<td>Blood urea nitrogen</td>
<td>$14±5$</td>
<td>$17±5$</td>
</tr>
<tr>
<td>Creatinine</td>
<td>$1.1±0.2$</td>
<td>$1.1±0.3$</td>
</tr>
<tr>
<td>Blood chemistry (mg/dl)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$PaCO_2$ (mm Hg)</td>
<td>$40.2±2.2$</td>
<td>$40.0±4.1$</td>
</tr>
<tr>
<td>$Pao_2$ (mm Hg)</td>
<td>$75.5±7.2$</td>
<td>$78.4±11.9$</td>
</tr>
<tr>
<td>PH</td>
<td>$7.42±0.02$</td>
<td>$7.42±0.03$</td>
</tr>
<tr>
<td>Hemoglobin concentration (g/dl)</td>
<td>$13.7±1.2$</td>
<td>$13.2±1.2$</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>$42.2±4.8$</td>
<td>$40.3±3.4$</td>
</tr>
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</table>

Values are mean±SD, except for risk factors, which are number of patients.

Table 2 depicts the group means for serum chemistries and the incidence of smoking and drinking habits on admission. The average values for arterial blood gases, arterial pH, hemoglobin, and hematocrit measured during the PET study are also listed in Table 2; all were within normal ranges. None of these values differed significantly between the groups.

Table 3 depicts the group means for $rCBF$, $rOEF$, $rCMROj$, $rCBV$, and the $rCBF$: $rCBV$ ratio at 10 brain regions in the two groups. The values of the cerebral cortices differed significantly between the groups. MABP on admission was significantly higher in the hypertensive than in the normotensive group (Table 1). Three of the eight hypertensive patients (10, 12, and 14) had received antihypertensive treatment, and after admission the treatment was continued in patient 10 but was stopped in patients 12 and 14. Blood pressure in the normotensive patients changed very little after admission, while that in the hypertensive patients tended to decrease; the difference in MABP between the groups became nonsignificant by the time of the PET study. Mean scoring points for the normotensive and hypertensive groups averaged 0.32 and 1.44, respectively. Electroencephalograms showed no focal or diffuse abnormalities. Brain CT revealed very small low-density areas in one normotensive and three hypertensive patients. Angiography disclosed stenosis of the major arteries or diffuse arteriosclerosis in three normotensive and four hypertensive patients. The degree of stenosis of all these vessels was <50% of the lumina. The incidences of abnormal findings on CT and angiography did not differ significantly between the groups.

Results

Table 1 summarizes the clinical and neuroradiologic findings in the seven normotensive and the eight hypertensive patients. Age and sex ratio did not differ between the groups. MABP on admission was significantly higher in the hypertensive than in the normotensive group (Table 1). Three of the eight hypertensive patients (10, 12, and 14) had received antihypertensive treatment, and after admission the treatment was continued in patient 10 but was stopped in patients 12 and 14. Blood pressure in the normotensive patients changed very little after admission, while that in the hypertensive patients tended to decrease; the difference in MABP between the groups became nonsignificant by the time of the PET study. Mean scoring points for the normotensive and hypertensive groups averaged 0.32 and 1.44, respectively. Electroencephalograms showed no focal or diffuse abnormalities. Brain CT revealed very small low-density areas in one normotensive and three hypertensive patients. Angiography disclosed stenosis of the major arteries or diffuse arteriosclerosis in three normotensive and four hypertensive patients. The degree of stenosis of all these vessels was <50% of the lumina. The incidences of abnormal findings on CT and angiography did not differ significantly between the groups.

