

Cerebral Arterial Insufficiency: One to 11-Year Results Following Arterial Reconstructive Operation *

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CEREBROVASCULAR INSUFFICIENCY constitutes a problem of considerable magnitude in terms of both death and disability. At least two million people now alive in the United States are victims of this condition and that it ranks third as a cause of death in this country. Studies of the natural course of the disease in patients in whom the diagnosis was made clinically without arteriography reveal that death occurs within 5 years after onset in 80 per cent of the patients, with 21 per cent dying during the initial attack.^{1,2} Survival studies of patients with extracranial carotid artery occlusion proved by arteriography suggest a similarly grave prognosis.¹⁰ Reports of collaborative studies of patients randomized into a control group receiving no treatment and a group receiving treatment with anticoagulants indicate that the latter form of therapy does not significantly alter the course of the disease, particularly as it affects survival.^{1, 2}

During the past decade—and as a consequence of surgical experience, more frequent use of arteriography and more intensive investigations—a much better understanding of this problem has been obtained. It is now known, for example, that

the disease tends to assume certain characteristic and recognizable pathologic, anatomic and clinical patterns of involvement. Most frequent are those resulting from well localized occlusive lesions in the extracranial arterial bed which are amenable to surgical treatment. About three fourths of patients with extracranial occlusions have forewarning symptoms. Early recognition of these manifestations—along with precise diagnosis by means of arteriography demonstrating the presence of an occlusive lesion in the extracranial arterial bed, followed by application of surgical treatment—may not only relieve the symptoms of cerebral ischemia but also prevent the development of a subsequent stroke. It is thus apparent that surgical therapy constitutes an effective approach to this problem in a significantly high proportion of these patients.

Clinical Material

Our own experience with this surgical approach, beginning with the performance of our first operation for correction of an extracranial arterial occlusion causing cerebrovascular insufficiency on August 7, 1953, now extends for more than 11 years. During this period we have employed some form of arterial reconstructive operation in the treatment of 1,155 patients with cerebrovascular insufficiency produced by extra-

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TABLE 1. *Patients Treated for Cerebrovascular Insufficiency from August 1953 to June 1964 According to Clinical Manifestations*

Clinical Manifestations	No. Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymptomatic	Total
Prophylactic	56	3 (5%)	1 (2%)	0	0	52 (93%)	52 (93%)
Transient cerebral ischemia	496	22 (4%)	19 (4%)	7 (1%)	12 (2%)	436 (88%)	448 (90%)
Persistent progressive stroke	62	5 (8%)	3 (5%)	16 (26%)	17 (27%)	21 (34%)	38 (61%)
Completed stroke	541	37 (7%)	26 (5%)	98 (18%)	286 (53%)	94 (17%)	380 (70%)
Total	1155	67 (6%)	49 (4%)	121 (10%)	315 (27%)	603 (52%)	918 (80%)

cranial arterial occlusions (Table 1). These patients represent about 40 per cent of all those with manifestations of cerebrovascular insufficiency observed during this period, most of whom were studied arteriographically. This report, however, is based upon a study of the 812 patients in this series whose operations were performed prior to April 1, 1963, in order to provide follow-up results ranging from 1 to about 11 years (Tables 2, 3).

Current follow-up studies were obtained in 804 patients (99%) by personal examination, from questionnaires received from patients and their physicians, and from information obtained from insurance companies, the Veterans Administration, state

bureaus of vital statistics and employers. The conditions of the remaining eight patients were known from 1 to 3 years after operation; thus no patient was completely lost to follow up. Accordingly, this report is concerned with certain significant observations derived from an analysis of this experience, with particular emphasis upon long-term survival and neurologic functional results.

The ages of the patients ranged from 20 to 85 years, with the highest incidence occurring in the sixth and seventh decades of life. The ratio of men to women was 5:2, but their mean ages were about the same, 60.3 and 59.8 years respectively. Arteriosclerotic heart disease—demonstrated in

TABLE 2. *Results After Operation at Time of Discharge from Hospital According to Clinical Manifestations*

Clinical Manifestations	No. Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymptomatic	Total
Prophylactic	48	2 (4%)	1 (2%)	0	0	45 (94%)	45 (94%)
Transient cerebral ischemia	324	16 (5%)	15 (5%)	6 (2%)	8 (2%)	279 (86%)	287 (89%)
Persistent progressive stroke	34	4 (12%)	3 (9%)	7 (21%)	11 (32%)	9 (26%)	20 (59%)
Completed stroke	406	29 (7%)	25 (6%)	86 (21%)	206 (51%)	60 (15%)	266 (66%)
Total	812	51 (6%)	44 (5%)	99 (13%)	225 (28%)	393 (48%)	618 (76%)

TABLE 3. Results According to Clinical Manifestations at Time of Follow Up or at Time of Death in Follow-Up Period

Clinical Manifestations	No. Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymptomatic	Total
Prophylactic	46	9 (20%)	1 (2%)	0	0	45 (98%)	45 (98%)
Transient cerebral ischemia	308	46 (15%)	16 (5%)	17 (6%)	9 (3%)	266 (86%)	275 (89%)
Persistent progressive stroke	30	6 (20%)	2 (7%)	2 (7%)	10 (33%)	16 (53%)	26 (86%)
Completed stroke	377	90 (24%)	26 (7%)	48 (13%)	136 (36%)	167 (44%)	303 (80%)
Total	761	151 (20%)	45 (6%)	67 (9%)	155 (20%)	494 (65%)	649 (85%)

most cases by electrocardiographic evidence of old myocardial infarction, and in some by manifestations of angina pectoris and congestive heart failure—was present in 156 normotensive patients (19%) (Fig. 1). Patients with blood pressure higher than 150 mm. Hg systolic and 90 mm. Hg diastolic were considered hypertensive, and on this basis 420 patients (52%) had hypertension. Of these, 251 (31%) had both hypertension and heart disease.

