ALTERATIONS OF neurotransmitter functions in cerebral ischemia and stroke have recently received increasing attention. Studies in various animal species have shown that catecholamine (CA), serotonin (5-HT) and amino acid (AA) biosynthesis in brain is dependent on arterial and tissue pO_2. Severe ischemic conditions with derangement of the cerebral energy state markedly reduce monoamine and protein biosynthesis with depletion of noradrenaline (NA), dopamine (DA) and 5-HT and reduction of AA metabolism.

After severe unilateral ischemia these modifications are present not only in the damaged tissue but also in remote "non-ischemic" areas and in the contralateral hemisphere. In the post-ischemic phase the main metabolite of DA, homovanillic acid (HVA) and of 5-HT, 5-hydroxyindoleacetic acid (5-HIAA), accumulate in the damaged tissue and in the adjacent edema zones.

Human post-mortem studies confirmed the findings in animal models. After recent brain infarct severe depletion of CA, 5-HT and their metabolites was found in necrotic and intact areas. In older brain infarcts a reduction of 5-HT and 5-HIAA was still present in necrotic tissue while adjacent tissues showed almost normal levels indicating some recovery. Thus, both animal and human studies have shown that marked changes of neurotransmitter metabolism occur in ischemic brain tissue and that these changes may have a complex time pattern. It therefore appears important for the understanding of the relationships between ischemia and neuron function to study the temporal profile of neurochemical changes in the ischemic brain. In patients this can only be accomplished by the investigation of neurochemical indices in the CSF.

CSF levels of monoamines and their metabolites can be considered to reflect the neurotransmitter metabolism in the brain. Increased levels of NA and 5-HT were found in the CSF of patients with stroke, and the concentrations of these amines were inversely correlated with the duration of stroke and the severity of neurological deficit. Previous studies of 5-HIAA and/or HVA concentrations in CSF at various times after stroke were inconsistent, levels varying from high to undetectable and showing no correlation with other parameters, e.g. time or clinical deficit.

The aims of our study were to determine the temporal profile of HVA and 5-HIAA in CSF of patients with stroke and the effects of persisting ischemia on acid metabolites in the CSF of patients with multi-infarct dementia (MID).

Patients and Methods

The study included thirty four patients who had had complete ischemic stroke of the superficial Sylvian territory, confirmed by clinical evaluation, computed tomographic (CT) scan, EEG, and in three cases by autopsy. Our standard diagnostic protocol also included a lumbar puncture for routine CSF examination, since at the time of the study, CT scans could not always be performed immediately upon admission. These patients were divided into three groups according to the time elapsed between the first signs of stroke and the lumbar puncture: group A, 22-47 h; group B, 48-71 h; group C, 72-96 h. Nineteen patients with multi-infarct dementia (MID) assessed by neurologic and neurophysiologic examinations were also studied. The severity of the neurological deficit was assessed by the Norris rating scale. Nine age-matched subjects without neurologic disease served as controls. Levels of homovanillic acid (HVA) and 5-hydroxyindolacetic acid (5-HIAA) were determined in lumbar CSF by a fluorimetric method after separation on Sephadex G-10 columns. HVA levels decreased as the length of time after stroke increased and were lower than controls in MID, while 5-HIAA levels were low in group B and MID. Our results in stroke can be interpreted as showing they are the consequence of dopamine and serotonin global depletion in the early phases of brain ischemia. In MID, the CSF changes might reflect not only tissue loss secondary to multiple infarcts but also the persistence of a state of diffuse ischemia.
Since HVA and 5-HIAA concentrations in the first and third CSF samples were never significantly different, the average value for the two determinations was used in the calculations.

In all groups of patients, HVA concentrations were significantly lower than in controls (table 2). Moreover, in groups B, C, and MID, the levels of HVA were also lower than in the group with the shortest duration after stroke (group A). The progressive decline of HVA levels in the first five days after stroke is further documented by a significant inverse correlation \( r = -0.49, p < 0.01 \) between the time of the lumbar puncture after stroke and the HVA concentrations.

