Blood pressure in the artery distal to an intraarterial embolus during thrombolytic therapy for occlusion of a major artery: a predictor of cerebral infarction following good recanalization

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**Object.** The aim in this study was the investigation of back pressure in arteries distal to the occlusion site during intraarterial thrombolysis as well as the usefulness of back pressure measurement in combination with diffusion-weighted (DW) magnetic resonance (MR) imaging to predict the occurrence of ischemic lesions following good recanalization.

**Methods.** Twenty-five consecutive patients with severe hemiparesis caused by embolism of the internal carotid artery (10 patients) and the proximal middle cerebral artery (15 patients) were treated using intraarterial thrombolysis. Systolic back pressure, measured through a microcatheter in the artery just distal to the emboli, ranged from 22 to 78 mm Hg. According to an angiographic inclusion criterion for good recanalization—that is, recanalization of the M or more distal arteries at the end of thrombolysis—21 of 25 patients underwent evaluation in this study. In 14 patients volumes of low-density areas on computerized tomography (CT) scans obtained 2 months postthrombolysis were smaller in comparison with volumes of hyperintense areas on DW MR images acquired before treatment, whereas these low-density areas were larger in seven patients. Compared with those on initial DW MR images, the volume of abnormalities on CT scans obtained 2 months posttreatment were significantly reduced in patients with a systolic back pressure greater than 30 mm Hg (16 patients) than in those with a back pressure of 30 mm Hg or less (five patients) (p < 0.05). Systolic back pressures greater than 30 mm Hg were associated with significantly better modified Rankin Scale scores than those 30 mm Hg or less (p < 0.05).

**Conclusions.** Back pressure measurement in combination with DW MR imaging can be used to predict the occurrence of infarction as demonstrated on CT scans following thrombolysis.

**KEY WORDS** • back pressure • diffusion-weighted imaging • fibrinolysis • magnetic resonance imaging • stump pressure

Diffusion-weighted MR imaging, which can display focal brain abnormalities during the early stages of ischemia, is one of the most widely used tools for predicting infarction in a clinical setting. The hyperintense areas on DW MR images are assumed to indicate irreversible injury; therefore, large areas of abnormality on such images are regarded as an exclusion criterion for intraarterial thrombolysis in cerebral ischemia. Hyperintense areas on initial DW MR images have been reported to normalize later in some cases of transient ischemic attack and postthrombolytic therapy, when early recanalization occurred. Nonetheless, no accurate indicator of the reversal of abnormalities on early DW MR images has been investigated. A good correlation reportedly exists between the stump pressure in the distal ICA during CEA and the incidence of postoperative neurological complications.

We have reported the clinical usefulness of blood pressure measurement through a microcatheter in arteries feeding cerebral arteriovenous malformations and in cerebral aneurysms during intravascular surgery. To the best of our knowledge no prior study has been published in which back pressure was evaluated in intracranial arteries distal to the site of occlusion in cerebral ischemia. In this study, however, we measured the back pressure in arteries just distal to emboli by using a microcatheter during thrombolytic therapy for an embolism in a major cerebral artery.

Our purpose in this study was the investigation of both the back pressure in arteries just distal to the occlusion site during intraarterial thrombolysis and the usefulness of back pressure measurement in predicting tissue damage after good recanalization as an adjunct to DW MR imaging. In analyzing the latter, we compared hyperintense areas on initial DW MR images with low-density areas on CT scans obtained after sufficient recanalization through thrombolysis. We then evaluated the relationship between back pressure and the changes in ischemic lesion volumes obtained during the comparison.

Abbreviations used in this paper: ADC = apparent diffusion coefficient; CEA = carotid endarterectomy; CT = computerized tomography; DW = diffusion-weighted; ICA = internal carotid artery; MCA = middle cerebral artery; MR = magnetic resonance; mRS = modified Rankin Scale.
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Clinical Material and Methods

