Long-Term Results of Endarterectomy of the Internal Carotid Artery for Cerebral Ischemia and Infarction

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SUMMARY
The immediate and long-term results of carotid endarterectomy for treatment of acute cerebral ischemia or infarction were studied in 95 patients who were observed for an average period of 40 months after the surgical procedure. The operation resulted in death for 12 patients and worsening of the neurological deficit in six others. During the follow-up period, there were 22 additional deaths, most of which were caused by myocardial infarction or other complications of systemic atherosclerotic vascular disease.

The significant factors adversely affecting the prognosis of these patients consisted of severe electrocardiographic abnormalities, the presence of bilateral carotid occlusive lesions, cerebral infarction prior to endarterectomy, and the age of the patient.

Following endarterectomy only five patients were observed to have recurrent attacks of transient cerebral ischemia which were few in number and stopped spontaneously. Recurrent cerebral infarction developed in only seven patients, six of whom had unsuccessful or incomplete removal of the carotid occlusive lesions. Although this low incidence of recurrent ischemia and infarction seems to be evidence for the therapeutic value of carotid endarterectomy, further observations on a comparable group of patients treated nonsurgically are needed to support this conclusion.

Additional Indexing Words:
Electrocardiograms  Age  Mortality  Neurological episode
Hypertension

Surgical removal of atherosclerotic occlusive lesions in the internal carotid arteries is now generally recommended as a useful measure for the treatment of acute transient cerebral ischemia, but the long-term prognosis for patients undergoing such procedures is not so well documented. Although there have been several reports recently of large groups of patients with cerebrovascular disease observed for 5 years or more after this form of treatment, the lack of an adequate population for comparison makes interpretation of the surgical survival rate difficult. In one study the 5-year survival rate of patients treated surgically for extracranial cerebrovascular disease was compared with the survival rate of the normal United States population of comparable age, with gross differences favoring the latter. In another study of 175 patients undergoing carotid endarterectomy for cerebrovascular disease, only half the group, or 87 patients, were found to be cured or improved during an observation period averaging 26 months after the operation. The remainder had died, worsened, or showed no change. It is not known whether the outcome of these patients following surgical therapy is better than that obtained with nonsurgical methods. Although a definite answer to this
problem must await appropriately controlled studies of large numbers of cases, it should be noted that in most studies of carotid endarterectomy the patients surviving the operative procedures seem to have a low recurrence rate of cerebral infarction.

This report presents our observations on patients with extracranial cerebral occlusive disease during a follow-up period of 2 to 8 years after endarterectomy of the internal carotid arteries. The prognostic factors influencing the outcome are also presented, particularly as to the effects of the pre-existing neurological deficit, the extent of the occlusive disease in the carotid arteries, and the presence of coronary vascular disease.

**Cases Studied**

Ninety-five patients who had undergone endarterectomy for occlusive disease of one or both internal carotid arteries at Duke University Hospital from 1958 to 1964 were studied. Each of the patients was examined by one of us (A.H.) before the surgical operation and at regular intervals thereafter. Sixty-two of the patients were men, 33 were women. All but two (both Negroes) were white. The average age of the patients was 59, with an age range from 42 to 81 years. Approximately 15% of the patients were under the age of 49; an equal percentage was over the age of 70 years. Of the remaining patients an almost equal number were in the 50 to 59 age range and in the 60 to 69 age range. Seventy-four of the patients had been admitted to the private service of the hospital and were operated on by one of three vascular surgeons on the senior staff. The remaining 21 patients were on the public wards and had endarterectomy by one of the surgical house officers. The public and private patients also differed somewhat in the severity of their vascular disease. Although slightly younger than the private patients, the public group showed a greater percentage of patients with cerebral infarction in contrast to transient ischemia, and a higher incidence of electrocardiographic abnormalities indicating prior severe myocardial disease.