Since the predominant underlying pathologic factor in this disease is arteriosclerosis, lesions of this nature—either in the form of segmental occlusive or aneurysmal disease

in other parts of the aorta and major arterial trunks—occur not infrequently in the same patient. With greater experience and awareness of these characteristic forms of arteriosclerosis and the pattern which they assume, an increasing number of patients with multiple associated lesions of this type have been encountered. In this series 424 patients (52%) were found to have different forms of vascular disease such as renovascular hypertension, arterial insufficiency of the lower extremities and aneurysm of the aorta and major arterial branches. Surgical treatment is frequently indicated for these combined lesions and, accordingly,

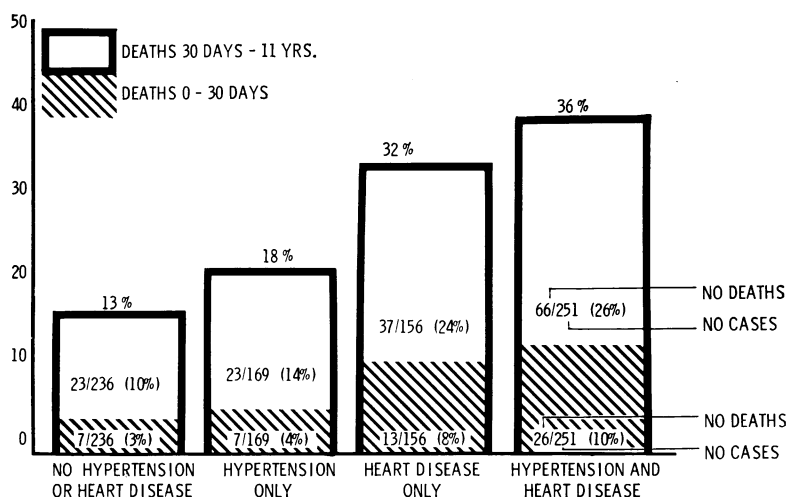


FIG. 1. Graph showing mortality rates according to presence of hypertension and heart disease in patients submitted to operation for cerebral arterial insufficiency.

TABLE 4. Results at Time of Discharge from Hospital in Patients with Persistent Neurologic Deficits According to Duration

Duration	No. Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymp- tomatic	Total
Acute	122	17 (14%)	9 (7%)	18 (15%)	54 (44%)	24 (20%)	78 (64%)
Chronic	318	16 (5%)	19 (6%)	75 (24%)	163 (51%)	45 (14%)	208 (65%)
Total	440	33 (7.5%)	28 (6%)	93 (21%)	217 (49%)	69 (16%)	286 (65%)

was applied for associated vascular lesions at some time before or after operation for cerebrovascular disease in 222 patients (27%).

Clinical Manifestations

There were 48 patients in this series who had little or no neurologic disturbance but had other manifestations of occlusive lesions of the extracranial arterial bed such as ear noises, pulse and blood pressure changes or murmurs in the neck. Most of these patients were admitted primarily for surgical treatment of other vascular lesions. Arteriographic studies in these patients revealed sufficiently extensive and severe stenotic lesions to justify operation both for symptomatic relief and prevention of possible development of a stroke during or following operation for other vascular lesions. Thus, from a neurologic point of view, surgical treatment in most of this group of patients may be classified as prophylactic (Tables 2, 3).

The remaining patients had neurologic manifestations ranging from vertigo, visual disturbances and mild motor and sensory changes to complete hemiplegia, aphasia and coma. On the basis of neurologic manifestations, these patients were classified into three categories (Table 2, 3):

1) *Transient cerebral ischemia*, 324 patients (40%), characterized by intermittent episodes of minimal dysfunction to complete paralysis lasting from a few minutes to several days.

2) *Persistent progressing stroke*, 34 patients (4%), characterized by neurologic deficits that were persistent and progressively getting worse.

3) *Completed strokes*, 406 patients (50%), characterized by persistent neurologic deficits that were stable in most patients or were improving at the time of operation in others.

The persistent neurologic deficit in 122 patients (15%) had been present from a

TABLE 5. Results at Time of Follow Up or at Time of Death in Patients with Persistent Neurologic Deficits According to duration

Duration	No. Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymp- tomatic	Total
Acute	106	30 (28%)	7 (7%)	8 (8%)	41 (39%)	50 (47%)	91 (86%)
Chronic	301	66 (22%)	21 (7%)	42 (14%)	105 (35%)	133 (44%)	238 (79%)
Total	407	96 (24%)	28 (7%)	50 (12%)	146 (36%)	183 (45%)	329 (81%)

TABLE 6. Results at Time of Discharge from Hospital According to Character of Symptoms

Symptoms	No. Patients	Results					
		Deaths	Worse	No Change	Better		Total
					Improved	Asymp-tomatic	
Carotid	476	32 (7%)	30 (6%)	77 (16%)	163 (34%)	174 (37%)	337 (71%)
Vertebral-basilar	288	17 (6%)	13 (5%)	22 (7%)	62 (22%)	174 (60%)	236 (82%)
Total	764	49 (6%)	43 (6%)	99 (13%)	225 (29%)	348 (46%)	573 (75%)

few hours to one week and these patients were considered to have had acute strokes (Tables 4, 5). In 318 patients (39%) the persistent neurologic deficit had been present for more than one week and these patients were considered to have had chronic strokes. Of 764 patients with neurologic symptoms, 476 (62%) had symptoms primarily related to the carotid system and 288 (38%) had symptoms considered chiefly as vertebral-basilar in origin (Tables 6, 7).