Patient Population

Between April 2001 and June 2004, 25 consecutive patients (15 men and 10 women) younger than 85 years of age (mean age ± standard deviation 73.4 ± 8 years, range 56–84 years) who had experienced the sudden onset of severe hemiparesis as well as gaze palsy to the hemiparetic side within the last 4 hours of hospital admission were treated using intraarterial thrombolysis. All patients suffered from cerebral ischemia caused by occlusion of a major artery. Ten patients had blockage of the terminal ICA, and 15 of the proximal MCA. The patients’ initial neurological status, rated according to the National Institutes of Health Stroke Scale3 ranged from 16 to 28 (mean 21.8 ± 4). Computed tomography scanning was performed in all patients. Magnetic resonance imaging was performed a mean of 40.6 ± 49.4 minutes (range 45–225 minutes) after the onset of symptoms. Intraarterial thrombolysis with mechanical disruption, via a microcatheter and a guidewire, was started from 60 to 255 minutes (mean 121 ± 52.1 minutes) after the onset of symptoms. The details of thrombolysis with mechanical disruption have been described previously.11 During this procedure blood pressure was measured in the intracranial arteries just distal to the emboli. Thrombolysis was completed in 130 to 360 minutes (mean 209.8 ± 56.1 minutes). Arterial pressure just distal to the embolus was measured using digital subtraction angiography at the end of thrombolytic therapy. The angiographic recanalization criterion for good recanalization in this study was recanalization of the M1 or more distal arteries. Occlusion of either the M1 portion of the MCA or the ICA on angiography at the end of the procedure was regarded as insufficient recanalization, and the patient was excluded from further study. Computerized tomography scanning was performed 2 months after treatment. Patient outcome at 3 months after treatment was assessed according to the mRS.35 Our study protocol was approved by the institutional review committee of our facility, and informed consent was obtained from each patient’s family members.

Imaging Methods

Magnetic resonance imaging studies were performed using a 1-tesla unit (Signa; General Electric, Waukesha, WI) with a birdcage headcoil. In each case, DW MR imaging was performed using diffusion gradients in three orthogonal directions, with a maximal b value of 1000 seconds/mm². The DW MR imaging studies were performed using a single-shot, multislice, spin echo–echo planar imaging sequence with the following parameters: TR 5000 msec, TE 120 msec, flip angle 90°, matrix size 128 × 128, and field of view 22 × 22 cm. Nineteen axial sections with a thickness of 6 mm and an intersection gap of 1 mm were obtained.

For CT studies we used a scanner (HiSpeed DX/I; General Electric) according to the following parameters: 120 kV, 220 mA, matrix size 512 × 512, section thickness 5 mm, and field of view 25 × 25 cm.

In each case lesion volumes on DW MR images obtained on admission were identified through visual inspection for regions of hyperintensity and then were measured by outlining regions of interest by hand with the aid of an image analysis system. The final lesion volume was calculated by multiplying the area obtained from each section by the slice thickness. If multiple scattered or noncontiguous abnormalities were noted, volumes were calculated by summing the individual volumes of all abnormal lesions. The volumes of newly developed lesions that appeared on CT scans 2 months after treatment compared with admission scans were calculated using the same method as that used for DW MR imaging. A change in lesion volume was expressed as an improvement in ischemic volume, or an index of radiological improvement following recanalization, and was calculated according to the following equation: (volume of hyperintense areas on the initial DW MR image – volume of low-density areas on the CT scan obtained 2 months posttreatment)/volume of hyperintense areas on the initial DW MR image. A positive value indicated shrinkage of the ischemic lesion, whereas a negative value signified expansion (deterioration). Regional distribution of the ischemic lesions was evaluated on both initial DW MR images and CT scans 2 months after treatment.

Blood Pressure Measurement

A microcatheter (Renegade-18; Boston Scientific, Natick, MA) was introduced beyond the embolus. Superselective angiography studies were performed through a microcatheter to assess the precise site of occlusion and the size of the embolus. Arterial pressure just distal to the embolus was measured by connecting the microcatheter to a pressure transducer (model DX-312; Nihon Koden Corporation, Tokyo, Japan) and a digital pressure monitor (model KC-013P; Nihon Koden Corporation).32,33 When the distal end of the embolus was located in the M1 portion of the MCA, blood pressure was measured in the M1 supplying mainly the parietal lobe. Systolic blood pressure, that is, systolic back pressure, was used in this study.

Statistical Analysis

Statistical evaluation was performed using the Mann–Whitney U-test for between-group comparisons. A probability value less than 0.05 was considered statistically significant.

Results

The clinical characteristics of all 25 patients are presented in Table 1. In each patient hyperintense areas were demonstrated on initial DW MR images. Systolic back pressure ranged from 22 to 78 mm Hg (mean 39.5 ± 14.1 mm Hg). Two patients died: one (Case 3) of thrombocytopenia 7 days after treatment and another (Case 19), in whom the M1 occlusion remained after thrombolysis, of transtentorial herniation 6 days after thrombolysis. The occluded vessels were recanalized in 24 patients; in only one patient (Case 7) with a right C1 occlusion was the procedure discontinued without recanalization. In two patients (Cases 18 and 19), including one who died, the M1 portion of the MCA was the occlusion site demonstrated on angiograms obtained immediately after thrombolysis. Four patients were excluded from analysis: two (Cases 3 and 19) who died and two (Cases 7 and 18) who survived with insufficient recanalization. In the remaining 21 patients with good recanalization, hyperintense areas on initial DW MR images were com-
Thrombolysis with improved just distal to the occlusion. Thrombolysis with illustrates the relationship be-

Improvement in patients with a back pressure of 30 mm Hg or less (five patients; p < 0.05). One patient with improvement had an mRS score of 4 because of a leg embolism; the remaining 13 patients with improvement had an mRS score of 3 or better. Figure 2 right illustrates the relationship between systolic back pressure and mRS score. Patients with systolic back pressure greater than 30 mm Hg (16 patients) a significantly better mRS score was demonstrated than in those with a back pressure of 30 mm Hg or less (five patients; p < 0.05).