Twelve patients died shortly after the surgical procedure, that is, before discharge from the hospital; 22 others died during the period of follow-up observation. The surviving 61 patients have been observed for an average period of 40 months: 17 of them 13 to 24 months, 24 for 25 to 48 months, and the remaining 20 patients from 49 to 96 months. Ninety-one of the 95 patients had definite focal neurological mani-

festations of cerebrovascular disease prior to surgical therapy; the remaining four had no neurological complaints. In these four "asymptomatic" patients, carotid endarterectomy was carried out as a prophylactic measure, that is, to prevent cerebral infarction during subsequent surgical operation for vascular disease of the abdominal aorta or renal arteries. The diagnosis of carotid occlusive disease was made in these four patients on the basis of loud carotid bruits, decreased ipsilateral ophthalmic artery pressures, and subsequent arteriographic examination.

The predominant or presenting neurological signs or symptoms consisted of weakness of the limbs (45 patients), hemisensory loss (eight patients), aphasia (four patients), transient alterations of consciousness (four patients), and transient monocular blindness or visual field defects (30 patients). These symptoms either appeared alone or in combination. Forty-nine patients were considered to have recurrent transient cerebral ischemia, their neurological manifestations having either cleared completely at the time of surgery or were manifested by very minor residual neurological deficits. A diagnosis was made of cerebral infarction in the remaining 42 patients who showed mild to moderately severe hemiplegia, sensory loss, or aphasia over a period of several days to weeks. Eighteen of these 42 patients were admitted to the hospital with what appeared to be gradually progressive neurological deficit (thrombosis-in-evolution), but for the purpose of this report they are considered as having cerebral infarction. Each of these 91 symptomatic patients had their last episode of transient cerebral ischemia or the onset of cerebral infarction within a few weeks prior to surgical therapy. None of the patients was unconscious or had severe mental changes at the time of surgery. An attempt was made to exclude patients from this study whose major symptoms consisted of vague dizziness, mental changes, or visual disorders which were not clearly related to cerebral ischemic disease.

Both carotid arteries, as well as one or both vertebral arteries, were visualized by arteriographic examination in 57 patients. Bilateral carotid arteriography without vertebral artery visualization was carried out in 36 patients. In the two remaining patients, only one carotid artery was examined by arteriography because of sudden worsening during the arteriographic procedure and the need for immediate surgical intervention.

Patients with symptoms predominantly of vertebral-basilar artery insufficiency and those with significant subclavian arterial disease (as manifested by differences of blood pressure in the two arms) were excluded from this study to
obtain a homologous group of patients in whom the clinical symptoms were definitely related to occlusive disease of the carotid arteries.

Lesions were present in only one carotid artery of 62 patients, 16 of whom had complete obstruction (hereafter called "occlusion") and 46 of whom had partial obstruction (hereafter designated as "stenosis"). Thirty-three others had involvement of both carotid arteries: 11 with bilateral stenosis, two with bilateral occlusion, and 20 with stenosis of one internal carotid artery and complete occlusion of the contralateral internal carotid artery or common carotid artery. In all of the patients in this study at least 30% of the diameter of one or both carotid arteries was obstructed by the atheromatous plaque as shown by roentgenographic examination. In most of the patients, however, the degree of stenosis was considerably greater. In almost every patient, the obstructive lesion was located in the internal carotid artery at or immediately distal to the bifurcation of the common carotid artery. In general, patients with complete arterial occlusion tended to present with cerebral infarctions, whereas those with stenotic lesions only, had fewer cerebral infarcts and a higher percentage of transient cerebral ischemic attacks. Ten of the 95 patients gave a history of a previous cerebral infarction, usually a mild hemiparesis which occurred within 5 years prior to admission to the study.