The extracranial location of the occlusive process was suggested in 65 per cent of cases by the presence of murmurs in the neck, supraclavicular region and upper chest, pulse changes in the neck and upper extremities, and blood pressure changes in the upper extremities. The location of the occlusive process was not evident on clinical grounds in the remaining cases. Arteriography was therefore essential to determine both the location and extent of disease. Complete arteriographic visualiza-

tion of the extracranial, as well as the intracranial, arterial bed is considered essential for this purpose.

Pathology

The occlusive process assumed the characteristic extracranial location: in the internal and external carotid arteries near their origins; in the vertebral arteries near their origins from the subclavian arteries; and in the innominate, common carotid and subclavian arteries, beginning usually at or near their origins from the aortic arch. Multiple arterial involvement occurred in more than 75 per cent of cases. Operability depended upon the location and extent of the occlusive process. All lesions of the innominate, common carotid and subclavian arteries were amenable to reconstructive operation because a patent distal segment was always present—as were those with incomplete occlusion of the internal carotid, external carotid and vertebral arteries because of their well localized segmental na-

TABLE 7. Results at Time of Follow Up or at Time of Death According to Character of Symptoms

Symptoms	No. Patients	Results					
		Deaths	Worse	No Change	Better		Total
					Improved	Asymp-tomatic	
Carotid	444	92 (21%)	33 (8%)	45 (10%)	116 (26%)	250 (56%)	366 (82%)
Vertebral-basilar	271	50 (18%)	11 (4%)	22 (8%)	39 (14%)	199 (73%)	238 (88%)
Total	715	142 (20%)	44 (6%)	67 (9%)	155 (22%)	449 (63%)	604 (85%)

TABLE 8. Results at Time of Discharge from Hospital According to Relationship of Location of Lesion Treated to Symptoms

Location of Lesion	No. Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymptomatic	Total
Appropriate	521	32 (6%)	28 (5%)	55 (11%)	163 (31%)	243 (47%)	406 (78%)
Inappropriate	243	17 (7%)	15 (6%)	44 (18%)	62 (26%)	105 (43%)	167 (69%)
Total	764	49 (6%)	43 (6%)	99 (13%)	225 (29%)	348 (46%)	573 (75%)

ture. Operability in patients with complete occlusion at the latter levels varied with the duration of symptoms. Successful restoration of circulation was possible in most patients during the first 12 to 24 hours after onset of symptoms, but because of intracranial extension of the thrombotic process and its organization, the incidence of restoration of circulation for complete occlusion at this level declined sharply after 24 hours. The longest period between onset of symptoms and successful operation was in a patient with complete obstruction of the internal carotid artery manifested by progressing neurologic manifestations of 3 months' duration.

Treatment

Treatment, directed toward the occlusive process, was designed to restore normal distal blood flow, relieve symptoms and prevent progression of the disease. Of 764 patients with symptoms, operation was di-

rected toward lesions located in appropriate relationship to the manifestations in 521 (68%) (Tables 8, 9). The appropriately located occlusive process in the remaining patients, involving either the internal carotid or vertebral arteries, was considered inoperable. Operation in these cases was directed toward severe but incomplete segmental occlusive lesions, located in one or more of the remaining arteries of the extracranial arterial system, in order to increase blood flow—not only into the asymptomatic region of the brain but also into the involved area through intracranial collateral vessels⁵ (Fig. 2-5). The *pattern of arterial involvement* and the *surgical approach* in the latter cases may be divided into four major categories:

1) Internal carotid artery operation on the opposite side of an inoperable completely obstructive lesion of the internal carotid artery appropriately located to symptoms (Fig. 2).

TABLE 9. Results at Time of Follow Up or at Time of Death According to Relationship of Location of Lesions Treated to Symptoms

Location of Lesion	No. of Patients	Results					
		Deaths	Worse	No Change	Better		
					Improved	Asymptomatic	Total
Appropriate	489	87 (18%)	27 (6%)	30 (6%)	100 (20%)	332 (68%)	432 (88%)
Inappropriate	226	55 (24%)	17 (8%)	37 (16%)	55 (24%)	117 (52%)	172 (76%)
Total	715	142 (20%)	44 (6%)	67 (9%)	155 (22%)	449 (63%)	604 (85%)