**Illustrative Cases**

**Case 2**

This 81-year-old woman with a history of arterial fibrillation presented to the emergency room 40 minutes after the acute onset of aphasia and right hemiplegia. Emergent DW MR imaging performed 60 minutes after onset revealed hypointense areas in the left frontal and parietal regions and the insula (Fig. 3A). Angiography confirmed the left M1 occlusion (Fig. 3B). Systolic back pressure was 27 mm Hg in the M1 just distal to the occlusion. Thrombolysis with

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Initial Occlusion Site</th>
<th>Time From Symptom</th>
<th>Occlusion Site After Thrombolysis</th>
<th>Systolic Back Pressure (mm Hg)</th>
<th>Vol of HIA on Initial DWI (ml)</th>
<th>State of Ischemic Vol</th>
<th>mRS Score at 3 Mos Posttreatment</th>
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<td>1</td>
<td>70, F</td>
<td>rt M1, proximal</td>
<td>160</td>
<td>none</td>
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<td>2</td>
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<td>180</td>
<td>temporal M1</td>
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<td>−1.54</td>
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<td>240</td>
<td>M1</td>
<td>59</td>
<td>97</td>
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<td>330</td>
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<td>64</td>
<td>−1.31</td>
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<td>parietotemporal M1</td>
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<td>230</td>
<td>parietal M1</td>
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<td>137</td>
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<td>M1 middle</td>
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<td>33</td>
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<td>68, F</td>
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<td>M1 middle</td>
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<td>144</td>
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<td>lt M1, proximal</td>
<td>150</td>
<td>frontal M1</td>
<td>78</td>
<td>17</td>
<td>0.65</td>
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<tr>
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<td>74, M</td>
<td>rt M1, proximal</td>
<td>360</td>
<td>frontal M1</td>
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<td>4</td>
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<tr>
<td>22</td>
<td>80, F</td>
<td>lt M1, distal</td>
<td>270</td>
<td>none</td>
<td>32</td>
<td>37</td>
<td>0.92</td>
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<td>23</td>
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<td>rt M1, proximal</td>
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<td>22</td>
<td>96</td>
<td>−0.17</td>
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<td>24</td>
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<td>25</td>
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<td>lt M1, proximal</td>
<td>150</td>
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<td>33</td>
<td>33</td>
<td>0.85</td>
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</table>

* DWI = DW imaging; HIA = hyperintense area; — = not applicable.
mechanical disruption was performed, and almost complete recanalization was achieved 180 minutes after symptom onset (Fig. 3C). No remarkable change in symptoms was observed after the procedure. A CT scan obtained 2 months postthrombolysis demonstrated low-density areas in the left temporal region and the corona radiata; lesions had not been demonstrated at these sites on initial MR imaging (Fig. 3D).

Case 4

This 70-year-old man with a history of arterial fibrillation presented to the emergency room 60 minutes after the acute onset of left hemiplegia. Emergency DW MR imaging performed 80 minutes after onset revealed hyperintense areas in the right frontal region, putamen, and corona radiata (Fig. 4A). Angiography confirmed the right M1 occlusion (Fig. 4B). Systolic back pressure was 34 mm Hg in the M2 just distal to the occlusion. Thrombolysis with mechanical disruption was performed, and complete recanalization was achieved more than 300 minutes after the onset of the ischemia.

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**TABLE 2**

Regional distribution of ischemic lesions in 14 patients whose lesion volume improved

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of HAs on Initial DWI</th>
<th>No. of LDAs on CT*</th>
<th>% Amelioration of Ischemic Regions</th>
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<tr>
<td>frontal region</td>
<td>10</td>
<td>8</td>
<td>20</td>
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<tr>
<td>parietal region</td>
<td>7</td>
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</tr>
<tr>
<td>temporal region</td>
<td>8</td>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>putamen</td>
<td>6</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>corona radiata</td>
<td>9</td>
<td>3</td>
<td>67</td>
</tr>
<tr>
<td>insula</td>
<td>5</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>internal capsule</td>
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<td>0</td>
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</tr>
</tbody>
</table>