On the other hand, the concentrations of 5-HIAA in group B and MID were significantly lower than in controls and group A, and the 5-HIAA/HVA ratio was lower in groups A and B than in controls.

Regression analysis did not show any significant correlations between HVA, 5-HIAA, 5-HIAA/HVA and the Norris scores. The CSF levels of the acid metabolites were also not related to the outcome at six months.

**Conclusions**

The study of the temporal profile of effects of ischemia on brain transmitter function after acute stroke appears to constitute an important approach to the understanding of pathogenetic mechanisms of the disease.

Since for ethical reasons a longitudinal study could not be carried out, we performed our research in stroke patients similar for type of the lesion (e.g. ischemic) and vascular territory involved (e.g. superficial Sylvian) at different times after stroke.

In this respect our study is, to our knowledge, the first neurochemical investigation of CSF monoamine metabolites in such a well-defined condition. Previous reports of patients with stroke have not specified the type of lesion, the vascular territory, or the entity of edema, evaluated either directly by CT scan or indirectly by the degree of impairment of consciousness, EEG, or angiography.

We documented a clear time pattern of HVA and 5-HIAA levels both these substances significantly declining in the first five days after stroke. There may be more than one reason for altered concentrations of monoamine metabolites in CSF after cerebral ischemia.

### Table 1

**Basic and Clinical Data for Controls and Patients with Stroke and MID**

<table>
<thead>
<tr>
<th>Groups</th>
<th>Sex</th>
<th>Age</th>
<th>Norris Score</th>
<th>6-Month follow up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td></td>
<td>U</td>
<td>I</td>
</tr>
<tr>
<td>Stroke</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>group A</td>
<td>16</td>
<td>7</td>
<td>9</td>
<td>72 ± 8‡</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>5</td>
<td>66 ± 11</td>
<td>85 ± 43</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3</td>
<td>60 ± 11</td>
<td>71 ± 58</td>
</tr>
<tr>
<td>Mid</td>
<td>19</td>
<td>4</td>
<td>60 ± 5</td>
<td>66 ± 40</td>
</tr>
<tr>
<td>Controls</td>
<td>9</td>
<td>5</td>
<td>64 ± 5</td>
<td></td>
</tr>
</tbody>
</table>

*Mean ± SD; ‡number of cases; §p < 0.01 vs MID.

1 = improved; U = unchanged; W = worsened; D = dead.

For all patients the severity of the neurological deficit was assessed by the Norris rating scale, slightly modified. Surviving stroke patients were reassessed after six months with the same scale and evaluated as: “improved” (score decreased 10%), “worsened” (score increased 10%), or “unchanged” (table 1).

Nine age-matched subjects who underwent myelography for lumbar pain and had normal diagnoses served as controls (table 1).

None of the MID patients and controls included in the study took any psychotropic drugs for two weeks before CSF sampling. Antihypertensive, antidiabetic or cardioactive drugs if previously taken were neither be started, diuretics, insulin and strophanthine were discontinued nor modified; but if such therapy had to be continued the drugs used. Only two patients were taking methyl-DOPA (group A). None were taking reserpine or other drugs known to affect monoamine metabolism.

Twenty patients were given antiaggregating agents and stroke patients were receiving corticosteroids (n = 8) or glycerol (n = 6) and papaverine (n = 3) or dihydroergotoxine (n = 8). Treated patients were evenly scattered in the three groups (A, B, C).

Lumbar punctures were performed at 8 A.M., after twelve hrs of fasting and bed rest. Three 5 ml samples of CSF were collected. The first and third were immediately centrifuged, transferred to fresh tubes and stored at -30°C until assayed for HVA and 5-HIAA. The second aliquot was used for routine laboratory CSF analysis. HVA and 5-HIAA concentrations were measured by a fluorimetric method after separation on columns of Sephadex G-10 as previously described.

The data were analyzed statistically by analysis of variance and Tukey’s test for multiple comparisons.

### Results

None of the patients had severe impairment of alertness nor signs of severe diffuse edema and the CT scans never showed any distortion of the ventricular system.