Severe electrocardiographic abnormalities were present in 29 patients indicating old myocardial infarction, myocardial ischemia, or disturbances in rhythm such as atrial fibrillation or flutter. The 17 patients with electrocardiographic changes, such as questionable ventricular ischemia, ventricular hypertrophy, or extrasystoles, were classified as having borderline abnormalities and are considered together with 42 patients with normal records. Electrocardiograms were not made on seven patients.

Twenty-two of the patients had systemic blood pressure persistently greater than 150/110 mm Hg, and 35 others had moderately elevated blood pressures, in the range of 150/90 to 180/110 mm Hg. The remaining 38 patients were normotensive.

Surgical Procedures

Early in the study, endarterectomy was carried out under local anesthesia. In the last 1 or 2 years of the study, general anesthesia was employed by all but one of the surgeons (K.S.G.) who prefers cervical block anesthesia. Patients with severe occlusive disease of both carotid vessels were usually operated on under hypothermic conditions, the body temperature being reduced to 32 C by surface cooling. In the early part of the study, a shunt was inserted into the internal carotid artery to provide circulation to the brain during clamping of the vessels and removal of the atheromatous plaque. Later in the study, however, shunts were not employed, cerebral protection being provided by hypercarbia induced by rebreathing and maintenance of blood pressure by hypertensive agents. The use of vein grafts or plastic patches to widen the lumen of the endarterectomized vessel was a routine practice early in the study but was rarely employed in the later period. The carotid artery was clamped during removal of the atheromatous material for 5 to 30 minutes, with an average of 15 minutes. In most instances, the atheromatous plaque in the carotid artery produced a greater degree of stenosis than was apparent on arteriographic examination, the effective lumen of the vessel often being as small as 1 to 2 mm in diameter. In a small percentage of cases, possibly 10%, a fresh thrombus was found attached to the plaque, and hemorrhage into the plaque was occasionally observed. In several instances, the plaque showed considerable gumose material which could have been the source for dissemination of platelet or cholesterol emboli to the brain.

The operation was unsuccessful in removing the lesions in 11 of the 16 patients with unilateral occlusion, in four of the 46 with unilateral stenoses, and in both patients with bilateral carotid occlusion. In addition, endarterectomy of both carotid arteries was attempted in six of the 20 patients with unilateral stenosis and contralateral occlusion, but was unsuccessful in removing the complete occlusions in four of the six patients. Unsuccessful endarterectomy was usually evident during the operation of patients with total occlusion since no back flow was observed from the intracranial or distal portions of the internal carotid arteries. In the four patients with unsuccessful operations on stenotic lesions, recurrent thrombi developed shortly after the surgical procedure as indicated by measurement of ophthalmic artery pressures, arteriography, or both.

Prior to endarterectomy, measurements of ophthalmic artery pressures provided useful diagnostic information in 67 of the 92 patients in whom this procedure was carried out. Abnormal pressure readings (that is, differences in either systolic or diastolic pressures of 15 g or more) were obtained in 34 of the 46 patients with unilateral carotid stenosis, four of 11 with bilateral stenosis, 14 of 20 patients with bilateral occlusion or occlusion of one artery and stenosis of the other, and in each of 15 patients with unilateral occlusion. Ophthalmic artery pressures were also measured several times in each
patient during the first postoperative year to determine whether the carotid arteries remained patent. In addition, arteriography or thermography was carried out in approximately one third of the patients several months after the operation. Only five of the patients were given long-term anticoagulant therapy postoperatively.

A definite bruit was heard over one or both carotid arteries in 71 of the 94 patients in whom auscultation of the neck vessels was carried out prior to the surgical procedure. In 14 of the 46 patients with unilateral carotid stenosis, the bruit was heard only over the site of the lesion. Bruits were heard bilaterally in 18 of these 46 patients and over the normal carotid artery in three patients and were not heard in the remaining 11 patients. Bruits were present in seven of the 16 patients with unilateral occlusion and were heard over the normal carotid vessel in four patients, over the obstructed artery in one, and bilaterally in two patients.

