SUMMARY  Clinical, angiographic and computed tomographic (CT) findings, and the volume of an infarced area as estimated from tomograms, were evaluated in 26 patients with proven, unilateral, internal carotid artery (ICA) occlusion. The volume of cerebral infarction (CI) ranged from 0 cm³ to 200 cm³. It was shown that the CI volume in the group of patients with good collateral flow was smaller than that in the group with poor or no collaterals ($p < 0.05$). It was also found that the smaller the volume of infarcted area, the better the patient's ability to carry out activities of daily living (ADL). The volume of infarction in patients without disturbance of consciousness was smaller than in patients with such disturbance. Thirteen of 15 patients with infarction of less than 50 cm³ eventaually showed good ADL. The patients with a deeply located infarction had a good prognosis and no disturbance of consciousness. In patients with superficial infarction there were relationships between the volume of infarction and prognosis, and between the volume and disturbance of consciousness. It is concluded that estimation of the volume of an infarcted area is important in assessing the clinical state and prognosis in patients with ICA occlusion.

THE RELATIONSHIP between clinical manifestations and angiographic findings in patients with internal carotid artery (ICA) occlusion has been studied by several authors. It is difficult to determine the location and the extent of cerebral infarction (CI) by means of cerebral arteriography (CAG). Computed tomography (CT) provides a means for visualizing these changes in the cerebral parenchyma in vivo. Although the relationship between location of an infarction and clinical findings in ICA occlusion has been reported by some investigators on the basis of necropsy studies, the relation of the volume of infarction to other clinical findings has not been evaluated. The purpose of this study was to evaluate the relationships among the clinical, angiographic and CT findings, and the volume of an infarcted area as estimated from CT films in a series of patients with proven occlusion of the ICA.

Patients and Methods

Twenty-four patients with occlusion of the unilateral carotid artery diagnosed by means of angiography were studied. They were 20 males and 4 females, and their ages ranged from 42 to 77 years, with a mean of 64 years. There were 11 right and 13 left ICA occlusions. Among them, 19 of 24 patients had bilateral carotid angiography to determine collateral flow from the non-occluded ICA. In the remaining 5 patients carotid angiography was performed on the occluded side only.

Clinical signs, laboratory data, complications and prognosis were evaluated in each patient. The CT-scan were obtained with a Varian CT scanner (V-360-3) on a plane parallel to the orbitomeatal line with 10 mm slice thickness, and were displayed on a 256 by 256 matrix. The area of decreased attenuation was considered as the infarcted area. CT findings were divided into 6 groups, according to the report by Radu et al. with some modifications. Group I contained patients with low attenuation areas involving most of a cerebral hemisphere. Group II included patients whose scans revealed an area of infarction which was confined to the fronto-parietal cortical (and subcortical) territory areas supplied by the middle cerebral artery (MCA). This group also included patients with cortical infarction in the inferior division of the MCA territory. In group III the infarct was largely confined to the deeper, capsular regions supplied by the MCA. In group IV the infarct was confined to the brain supplied by the anterior cerebral artery (ACA). In group V the infarct was confined to the area of brain supplied by the posterior cerebral artery (PCA). Lastly, there were patients who had no localized area which could be identified as an infarct; these patients formed group VI. The areas of low attenuation of each CT film were measured by means of a planimeter, and the volume of cerebral infarction was calculated. In order to estimate the volume of infarction accurately and to exclude an area of edema, CT films obtained 16 to 394 days after the onset of infarction were used for evaluation in most of the patients.

Because the main collateral flow is usually via the anterior communicating artery (Acom) from the contralateral ICA, further evaluation of the collateral flow was made in 19 patients in whom bilateral CAG was performed. These 19 patients were divided into 3 groups according to the angiographic findings. Group A contained patients in which both the ACA and MCA on the side of the occluded internal carotid artery were opacified well from one or more collaterals, such as carotid artery on the opposite side, vertebral arteries, ophthalmic artery, leptomeningeal anastomosis, or anastomosis in the neck between the vertebral artery and ICA distal to the occlusion. Group B contained patients in which either the ACA or the MCA on the side of the occluded ICA was opacified from one or more of these collaterals. Patients in whom the ACA and MCA on the occluded side were not opacified well formed group C.

All the patients were also divided into 4 categories according to prognosis: 1) fully independent in their activities of daily living (ADL), 2) those who required...
assistance in ADL, 3) totally disabled, and 4) died during the follow up period.