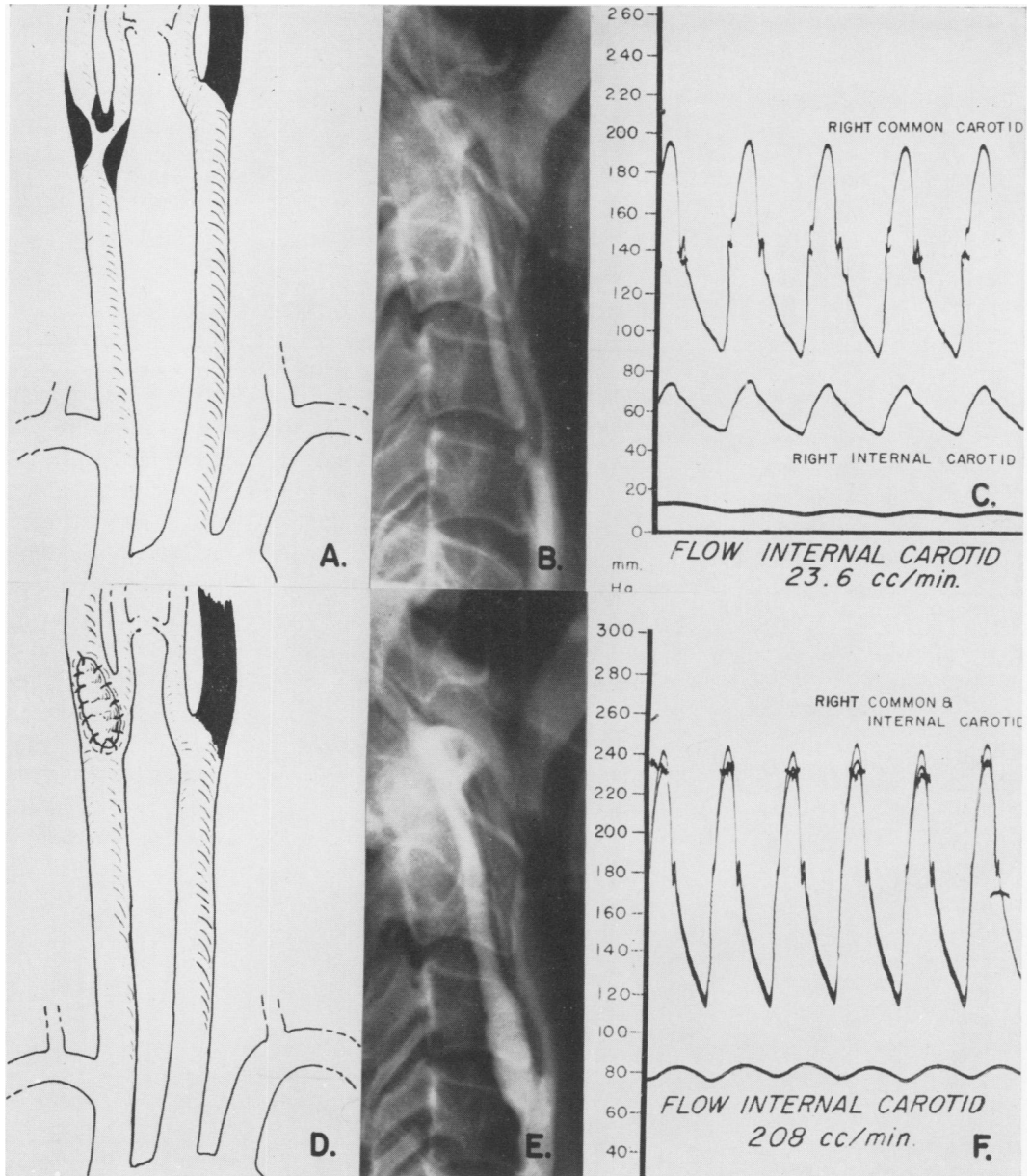
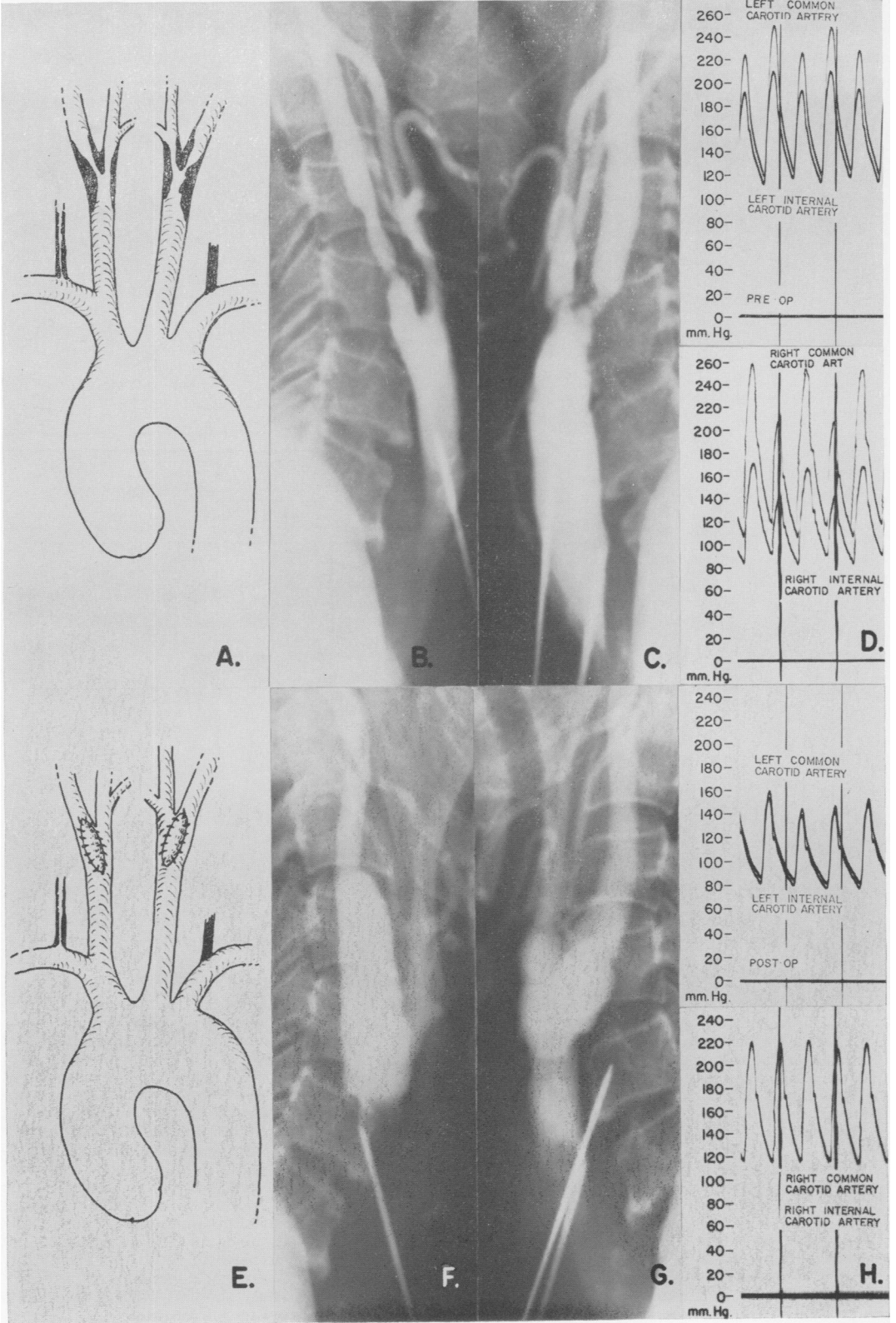