Results
Morbidity and Mortality Related to Endarterectomy

The surgical procedure produced more severe neurological manifestations in six of the 95 patients. The neurological worsening was transient in three patients but resulted in optic atrophy in another patient and moderate hemiparesis in the other two patients. Four other patients were found to have recurrent thrombosis at the site of the arteriotomy soon after the surgical procedure, but none of them had residual clinical manifestations.

The operation was considered to be responsible for deaths of 12 patients. Two of them died as a result of myocardial infarction which developed a few days after operation. Infarction developed in the operative wound of another, with formation of a false aneurysm; this patient died after recurrent cerebral infarction several weeks later. The nine remaining patients died soon after the surgical procedure as a result of anoxia or hypotension. Most of them failed to regain consciousness after the operation and developed severe hemiplegia. Surgical re-exploration or autopsy in three of them revealed a fresh thrombus at the site of the arteriotomy or in the contralateral carotid artery. One of the patients with hypotension during the surgical procedure was found at autopsy to have a large fresh hemorrhage in the area of the cerebral infarction.

Late Morbidity and Mortality

Of the 83 patients surviving the surgical procedure, only seven developed late neurological deficits, usually in the third or fourth year of the follow-up period (table 1). Six of these patients experienced hemiparesis of moderate severity (two of whom had repeated attacks of transient cerebral ischemia after operation). The remaining patient died following a massive brain stem infarction 4 years after an unsuccessful carotid endarterectomy. As would be expected, a number of other patients with severe cerebral infarction slowly worsened over the years subsequent to endarterectomy, and several were eventually confined to their homes or admitted to nursing homes or mental institutions. As best could be determined, none of them had an overt recurrence of cerebral infarction, and their downhill course could not be attributed solely to progression of their cerebrovascular disease.

Five additional patients developed recurrent cerebral ischemia within 1 or 2 months after operation, but these episodes were few in number and stopped spontaneously without residual neurological manifestations. An additional patient developed epileptic seizures. As seen in table 1, six of the seven patients with recurrent cerebral infarction had obstructive lesions in one or both carotid arteries, complete removal of which was either not attempted or was unsuccessful. Bilateral endarterectomy was also unsuccessful in both of the patients with bilateral carotid occlusion. One of them was alive and well 3 years later, the other died 6 months after the operation as a result of myocardial infarction.

As mentioned in the foregoing paragraph, only one of the seven patients developing late cerebral infarction died as a result of the recurrent episode. Of the remaining 21 late deaths, nine were due to myocardial infarction. Four patients died after other vascular illnesses, such as congestive heart failure, renal insufficiency, mesenteric thrombosis, or cerebral hemorrhage. The remaining patients