Results

1. CT Findings and Collateral Circulation

Table 1 shows the volume of infarction in 24 patients. Table 2 shows the location of infarction in these patients. The volume of infarction ranges from 0 cm³ to 200 cm³. Table 3 shows the appearance of collateral circulation in 19 patients in whom bilateral angiography was performed. The symbols (+), (±), and (−) show the extent of collateral circulation and indicate anastomoses to be “good”, “fair”, and “poor or none”, respectively. Of these 19 patients, 12 belong to group A, 5 to group B, and 2 to group C. Among the 12 patients in group A (good collateral flow), the MCA was opacified in 9 via the anterior communicating artery, in 2 via the ophthalmic artery, and in 1 via the posterior communicating artery (Pcom). Collateral circulation via the anterior half of the circle of Willis from the non-occluded ICA was the most important. Collateral circulation from the basilar artery via Pcom or via leptomeningeal anastomosis was apparent in some patients. Anastomosis via the ophthalmic artery from the external carotid artery and anastomosis in the cervical portion between vertebral artery and carotid artery distal to the occluded portion were also present. These collaterals, however, were not as frequent as those via the anterior half of the circle of Willis.

Table 4 shows the relationship between the volume of infarction and the extent of collateral circulation in 19 patients. Mean values of volume of infarction in patients in groups A and B were 45 ± 44 cm³ and 82 ± 52 cm³, respectively. Since there were only 2 patients in group C, further analysis was made on the combined group of (B + C), as a group of patients with angiographically incomplete collaterals. There was a statistically significant difference in the volume of infarction with a possible error of 5% or less between group A and combined group of (B + C) as determined by Wilcoxon’s rank-sum test. This indicated that good collateral circulation is associated with smaller infarctions. Most of the patients with cerebral infarctions smaller than 50 cm³ belonged to group A. As shown in Table 4, 5 of 7 patients in groups B and C had cerebral infarctions larger than 50 cm³. The 2 patients in groups B and C with infarction smaller than 50 cm³ did not have diabetes mellitus.

Table 4 also shows the relation between the location of infarction and the extent of collateral flow. No relationship between them is apparent.

2. Angiographic and CT Findings, and ADL

Table 5 shows the relationship between the volume of infarction and the activities of daily living (ADL) in 24 patients. Mean values of volume of infarction in the groups of ADL 1, 2, and 3 were 24 ± 26, 64 ± 52, and 112 ± 78 cm³, respectively; these results indicate that a large infarct predicts a poor prognosis. The volumes of infarction in the group of ADL 1 were smaller than those in the combined group of ADL (2 + 3), and the difference was statistically significant (p < 0.025).

Table 5 also shows the relationship between the region of infarction and ADL in the same patients. All but one patient with ADL levels of 3 or 4 had hemispheric (group I) or superficial (groups II, II + III) infarction, whereas patients with deep infarction (group III) had good ADL scores.

Table 6 also shows the relationships between region and volume of infarction and ADL in patients with superficial (Group II) and deep (Group III) infarction. All patients in group III had ADL levels of 1–2 irrespective of the size of infarction. There is a relationship between the size of infarction and ADL in

<table>
<thead>
<tr>
<th>Extent of collateral circulation</th>
<th>Via Ac</th>
<th>Via Pcom</th>
<th>Via leptomeningeal anastomosis</th>
<th>Via ophthalmic artery</th>
<th>Via cervical anastomosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+)</td>
<td>16</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>(±)</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>(−)</td>
<td>1</td>
<td>6</td>
<td>11</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>19</td>
<td>13</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>
TABLE 4  Collateral Flow in Relation to Volume and Region of Infarction in 19 Patients

<table>
<thead>
<tr>
<th>Collateral flow</th>
<th>Number of patients</th>
<th>mean ± S.D. (cm³)</th>
<th>Volume of infarction (cm³)</th>
<th>Region of infarction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A (good)</td>
<td>12</td>
<td>44.6* ± 44.2</td>
<td>0</td>
<td>I</td>
</tr>
<tr>
<td>Group B (fair)</td>
<td>5</td>
<td>81.6* ± 52.1</td>
<td>1-20</td>
<td>II</td>
</tr>
<tr>
<td>Group C (poor)</td>
<td>2</td>
<td></td>
<td>20-49</td>
<td>III</td>
</tr>
</tbody>
</table>

*Statistically significant difference between values of infarction in Group A and combined Group of (B+C) (p < 0.05). Combined group of (B+C) is a group of patients with angiographically incomplete collaterals.

TABLE 5  Activities of Daily Living (ADL) in Relation to Volume and Region of Infarction in 24 Patients

<table>
<thead>
<tr>
<th>ADL</th>
<th>Number of patients</th>
<th>mean ± S.D. (cm³)</th>
<th>Volume of infarction (cm³)</th>
<th>Region of infarction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>24.5*1 ± 25.5</td>
<td>0</td>
<td>I</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>64.0*1 ± 51.6</td>
<td>1-20</td>
<td>II</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>111.8*1 ± 77.6</td>
<td>20-49</td>
<td>III</td>
</tr>
</tbody>
</table>

*Statistically significant difference between the values of infarction in the groups of ADL 1 and ADL 3 (p < 0.05).
*Statistically significant difference between the values of infarction in the groups of ADL 1 and ADL (2 + 3) (p < 0.025).