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Table 4. Correlation Coefficients for rCBF, rOEF, rCMRO₂, rCBV, and rCBF:rCBV Ratio vs. Mean Arterial Blood Pressure on Admission in 13 Patients With Transient Neurologic Symptoms by Brain Region

<table>
<thead>
<tr>
<th>Supratentorial structures</th>
<th>Cerebral cortices</th>
<th>Deep gray matter</th>
<th>White matter</th>
<th>Infratentorial structures</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frontal</td>
<td>Temporal</td>
<td>Parietal</td>
<td>Occipital</td>
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<tr>
<td>rCBF* 30</td>
<td>-0.327</td>
<td>-0.580†</td>
<td>-0.521†</td>
<td>-0.570†</td>
</tr>
<tr>
<td>rOEF 26</td>
<td>0.480†</td>
<td>0.626†</td>
<td>0.559†</td>
<td>0.521†</td>
</tr>
<tr>
<td>rCMRO₂ 26</td>
<td>-0.206</td>
<td>-0.424‡</td>
<td>-0.422‡</td>
<td>-0.375</td>
</tr>
<tr>
<td>rCBV 26</td>
<td>-0.006</td>
<td>0.165</td>
<td>0.025</td>
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<tr>
<td>rCBF:rCBV 26</td>
<td>-0.234</td>
<td>-0.370</td>
<td>-0.342</td>
<td>-0.328</td>
</tr>
</tbody>
</table>

rCBF, regional cerebral blood flow; rOEF, regional oxygen extraction fraction; rCMRO₂, regional cerebral metabolic rate for oxygen; rCBV, regional cerebral blood volume; n, number of regions of interest. Data are values of r for n regions of interest, except for brainstem, which are values of r for number of patients.

*Data for 15 patients.
†p<0.01, 0.05, respectively, different from 0.

latter four measures for two patients (one normoten-

dising and one hypertensive) were excluded because of

inappropriate head position during the PET study. rCBF and rCMRO₂ in the hypertensive group were

lower than in the normotensive group, and the differ-

cence was significant in the frontal cortex for rCBF

and in the striatum and thalamus for both rCBF and

rCMRO₂. In contrast, rOEF in the hypertensive

group was significantly higher than in the normoten-

give group in all regions except the brainstem. rCBV

in the cerebral cortices and cerebellum were virtually

the same in the two groups. The rCBF:rCBV ratio

was slightly lower in the hypertensive than in the

normotensive group, but the values in both groups

were higher than the 5.5–6.0 thought to be the lower

limit of autoregulation.⁹

Table 4 shows the correlation coefficients (r) for

rCBF, rOEF, rCMRO₂, rCBV, and the rCBF:rCBV

ratio versus MABP on admission for the two groups

combined. Regions of interest for both hemispheres

were considered. Among the supratentorial struc-

tures, highly significant inverse correlations were

present between rCBF and MABP for all except the

frontal cortex. Similarly, rOEF was significantly

correlated with MABP in all supratentorial structures.

On the other hand, significant but weaker inverse

correlations were observed between rCMRO₂ and

MABP in the temporal and parietal cortices, the

thalamus, and the white matter. rCBV was signifi-

cantly (inversely) correlated with MABP only in the

white matter. The rCBF:rCBV ratio tended to

decrease with rising MABP, but the correlations

were not significant in any region. Among the infrat-

tentorial structures, there were no significant corre-

lations between MABP and any of these five mea-

sures. The relations between MABP and rCBF,

rOEF, and rCMRO₂ are shown in Figure 2.

The relation between rCBF and MABP on the day

of the PET study also revealed a highly significant

inverse correlation in the thalamus (r = -0.498,

p<0.01) but not in the other regions.

Table 5 depicts the standardized multiple regres-

sion coefficients for various clinical parameters ver-

sus rCBF. Age, male sex, and hematocrit were neg-

atively correlated with rCBF in the cerebral cortices

and white matter. Smoking was negatively correlated

with rCBF in the cerebral cortices and the thalamus.

MABP was also negatively and strongly correlated

with rCBF in the parietal and occipital cortices, the

striatum, and the thalamus. The correlation between

total cholesterol, triglyceride, or fasting blood sugar

concentrations and rCBF was relatively weak and

differed from region to region. On the other hand,

alcohol drinking was positively correlated with mean

cortical rCBF and with rCBF in the occipital cortex.

There was also a positive correlation between Paco₂

and rCBF in the cortices, the striatum, the white

matter, and the brainstem.