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### Table 1

**Patients with Late Recurrent Cerebral Infarction**

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yr)</th>
<th>Sex</th>
<th>Presenting episode</th>
<th>Internal carotid lesion(s)</th>
<th>Endarterectomy</th>
<th>Time of recurrence (mo)</th>
<th>Recurrent symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>F</td>
<td>TIA*; numbness left side; amaurosis left eye</td>
<td>Right stenosis, 50%; left stenosis, 90%</td>
<td>Left carotid, successful</td>
<td>22</td>
<td>TIA; mild left hemiparesis &amp; sensory deficit</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>M</td>
<td>Infarct; mild left hemiparesis for 10 days</td>
<td>Right stenosis; left stenosis</td>
<td>Right carotid, successful</td>
<td>7</td>
<td>Severe left hemiplegia</td>
</tr>
<tr>
<td>3</td>
<td>55</td>
<td>M</td>
<td>Infarct; moderate left hemiplegia for 2 days</td>
<td>Right occlusion</td>
<td>Right carotid, unsuccessful</td>
<td>32</td>
<td>Moderate left hemiplegia</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>M</td>
<td>Infarct; moderate left hemiplegia for 8 days</td>
<td>Right occlusion</td>
<td>Right carotid, unsuccessful; anticoagulant therapy</td>
<td>48</td>
<td>Death due to cerebral hemorrhage (?)</td>
</tr>
<tr>
<td>5</td>
<td>63</td>
<td>F</td>
<td>TIA; recurrent weakness of left arm &amp; leg; aphasia &amp; numbness right face, recovery</td>
<td>Right occlusion; left stenosis, 60%</td>
<td>Left carotid, successful</td>
<td>3</td>
<td>Moderate right hemiplegia with seizure</td>
</tr>
<tr>
<td>6</td>
<td>50</td>
<td>M</td>
<td>TIA; one episode right hemiparesis, with minor deficit</td>
<td>Left stenosis, 60%</td>
<td>Left carotid, successful</td>
<td>39</td>
<td>TIA; mild residual weakness left foot; anticoagulant therapy</td>
</tr>
<tr>
<td>7</td>
<td>48</td>
<td>M</td>
<td>TIA; 7-8 attacks right hemiparesis, sensory loss, recovery</td>
<td>Left occlusion</td>
<td>Left carotid, unsuccessful, resulting in hemiparesis &amp; aphasia; anticoagulant therapy</td>
<td>54</td>
<td>Right hemiparesis; left carotid patent by arteriography</td>
</tr>
</tbody>
</table>

*TIA = transient cerebral ischemic attacks.
Table 2
Relation of Presenting Neurological Episode to Cerebral Infarction or Death after Endarterectomy

<table>
<thead>
<tr>
<th>Presenting episode</th>
<th>Patients</th>
<th>Cerebral infarction associated with operation</th>
<th>Late cerebral infarction</th>
<th>Death due to other causes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Survived</td>
<td>Died</td>
<td>Survived</td>
</tr>
<tr>
<td>Transient cerebral ischemia</td>
<td>49</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Cerebral infarction</td>
<td>42</td>
<td>2</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>Asymptomatic</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>6</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

*Includes two patients dying of myocardial infarction shortly after endarterectomy.

Table 3
Relation of Pattern of Carotid Occlusive Lesions to Cerebral Infarction or Death after Endarterectomy

<table>
<thead>
<tr>
<th>Carotid lesions</th>
<th>Patients</th>
<th>Cerebral infarction associated with operation</th>
<th>Late cerebral infarction</th>
<th>Deaths due to other causes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Survived</td>
<td>Died</td>
<td>Survived</td>
</tr>
<tr>
<td>Unilateral stenosis</td>
<td>46</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Unilateral occlusion</td>
<td>16</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Bilateral stenosis</td>
<td>11</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Bilateral occlusion</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Unilateral stenosis with contralateral occlusion</td>
<td>20</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>6</td>
<td>10</td>
<td>6</td>
</tr>
</tbody>
</table>

*Includes one patient who died as a result of myocardial infarction shortly after endarterectomy.

Table 4
Relation of Electrocardiographic Findings to Death after Endarterectomy

<table>
<thead>
<tr>
<th>ECG findings</th>
<th>Patients</th>
<th>Associated with operation</th>
<th>Late</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severe myocardial disease</td>
<td>29</td>
<td>6 (1)*</td>
<td>12 (4)</td>
<td>18</td>
</tr>
<tr>
<td>Borderline or normal</td>
<td>59</td>
<td>4 (1)</td>
<td>10 (5)</td>
<td>14</td>
</tr>
<tr>
<td>No data</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>95</td>
<td>12</td>
<td>22</td>
<td>34</td>
</tr>
</tbody>
</table>

*Figures in parentheses indicate deaths known to be caused by myocardial infarction.

died as a result of neoplasm or leukemia (five patients) or from unknown causes (three patients).