TABLE 6  Region and Volume of Infarction in Relation to ADL and Disturbance of Consciousness

<table>
<thead>
<tr>
<th>Region of infarction</th>
<th>Volume of infarction (cm³)</th>
<th>ADL</th>
<th>Disturbance of consciousness</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>0-49</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>50-</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>III</td>
<td>0-49</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>50-</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Patients with group II infarction. Three of 4 patients with superficial infarction smaller than 50 cm³ had ADL 1 and the other had ADL 2. Three of 5 patients with superficial infarction larger than 50 cm³ had ADL scores of 3 or 4.

3. Angiographic and CT Findings, Level of Consciousness at Onset

The figure shows the relationship between level of consciousness at onset and volume of infarction. Six of 10 patients without disturbed consciousness had infarctions smaller than 10 cm³, and 10 of 14 patients with disturbed consciousness had infarctions larger than 10 cm³. The volume of infarction in groups with and without disturbed consciousness at onset was significantly different, with a possible error of 3% or less by Wilcoxon’s rank-sum test. No significant relationship was observed between the level of consciousness at onset and collateral flow which was evaluated by arteriography.

Table 7 shows the relationship between level of consciousness at onset and location of infarction. All patients in group III had normal consciousness.

4. Forms of Onset, and Effects of Complications

Table 8 shows the collateral flow, ADL, and volume of infarction in groups with or without hypertension as well as in groups with or without diabetes mellitus.
The difference did not reach the statistically significant level.

There were 5 patients with atrial fibrillation. The onset was abrupt in 3 of these patients, gradual in one, and during sleep in one.

Discussion

Until the development of CT scanning, data on carotid artery occlusion and its consequences arose from 2 sources; clinical observations, in which the clinical data were correlated with angiography and the presumed state of the brain, and the necropsy series, in which angiographic data were often lacking and clinical observations were retrospective. It is now possible to examine the patient, his blood vessels and the brain parenchyma in vivo more or less simultaneously. CT findings in ICA occlusion, however, have only been reported by Radfl et al. and Wodarz. Radl et al. classified the CT findings into 5 categories from group I to group V. It was sometimes difficult, however, to classify a patient into a particular group, so we combined group (II + III) and group (II + IV). We also combined the group in which the low density area (LDA) was confined to the territory of the posterior cerebral artery (PCA) to group V, although it is not proven whether this infarction is caused by ICA occlusion or not.

No previous report has referred to the volume of infarction following ICA occlusion. Our method for volume determination is essentially based on the planimetric technique. The outlines of the infarction were traced and the infarcted volume was determined by multiplying the area within each freehand contour by the effective slice thickness and summing up the total number of slices. Although this method cannot completely avoid the partial volume effect, the volume of infarction cannot be a normal distribution function. In such a case, the t-test is inapplicable, and statistical tests must be done by a non-parametric test such as Wilcoxon's rank-sum test, as performed in this study.

It is clear from our data that the volume of infarction is significantly related to the collateral flow evaluated from CAG findings. As expected, the smaller the volume of infarction, the better the collateral flow. Exceptional patients whose collateral circulation was good and infarctions were large, might have developed the collateral flow after the cerebral infarction. Exceptional patients with a small infarction and with fair or poor collateral flow did not have diabetes. In these patients small arterioles might not have sclerotic changes because of the absence of diabetes.

All patients with a deep infarction had ADL levels of 1–2 and were without disturbances of consciousness irrespective of the size of infarction. In patients with a superficial infarction, the volume of infarction was related to the ADL level and to disturbance of consciousness.

Table 8

<table>
<thead>
<tr>
<th>Complications</th>
<th>Number of patients</th>
<th>Collateral flow</th>
<th>ADL</th>
<th>Mean volume of cerebral infarction (cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>good</td>
<td>fair</td>
<td>poor</td>
</tr>
<tr>
<td>Hypertension (+)</td>
<td>14</td>
<td>8</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Hypertension (-)</td>
<td>10</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>DM (+)</td>
<td>13</td>
<td>6</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>DM (-)</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
consciousness (table 6). The mean volumes of infarction in patients with superficial infarction whose consciousness was normal and in those whose consciousness was disturbed were 44 cm$^3$ and 94 cm$^3$, respectively.

It is concluded that volume of infarction, as estimated from CT films, is closely and statistically significantly related to clinical findings, CAG findings, and ADL. Estimation of the volume is important in assessing the condition and prognosis of patients with ICA occlusion.

References

Internal carotid occlusion: volume of cerebral infarction, clinical findings, and prognosis.
S Takagi and Y Shinohara

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