Discussion

There are several limitations to interpreting our

results. The design of our study has its major disad-

vantage in the retrospective selection of patients and

their matching between groups. Multivariate regres-

sion analysis was necessary because we could not

exclude hypertensive patients with other risk factors

for stroke from the study due to the overall limited

number of patients. In addition, lack of magnetic

resonance imaging restricted our information about

underlying tissue changes such as white matter dis-

ease. Finally, our patients had a history of transient

neurologic deficits so our results cannot necessarily

be generalized to asymptomatic hypertensive per-

sons. Even considering these limitations, our study

has disclosed several interesting relations between

blood pressure and regional cerebral circulation and

metabolism.

rCBF was decreased in the hypertensive patients,

and the decrease was closely related to MABP. In

contrast, rCMRO₂ was less closely related to MABP.

Consequently, the brain in hypertensive individuals

extracts more oxygen from the blood (increased

rOEF) to maintain rCMRO₂, while rCBV and the

rCBF:rCBV ratio were unchanged. In addition,

interesting differences among brain regions were

disclosed. The relations of MABP with rCBF, rCMRO₂

was pronounced in the supratentorial struc-
Hypertension has been shown to be an important risk factor for reduced CBF among neurologically normal volunteers\textsuperscript{10} and among patients with transient ischemic attacks.\textsuperscript{11} An autopsy study in Hisayama, Japan,\textsuperscript{12} has shown that cerebral atherosclerosis occurs 20–30 years earlier in hypertensive than in normotensive patients.

**TABLE 5. Standardized Multiple Regression Coefficients for Clinical Parameters vs. Regional Cerebral Blood Flow in 15 Patients With Transient Neurologic Symptoms**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cerebral cortices</th>
<th>Deep gray matter</th>
<th>White matter</th>
<th>Infratentorial structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frontal</td>
<td>Temporal</td>
<td>Parietal</td>
<td>Occipital</td>
</tr>
<tr>
<td>Age (yr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male sex (yes)</td>
<td>-0.580*</td>
<td>-0.404†</td>
<td>-0.822*</td>
<td></td>
</tr>
<tr>
<td>Mean arterial blood pressure</td>
<td>-0.454‡</td>
<td>-0.614*</td>
<td>-0.621*</td>
<td>-0.680‡</td>
</tr>
<tr>
<td>Mean arterial blood pressure</td>
<td>-0.362†</td>
<td>-0.615*</td>
<td>-0.807*</td>
<td>-0.669*</td>
</tr>
<tr>
<td>Total cholesterol (mg/dl)</td>
<td>-0.234†</td>
<td>0.281‡</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triglyceride (mg/dl)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting blood sugar (mg/dl)</td>
<td>0.267‡</td>
<td>0.286‡</td>
<td>-0.420‡</td>
<td></td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>-0.398‡</td>
<td>-0.493*</td>
<td>-0.673*</td>
<td>-0.969*</td>
</tr>
<tr>
<td>Smoking (yes)</td>
<td>-0.424‡</td>
<td>-0.455‡</td>
<td>-0.393*</td>
<td>-0.327†</td>
</tr>
<tr>
<td>Drinking (yes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PacO\textsubscript{2} at PET study</td>
<td>0.237†</td>
<td>0.313†</td>
<td>1.183*</td>
<td>0.545†</td>
</tr>
</tbody>
</table>

PET, positron emission tomography. Values are \( r \) for 30 regions, except for brainstem, which are \( r \) for 15 patients. Only significant values are indicated.

*\( \alpha p < 0.001, 0.05, 0.01 \), respectively, different from 0.
ously hypertensive rats, it was suggested that thickening of the arterial wall at the terminal stage of severe hypertension caused an irreversible and severe decrease in rCBF. These findings suggest that rCBF is markedly influenced by structural vascular changes promoted by hypertension. Our patients had histories of transient signs of neurologic deficits and were considered to have advanced vascular changes. Thus, our hypertensive patients might have lower rCBF than asymptomatic hypertensive individuals.