Influence of Presenting Neurological Episode and Pattern of Carotid Lesions

Table 2 shows the relationship of the presenting neurological manifestations to subsequent cerebral infarction or death. Four (8%) of the 49 patients with transient cerebral ischemia prior to operation developed serious cerebral manifestations and died from the surgical procedure. Of the 42 patients with cerebral infarction prior to endarterectomy, six (14%) had worsening of the neurological manifestations immediately after the operation and died within a few days. It is of interest that none of the four asymptomatic patients developed cerebral infarction. Two of them died several years after the operation, however; one from myocardial infarction; the other from renal failure.
The relationship of cerebral infarction and death to the pattern and severity of the lesions in the carotid arteries is seen in table 3. Our findings tend to support the current concept that the endarterectomy carries greater risks in patients with bilateral carotid lesions. Of the 62 patients with unilateral lesions (either occlusion or stenosis), four (6.4%) developed more severe neurological deficits which resulted in death shortly after endarterectomy. Among the 33 patients with bilateral carotid lesions, six (19%) developed more severe cerebral damage and died immediately after the operation.

Effects of Electrocardiographic Abnormalities and Hypertension

Patients with electrocardiographic abnormalities indicating severe myocardial disease prior to endarterectomy had an increased mortality in the early postoperative period as well as during the later periods of follow-up observation (table 4). Eighteen (62%) of the 29 patients with marked electrocardiographic abnormalities died in contrast to only 14 (24%) of the 59 patients with normal or borderline electrocardiograms. Only five of the 11 patients dying of myocardial infarction, however, had severe electrocardiographic abnormalities prior to the surgical procedure; in the remaining six, the electrocardiogram was borderline or normal. Of the two patients dying of myocardial infarction in the immediate postoperative period, one had severe angina and a normal electrocardiogram. The other had no clinical evidence of myocardial disease but showed severe electrocardiographic abnormalities. He died suddenly 1 week after an unsuccessful endarterectomy for removal of a unilateral carotid occlusion.

The patients with hypertension did not show an increase in mortality. Of the 22 patients with arterial blood pressure levels greater than 180/100 mm Hg, eight died (five early and three late). There were 11 deaths among the 35 patients with blood pressures in the range of 150/90 to 180/110 mm Hg, and 15 deaths among the 38 normotensive patients.

Influence of Age and Socioeconomic Status

Of the 16 patients over 70 years of age in this study, five died soon after the surgical procedure and three others succumbed during the follow-up period. This mortality rate (50%) is, as would be expected, greater than in the younger age groups in which death occurred in approximately one third of the patients in each of the three age decades below 70 years.

The 21 patients admitted to the public wards of Duke Hospital and operated on by the resident staff had a higher percentage of deaths (five early and five late) than the 74 private patients (seven early and 17 late). As mentioned earlier, the public patients had a greater incidence of cerebral infarction than the private ones and, probably more significantly, showed a higher percentage of electrocardiographic abnormalities indicating severe myocardial disease.

Discussion

The results of this study demonstrate a very low incidence of recurrent cerebral infarction in patients surviving carotid endarterectomy. Of the 83 patients in this study surviving the surgical procedure, only seven (most of whom had unsuccessful or incomplete removal of the carotid lesions) developed cerebral infarction during the follow-up period. This low rate of recurrent infarction has been observed by others and has been considered as strong evidence for the therapeutic value of carotid endarterectomy. Unfortunately, there are no reports of large numbers of comparable patients treated nonsurgically, and the incidence of recurrent cerebral infarction during the natural course of extracranial cerebral occlusive disease is not known. Although previous studies have shown that approximately 20% of patients with cerebral infarction develop recurrent cerebral infarction within 2 years, such case studies cannot be used for comparison. Many of the patients included in such reports had severe cerebral damage (as a result of one or more previous infarcts), and few of them had arteriographic demonstration of carotid arterial disease.
Recurrent attacks of cerebral ischemia were also uncommon following endarterectomy and in most instances the ischemic attacks completely stopped after the surgical procedure. There is, however, little information as to the natural course of transient cerebral ischemia caused by extracranial vascular disease. The few recent papers on this subject indicate that patients with frequent attacks of carotid arterial insufficiency may have a relatively benign prognosis, the attacks often stopping spontaneously without producing infarction. Few of the patients with transient cerebral ischemia studied for long periods have had arteriographic evaluation of the extracranial cerebral circulation, and the outcome or natural course of such patients likewise cannot be compared with that of the surgically treated patients.