Patients in group A were slightly older, with more severe clinical deficits and worse final outcomes than the MID or the stroke patients in the other groups (table 1), but the differences were statistically significant only for age and Norris’ scores, when compared to the values for the MID group.

**Table 2**

**HVA and 5-HIAA Concentrations in CSF (Mean ± SD) of Controls and Patients with Stroke and MID**

<table>
<thead>
<tr>
<th>Groups</th>
<th>HVA</th>
<th>5-HIAA</th>
<th>5-HIAA/HVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>group A</td>
<td>35.8 ± 13.8*</td>
<td>32.1 ± 11.2</td>
<td>1.04 ± 0.39†</td>
</tr>
<tr>
<td>group B</td>
<td>22.2 ± 10.4*$</td>
<td>21.0 ± 8.2†</td>
<td>1.20 ± 0.81‡</td>
</tr>
<tr>
<td>group C</td>
<td>20.4 ± 8.2*$</td>
<td>20.3 ± 11.8</td>
<td>1.03 ± 0.38</td>
</tr>
<tr>
<td>Mid</td>
<td>23.3 ± 10.3*+</td>
<td>18.8 ± 7.7*†</td>
<td>1.04 ± 0.83</td>
</tr>
<tr>
<td>Controls</td>
<td>61.7 ± 9.6</td>
<td>32.3 ± 4.5</td>
<td>0.53 ± 0.13</td>
</tr>
</tbody>
</table>

*\( p < 0.01 \), vs controls; \( \hat{p} < 0.01 \), vs group A; \( \hat{p} < 0.05 \), vs controls; \( \hat{p} < 0.05 \) vs group A.
and infarction. Edema is one of the most important of these. Hachinski et al. found decreased levels of HVA in lumbar CSF of patients with brainstem infarcts. We agree with them that the most likely explanation is that edema in the periaqueductal region may have reduced the outflow of HVA-rich CSF from the ventricles to the spinal cord. Moreover, edema may not only functionally block CSF from the ventricles but, when it is diffuse, it may provoke a compensatory displacement of CSF from intracranial spaces, which would contribute to increasing the levels of HVA in the spinal CSF. The large interindividual variability of HVA levels (4 to 207) found in patients with hemispheric infarcts can probably be explained by differences in the relative importance of these two mechanisms in a given patient.

Our results can be interpreted as showing they are the consequence of earlier DA and 5-HT depletion in the brain. Experimental and human post-mortem studies have clearly shown that in recent ischemia and infarcts 5-HT and DA are severely depleted not only in the focal and perifocal brain areas but also in the hemisphere contralateral to the injury. Thus, the reduced HVA and 5-HIAA CSF levels we observed between the second and fifth day after stroke may reflect a general depletion of brain amines in the early phases of brain ischemia. It has been suggested that the monoamines released in the early phase may contribute to some aspects of the pathogenetic processes, i.e. vasoconstriction, brain edema and reduction of regional cerebral blood flow (rCBF). The changes in monoamines can be either a cause or an effect of diaschisis, i.e. remote effects of a focal ischemia. The fact that there is diffuse cerebral dysfunction after unilateral infarction is further supported by observations of marked reductions of rCBF in the "non-ischemic" hemisphere soon after the onset of stroke.

On the other hand, human post-mortem studies show that in old infarcts monoamine depletion is still present in necrotic areas, but in intact areas levels are almost normal, indicating some recovery in the previously ischemic brain. However, in patients with recurrent cerebral ischemic attacks and consequent multiple infarcts (MID), our results show low concentrations of acid monoamine metabolites in the CSF. It can be supposed that in these patients the persistence of diffuse ischemia maintains a reduced amine turnover even in morphologically intact areas.

In a previous study we found that in patients who had had a stroke but had been without further clinical evidence of ischemia for at least two months, HVA levels in CSF rose toward normal as the time after stroke lengthened. It appears therefore that the recovery of CSF metabolite levels can be considered a sign of functional recovery in intact areas and of the subsiding of ischemia.