* The CT scans were obtained 2 months posttreatment. Abbreviation: LDA = low-density areas.
Fig. 3. Case 2. Images demonstrating an increased lesion volume. A: Diffusion-weighted MR images obtained on admission, revealing hyperintense areas in the left frontal and parietal regions and the insula. B: Left ICA angiograms demonstrating occlusion of the M1 portion of the MCA (left, anteroposterior view; right, lateral view). C: Left ICA angiograms obtained immediately after thrombolysis (left, anteroposterior view; right, lateral view). The MCA is almost completely recanalized. D: Computed tomography scans obtained 2 months posttreatment, exhibiting low-density areas in the left frontal, parietal, and temporal regions and insula and corona radiata.
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Fig. 4. Case 4. Images demonstrating an improved lesion volume. A: Diffusion-weighted MR images obtained on admission, revealing hyperintense areas in the right frontal region, corona radiata, and putamen. B: Right ICA angiograms displaying occlusion of the M1 portion of the MCA (left, anteroposterior view; right, lateral view). C: Right ICA angiograms obtained immediately after thrombolysis (left, anteroposterior view; right, lateral view). The MCA is completely recanalized. D: Computerized tomography scans obtained 2 months posttreatment, exhibiting a low-density area in the right putamen.
achieved 165 minutes after symptom onset (Fig. 4C). All symptoms resolved after the procedure. A CT scan obtained 2 months later exhibited a low-density area in the right putamen (Fig. 4D). Ischemic lesions in the frontal region and corona radiata, which had been demonstrated on the initial DW MR image, did not appear on the CT scan.

Discussion

To our knowledge this is the first published study on back pressure measurement during intraarterial thrombolysis. Systolic back pressure ranged from 22 to 78 mm Hg.

Reversible DW MR Image Abnormality

The area of lowered perfusion-weighted and normal DW MR images (DW MR image/perfusion-weighted MR image mismatch) is an index of the penumbra, or tissue that has potentially reversible ischemia. Normalization of the DW MR image abnormality after early recanalization has been reported in clinical studies on both transient ischemic attack and thrombolytic therapy, and in animal studies. Moseley, et al. speculated that the decrease in the ADC resulting in hyperintensity on DW MR images is related to cytotoxic edema. Acute energy and ionic failure, which results in cytotoxic edema, does not per se indicate irreversible damage and may in part recover even after prolonged ischemia. No accurate method of predicting reversible DW MR imaging abnormalities in the early ischemic period has been reported. Note that ADC mapping is a useful tool in predicting the development of infarction in cases of prolonged occlusion. When early recanalization occurs, however, ADC decreases do not reliably indicate tissue infarction. Even severely decreased ADC values have been reported to normalize in the context of strokes in humans following early recanalization through thrombolytic therapy. In addition, a significant decrease below a specific ADC threshold value is not necessarily associated with histological changes in animal experiments. With sustained ischemia, both the magnitude of the ADC reduction and the size of the abnormality on DW MR imaging generally increase with time. Diffusion-weighted MR imaging performed immediately after admission does not seem to indicate accurately the condition of ischemic tissue immediately before recanalization and during treatment because of the time lag. The occurrence of infarction in brain tissue exposed to local anemia depends on the duration and severity of the ischemia. In this study back pressure was used as an index for the severity of ischemia. Back pressure values do not seem to change remarkably over time unless collateral circulation isagrivated by thrombus extension and/or edema development. After a change in intensity on DW MR images caused by acute energy and ion failure (ischemic depolarization), neuronal death occurs if the ischemia continues. An interval between ischemic depolarization and neuronal death might be longer in ischemia with high back pressure in comparison to ischemia with low back pressure because of good collateral circulation.

Back Pressure Measured in an ICA Distal to Occlusion

Back pressure in a completely occluded artery is mainly determined by back flow via collateral circulation. The following factors are considered to affect collateral circulation:
ed MR imaging is more sensitive than CT scanning for the detection of ischemic lesions. In comparison with CT scanning, T2-weighted MR imaging takes a longer time period and tends to display motion artifacts. Patients with occlusion of a major artery are often restless; therefore, in this study we used CT scanning rather than T2-weighted MR imaging. Newly developed ischemic lesions can be confirmed by comparing CT scans obtained on admission and those obtained 2 months after thrombolytic therapy. Selective neuronal loss has been observed in regions of normal-ap-
tearing T2 signal on postischemic MR images. Neither CT scanning nor T2-weighted MR imaging can accurately demon-
strate the true extent of neuronal damage. In this study, patients whose CT scans had revealed a reduction in ischemic lesions experienced significantly better outcomes than those whose scans demonstrated enlargement. This result indicates that CT scanning is an appropriate tool for evaluating ischemic damage with regard to clinical impairment.

Conclusions
Back pressure values, measured through a microcatheter during intraarterial thrombolysis, ranged from 22 to 78 mm Hg in this study. Back pressure measurements in combina-
tion with DW MR imaging could predict the development of infarction following thrombolysis. Thus, back pressure values might indicate appropriate strategies during intra-
arterial thrombolysis.

Acknowledgment
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