The prognosis for patients with extracranial carotid occlusive disease is extremely variable and depends on numerous factors. The outcome of large numbers of surgically treated and nontreated patients must therefore be compared before the results of endarterectomy can be considered reliable. Bauer and his associates reported the immediate and late outcome of a relatively small group of patients with atherosclerotic cerebral occlusive disease who were selected for surgical and nonsurgical treatment on a random basis. In their study, the percentage of patients who died after carotid endarterectomy (30.3%) was higher than that (21.2%) of the control group who were followed for as long as 42 months. It is conjectural whether a longer period of follow-up will eventually demonstrate a greater survival rate among the surgically treated group. Large scale cooperative studies like those now in progress may provide an answer to this problem.

The low incidence of recurrent cerebral infarction following successful carotid endarterectomy is generally attributed to the improvement of the cerebral circulation in these cases. Conversely, six of the seven patients in this study who developed recurrent cerebral infarction had incomplete resection of the carotid obstructive lesions. This observation suggests that failure to remove all such surgically accessible lesions is the cause of recurrent cerebrovascular manifestations. It should be noted, however, that 29 other patients in this study also had unsuccessful or incomplete removal of their carotid lesions, but these patients had no worsening or recurrence of their neurological deficit. Other investigators have also shown that unilateral or even bilateral occlusion of the carotid arteries may not indicate a serious prognosis. Yates and Hutchinson found cerebral infarction in only six of the 18 autopsied cases in which significant arterial stenosis was confined to one or both carotid arteries. In four of the six patients, moreover, the intracranial artery supplying the infarcted territory was also obstructed. Considerable other evidence also indicates that if only one carotid artery is occluded and the rest of the cerebrovascular tree is healthy, the patient is often able to survive and be free of neurological dysfunction.

The known coexistence of cerebral and coronary atherosclerosis is confirmed in this study as shown by the fact that a significant number of our patients had evidence of myocardial infarction before or after endarterectomy. Approximately one third of the patients had electrocardiographic changes indicating severe myocardial disease prior to endarterectomy, and 11 patients subsequently died as a result of myocardial infarction. In De Bakey's follow-up study of surgical treatment of extracranial cerebrovascular disease, the 5-year mortality rate of patients with arteriosclerotic heart disease was two to three times that of patients without hypertension or heart disease. Other studies of carotid endarterectomy have shown that among patients with normal electrocardiograms, 78% had a favorable outcome in contrast to 53% among patients with electrocardiographic evidence of old myocardial infarction. It is thus apparent that greater attention should be given to the recognition and treatment of coronary artery disease as well as the thromboembolic complications of generalized atherosclerosis if the overall mortality following
carotid endarterectomy is to be significantly reduced.

In the present study, the evaluation of surgical therapy is based largely on the incidence of recurrent cerebral infarction and survival following endarterectomy. The degree of immediate improvement or gradual recovery of the neurological manifestations present at the time of the surgical procedure has not been considered in evaluating this form of treatment, since the degree of natural recovery of the neurological dysfunction is known to vary considerably. We have not observed any dramatic postoperative neurological improvement which could be definitely attributed to the effect of surgery. Although a few patients appeared to show considerable improvement of the hemiplegia or aphasia within a few days or a week after endarterectomy, we have observed such recovery during the natural course of the disease as well as in patients in whom endarterectomy was unsuccessful in removing the obstructive lesion. Thus, the reports in which the value of surgical therapy is largely based on "improvement" or "recovery" from hemiplegia or other neurological deficits are open to criticism.4