FIG. 2. A) Drawing made from complete arteriographic studies showing complete occlusion of left internal carotid artery and severe stenosis of right internal carotid artery in a 57-year-old white man who developed a stroke 1 year prior to admission producing aphasia and right hemiplegia. Over a period of several months the patient recovered from the stroke with only moderate speech difficulty, but beginning about 2 weeks prior to admission he began to develop symptoms of progressive weakness in right arm and increasing speech difficulty. B) Preoperative right carotid arteriogram showing severe stenosis at origin of right internal carotid artery. C) Arterial pressure measurements made at operation showing severe pressure gradient across stenotic lesion in right internal carotid artery. Blood flow measurements using electromagnetic flow meter revealed blood flow in internal carotid artery to be 23.6 cc./min. D) Drawing illustrating operative procedure consisting of thromboendarterectomy of right common and internal carotid arteries and patch graft angioplasty. E) Arteriogram made approximately 1 year after operation showing restoration of a normal lumen and normal circulation in right internal carotid artery. Patient has shown marked improvement in speech and strength of right upper extremity and has resumed his business activities. F) Arterial pressure measurements made immediately after operative procedure of thromboendarterectomy of right internal carotid artery showing virtual elimination of pressure gradient. Blood flow in internal carotid artery was increased to 208 cc./min.



2) Carotid artery operation in patients with vertebral basilar symptoms and inoperable occlusive lesions of the vertebral arteries (Fig. 3, 4).

3) Vertebral artery operation in patients with carotid symptoms and inoperable, completely obstructed internal carotid arteries (Fig. 5).

4) External carotid artery operation on the side of appropriately located inoperable, completely obstructed internal carotid arteries (Fig. 6).

As described in detail previously,⁴⁻⁶ three types of procedures were employed in the treatment of these cases: endarterectomy, angioplasty and end-to-side bypass graft. *Thromboendarterectomy* was employed in the treatment of the majority of patients with occlusion of the internal carotid artery and in many patients with occlusion of the vertebral artery (Fig. 2-6, 10-11). The arterial incision in most of these cases was closed by inserting a patch graft. Patch graft *angioplasty* only was employed in some patients with occlusion of the internal carotid artery and not infrequently in patients with occlusion of the vertebral artery. The occlusive process in these cases was diaphragmatic in nature and involved primarily the intima of the common carotid or subclavian artery. To simplify operation and to avoid distal dissection, the area of stenosis was widened by incising the artery and inserting a patch graft.⁵ Various types of procedures classified as simple angio-

plasties were employed in a small number of cases. For example, a redundant dilated loop of vertebral artery located distal to an occlusive process may have been attached by side-to-side anastomosis to the subclavian artery. This procedure bypassed the obstruction and straightened the vertebral artery. The *end-to-side bypass graft* procedure, using knitted Dacron tubes, was employed in the majority of patients with occlusion of the innominate, common carotid and subclavian arteries. Multiple arterial involvement was present in most of these cases, and the graft extended from the ascending aorta to the distal patent segment or segments in the neck and supraclavicular regions (Fig. 7). When only one or two arteries were involved, operation could be simplified by confining operation to the neck and supraclavicular region. For example, when either the common carotid or subclavian artery was involved, normal circulation could be restored by inserting a graft by end-to-side anastomosis between these vessels in the neck and supraclavicular regions (Fig. 8, 9). Blood flow studies performed at operation indicate that such a procedure does not reduce distal flow in the vessel providing flow through the graft; thus, there is no "steal" phenomenon.

The occlusive lesions for which operation was performed were located most frequently at the bifurcation of the common carotid and the origin of the internal carotid arteries (69.5% of cases) (Tables 10, 11).