Interestingly, the correlation between MABP on the day of the PET study and rCBF was weak and nonsignificant except in the thalamus. The blood pressure of hypertensive patients usually falls after hospital admission, although the mechanism is not fully understood. Restriction of sodium intake to 137–171 meq/day with the Japanese average daily sodium intake of 222–256 meq/day and bed rest during hospitalization may be part of the reason for the decline in blood pressure. Thus, the lack of a significant relation between rCBF and MABP on the day of the PET study seems to be due to narrowing of the MABP range by a spontaneous decline in blood pressure after hospital admission. The reason why a significant correlation was observed only in the thalamus is unclear.

The above-mentioned reduction in MABP might reduce cerebral perfusion pressure and CBF in hypertensive individuals in whom the autoregulatory curve is shifted to the right, especially patients receiving antihypertensive treatment. In such patients with hemodynamic failure, the cerebral vessels usually dilate and increased rCBV and a decreased rCBF:rCBV ratio are expected in addition to an increased rOEF. However, neither rCBV nor the rCBF:rCBV ratio in our hypertensive group differed from those in the normotensive group. The absence of increased rCBV and a decreased rCBF:rCBV ratio despite increased rOEF and similar MABP during the study in our patients with chronic hypertension rather suggests a baseline narrowing of vessel lumen, probably due to either advanced arteriosclerosis or excess vasoconstriction.

The differences in rCBF and rCMRO<sub>2</sub> between our normotensive and hypertensive groups were more pronounced in the deep gray matter, that is, in the striatum and thalamus, than in the cerebral cortices. In the deep gray matter, the reduced rCMRO<sub>2</sub> in the hypertensive group seemed not to be effectively compensated for in spite of increased rOEF. The increased rOEF, including measurements in two hypertensive patients with deep-seated small lesions proven by CT, minimizes the possible effects of infarction, where matched hypoperfusion is expected. The absence of increased rCBV and a decreased rCBF:rCBV ratio in the deep gray matter as in the cerebral cortices suggests a minimal contribution of the reduction in MABP after admission in patients with hypertension to the greater reduction in rCBF. Also, it is well known that systemic hypoten-

sion and/or arterial occlusive disease in the neck mainly produce ischemic lesions in arterial border zone territories and not in the deep gray matter. A greater reduction of rCBF within the striatum and thalamus suggests that hypertensive vascular alterations occurred more markedly and selectively with elevated vascular resistance in the deep structures of the brain. The striatum and thalamus are the areas most susceptible to lacunar thrombotic infarction. Since their small branches are separated directly from the main trunks of the middle cerebral artery or the posterior cerebral artery, high intraluminal pressure is conducted directly to the vessel wall, which may lead to intimal thickening, angionecrosis, and the formation of fibrous nodules. In contrast, the relation of MABP with rCBF and rCMRO<sub>2</sub> was obscure in the infratentorial structures, especially the cerebellum. Less marked arteriosclerosis in the cerebellum might account for this finding.

After multivariate regression analysis, strong negative correlations between MABP on admission and rCBF were still present in the striatum, the thalamus, and the parietal and occipital cortices. In several supratentorial structures, age, male sex, hematocrit, and smoking habits were negatively correlated with rCBF. These factors are risk factors for stroke, and our results suggest that they could also affect rCBF. In other studies, similar effects of sex and smoking on CBF are also shown. In our study, there were more smokers among the hypertensive than among the normotensive patients. Although this difference was not significant, it might be responsible in part for the greater reduction in rCBF in our hypertensive group. Hematocrit is a major determinant of blood viscosity and plays an important role in regulating CBF. Our results also support this concept.

In conclusion, patients with chronic hypertension had lower rCBF and higher rOEF than normotensive patients despite similar perfusion pressures (the rCBF:rCBV ratio). These findings suggest that hypertensive individuals have reduced hemodynamic reserve and are more susceptible to cerebral ischemia and perhaps to stroke during small reductions in cerebral perfusion pressure. One implication of these findings is that care should be taken in such individuals to avoid reductions in cerebral perfusion pressure, especially during antihypertensive treatment.

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