The overall survival rate in our patients 40 months after the operation, as determined by life table analysis, was 656 per 1,000, a figure less satisfactory than that of 768 per 1,000 found in the study by DeBakey and associates1 of a larger series of patients of the same mean age. The percentage of deaths in our study (35.8%) observed an average of 42 months after operation may be comparable to that observed by Yashon and his associates2 who reported that 25% of their patients died within an average of 26 months after endarterectomy. The data obtained in the present study indicate that differences in mortality rates are probably due to factors such as the presence of cerebral infarction, the existence of severe electrocardiographic abnormalities, the severity of occlusive lesions in the carotid arterial system, and the age of the patient. In the past few years, the acute morbidity and mortality associated with carotid endarterectomy in our hospital have shown definite improvement, presumably as a result of more careful case selection, greater surgical experience, and perhaps more complete pre-surgical arteriographic evaluation. Indeed, eight of the 12 deaths associated with the endarterectomy occurred during the initial portion of this study. Many of these patients were over the age of 70 years, had severe hypertension, and would not be candidates for operation at the present time.

Currently, "four vessel" arteriography (that is, visualization of the extracranial and intracranial portions of both vertebral and carotid arteries) is generally carried out to assess the overall state of the arterial supply to the brain. In the present report, no mention has been made of the presence of stenotic lesions in the vertebral and other extracranial or intracranial vessels which were sometimes present but were not considered to be directly related to the patient's symptoms. It must be admitted, however, that the exact relationship of such multiple lesions to the patient's symptoms and to his eventual outcome is difficult to assess. It is known that symptoms referable to one area of the brain may result from an occlusive lesion in distant collateral channels. In the present study, carotid endarterectomy was carried out only when there seemed to be a clear-cut relationship between the patient's neurological deficit and the vascular lesion. Moreover, in patients with bilateral carotid lesions, an attempt was made to limit the operation to the carotid artery corresponding to the patient's symptoms. None of our patients had endarterectomy of the vertebral arteries, nor was any attempt made to operate on lesions in the contralateral carotid artery once the patient's presenting symptoms had improved. Since the presence of multiple extracranial occlusive lesions are responsible for the overall decrease in cerebral blood flow,11 many investigators believe that endarterectomy should be carried out on as many such lesions as feasible regardless of their apparent relationship to the patient's presenting symptoms. The results obtained in the present study indicate that multiple
CAROTID ENDARTERECTOMY

operations are not usually necessary to produce satisfactory outcome, since relatively few of our patients had recurrent cerebral infarction even though endarterectomy was generally confined to the one lesion which seemed to be responsible for the acute symptoms.

Not only is there some controversy as to the number of extracranial vascular lesions which should be operated on, but there is the question as to the need for resection of a solitary stenotic lesion which appears to be producing relatively little obstruction of the vascular lumen. Flowmeter studies have shown that interference with carotid blood flow occurs only in the presence of very large intravascular lesions which must reduce the lumen to approximately 2 sq mm before producing a significant reduction in circulation. On the other hand, an irregular, friable atherosclerotic plaque of almost any size may provide a site for formation of emboli which may be carried to the brain and cause symptoms of transient cerebral ischemia or infarction. Thus, the indication for endarterectomy of a solitary lesion depends upon which of these two factors, that is, a reduction in blood flow or a site for embolic formation, seem to be operable in a given individual—a decision which is often difficult to make. Further investigation of this problem is needed.

Addendum

Following submission of this paper for publication, our attention was called to a related report by Bradshaw and Casey. This study of 47 patients with carotid obstructive lesions, followed for 6 months to 10 years, found that seven patients died of related disease and that more than 50% of the survivors had an overall satisfactory neurological outcome.

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References

Long-Term Results of Endarterectomy of the Internal Carotid Artery for Cerebral Ischemia and Infarction
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