FIG. 3. A) Drawing made from complete arteriographic studies showing complete occlusion of left vertebral artery, incomplete but severe and diffuse occlusion of right vertebral artery and severe stenosis of both internal carotid arteries in a 63-year-old white woman with progressive manifestations of basilar artery insufficiency characterized by vertigo, diplopia, transient blindness, ataxia, headaches and lapses of memory over a period of several years with more recent development of transient aphasia and hemiparesis in right arm and numbness in left arm. Following arteriographic studies performed elsewhere several years previously, patient was told that the vertebral artery occlusive disease was inoperable, and she was therefore placed on anticoagulant therapy. Although she has remained on this form of therapy, her manifestations have become progressively worse. B) Preoperative right carotid and C) left carotid arteriograms showing severe stenosis of both internal carotid arteries. D) Arterial pressure measurements showing pressure gradients produced by occlusive lesions in both internal carotid arteries. E) Drawing showing operative procedure consisting of thromboendarterectomy with patch graft angioplasty of both internal carotid arteries. F) Right carotid and G) left carotid arteriograms made about 1 year following operation showing restoration of normal lumen and circulation in both internal carotid arteries. Since operation patient has shown progressive improvement and is now virtually asymptomatic. H) Arterial pressure measurements made immediately following operative correction of occlusive lesions showing elimination of pressure gradient.

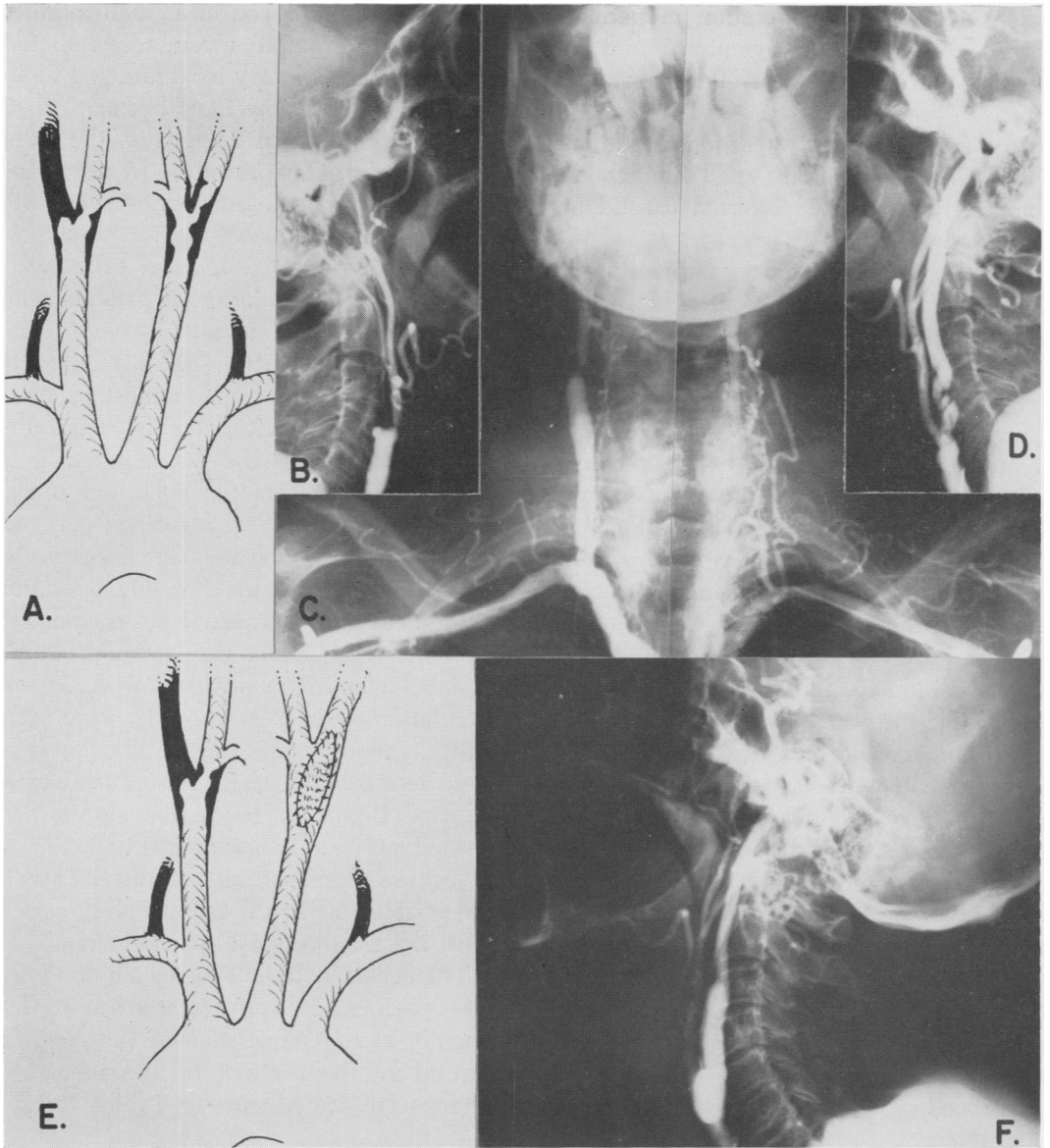
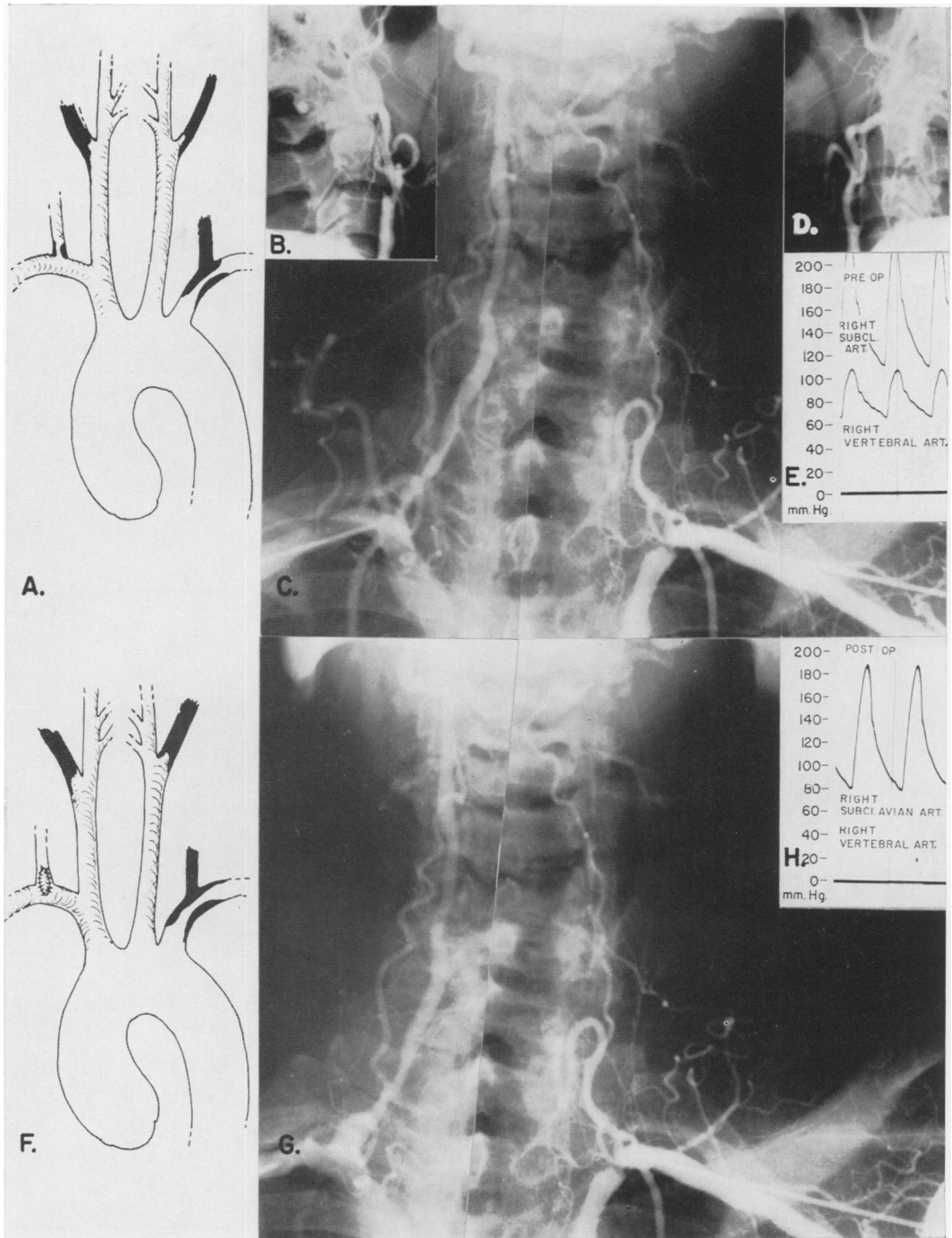