The lack of correlation between the severity of neurological deficit and HVA of 5-HIAA levels is not surprising considering that the severity of symptoms in patients with stroke depends mostly on the focal lesion while the reduced CSF HVA and 5-HIAA levels reflect diffuse brain dysfunction. Similarly, in MID the CSF changes might reflect not only tissue loss but also a state of diffuse ischemia which may not be clinically evident in patients with severe deficits due to multiple infarcts.

References

Diagnosis of Reversible Versus Irreversible Cerebral Ischemia by the Intravenous Administration of Naloxone

BRUNO ESTANOL, M.D., FRANCISCO AGUILAR, M.D., AND TERESA CORONA, M.D.

SUMMARY Naloxone was given as an I.V. bolus of 0.8 mgs to four groups of patients with stroke: 1) 20 patients with C.T. proven cerebral infarcts of longer than 7 days duration; 2) 20 patients with acute cerebral ischemia of less than 24 hours; 3) 5 patients with C.T. proven intracerebral hemorrhage of less than 24 hours; and; 4) 3 patients with hyperacute cerebral ischemia which occurred during the performance of a cerebral angiogram. The patients with established cerebral infarctions of more than 7 days duration and the patients with intracerebral hematomas had no response to intravenous naloxone. Of 20 patients with acute cerebral ischemia of less than 24 hours duration, 7 had prompt, complete and long-lasting recovery. These patients had no subsequent evidence of cerebral infarct by C.T. scanner 48 hours after the onset of the cerebral ischemia and were asymptomatic when discharged. The 3 patients with hyperacute cerebral ischemia secondary to cerebral angiography had a dramatic response to the injection of naloxone. These findings suggest that intravenous naloxone may differentiate reversible versus irreversible cerebral ischemia.

SEVERAL CONTROVERSIAL REPORTS regarding the use of naloxone in acute cerebral ischemia have recently appeared. Baskin and Hosobuchi found that two patients with focal cerebral ischemia had dramatic improvement with the intravenous administration of naloxone. Jabaily and Davis gave intravenous naloxone to thirteen patients with acute stroke, treatment given between 4 and 24 hours after the cerebral event. Three out of thirteen patients improved suggesting that naloxone reversal of ischemic cerebral deficits was a rare event. Two had intracerebral hemorrhages that did not respond and one had an immediate and long lasting recovery and was subsequently shown to have a C.T. scan without evidence of a cerebral infarction.

Cutler et al. gave intravenous naloxone to nineteen patients with cerebral ischemia of less than seventy-two hours duration. None of the patients responded to the intravenous naloxone. Two of their patients also had an intracerebral hemorrhage. Fallis, et al. gave intravenous naloxone in a double blind trial to 15 patients with symptoms between 8 and 60 hours in duration. None of the patients responded. One patient had an intracerebral hemorrhage. Faden suggested that the discrepancy of the different trials is partly due to a poor selection of patients, lack of early treatment and use of inadequate doses. In order to elucidate the time factor and the type of patients who respond to intravenous naloxone we conducted a trial in four different populations of stroke patients: 1) patients with an established cerebral infarction proven by C.T. scanner within the first 24 hours; 2) patients with hypertensive intracerebral hematomas proven by C.T. the naloxone being given within the first 24 hours of the inception of the symptoms; 3) patients with acute cerebral ischemia of less than twenty-four hours duration (normal C.T. and lumbar puncture in the first 24 hours); 4) patients with hyperacute focal cerebral ischemia secondary to angiographic accidents; the naloxone was given within the first ten minutes of the onset of the ischemia.

Patients and Methods
The first group were 20 patients with C.T. proven cerebral infarct of more than 7 days' duration (range...
Homovanillic acid and 5-hydroxyindoleacetic acid modifications in CSF of patients with stroke and multi-infarct dementia.
S Smirne, M Franceschi, G Truci, M Camerlingo, R Pirola, L Ferini-Strambi and S R Bareggi

Stroke. 1985;16:1003-1006
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