FIG. 4. Drawing (A) and preoperative arteriograms (B-D) showing complete occlusion of both vertebral arteries and severe stenosis of left internal carotid artery in a 65-year-old white man with manifestations predominantly of basilar artery insufficiency, including particularly vertigo, visual disturbances and transient episodes of right-sided weakness. Note extensive development of collateral circulation through left thyrocervical trunk. Patient also complained of intermittent claudication of the lower extremities and arteriographic studies showed extensive aorto-iliac occlusive disease. E) Drawing illustrating operative procedure performed consisting of thromboendarterectomy with patch graft angioplasty of left common and internal carotid arteries. F) Arteriogram made about 1 year after operation showing restoration of normal circulation in left internal carotid artery. Patient also had aorto-iliac bypass graft for occlusive disease about 10 days following operation on left common and internal carotid arteries. He is now virtually asymptomatic.

FIG. 5. Drawing (A) and preoperative arteriograms (B-D) showing complete occlusion of both internal carotid and left vertebral arteries and severe stenosis at origin of right vertebral artery in a 62-year-old white man with manifestations of carotid as well as basilar artery insufficiency characterized by diplopia, vertigo, left facial weakness and slight thickness of speech. E) Arterial pressure measure-



ments made at operation showing severe pressure gradient across stenotic lesion in right vertebral artery. F) Drawing showing operative procedure consisting of thromboendarterectomy with patch graft angioplasty of right vertebral artery. Since operation patient has shown progressive improvement and is now virtually asymptomatic. G) Arteriogram made after operation showing restoration of normal lumen and circulation in right vertebral artery. H) Arterial pressure measurements made immediately following operative correction of occlusive lesion in right vertebral artery showing elimination of pressure gradient.

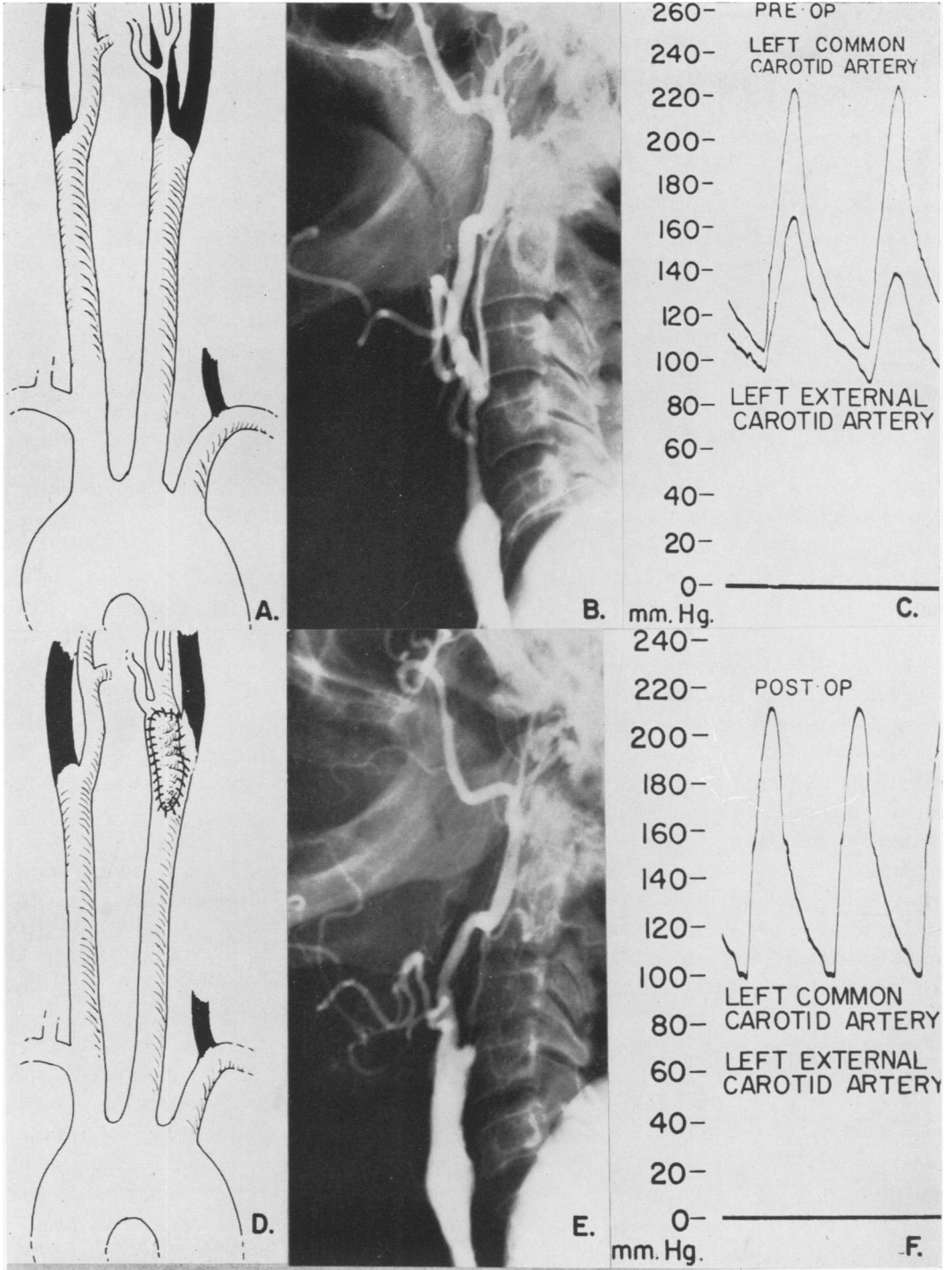


FIG. 6. A) Drawing made from complete arteriographic studies showing complete occlusion of both internal carotid and left vertebral arteries and severe stenosis of left external carotid artery in a 73-year-old white man with manifestations of episodes of syncope and dizziness associated with right-sided weakness of 2 months' duration. Patient also had a persistent sensation of ringing in left ear. B) Pre-operative left carotid arteriogram showing complete occlusion of left internal carotid artery and severe

TABLE 10. Results at Time of Discharge from Hospital According to Location of Lesions Treated

Artery Treated	No. Patients	Results					
		Deaths	Worse	No Change	Improved	Better Asymp- tomatic	Total
External carotid	8	0	1 (12%)	2 (25%)	3 (37%)	2 (25%)	5 (62%)
Internal carotid	564	38 (7%)	34 (6%)	75 (13%)	155 (27%)	262 (47%)	417 (74%)
Internal carotid and vertebral	60	3 (5%)	2 (3%)	4 (7%)	21 (35%)	30 (50%)	51 (85%)
Vertebral	88	4 (5%)	6 (7%)	9 (10%)	26 (30%)	43 (49%)	69 (78%)
Great vessel	92	6 (7%)	1 (1%)	9 (10%)	20 (22%)	56 (61%)	76 (83%)
Total	812	51 (6%)	44 (5%)	99 (12%)	225 (28%)	393 (48%)	618 (76%)

Lesions located in the great vessels arising from the aortic arch, in the vertebral arteries, and involving both internal carotid and vertebral arteries occurred in 11.3, 10.8 and 7.4 per cent, respectively (Tables 10, 11).

Multiple lesions were frequent, and when they produced sufficient obstruction to alter blood flow, associated lesions were treated whenever possible. To avoid complications in patients requiring treatment of multiple lesions, operation was frequently staged—limited to one side of the neck at a time. In patients with bilateral internal carotid artery occlusion and in patients with occlusion of an internal carotid artery and a contralateral vertebral artery, operation was first directed toward the lesion appropriately located to symptoms. Then by a second operation performed after the first incision had completely healed, usually within a week to 10 days, the other lesion was treated (Fig. 10). Patients requiring internal carotid artery and vertebral artery operation on the same side and patients re-

quiring bypass graft operations for multiple lesions of the great vessels were usually treated by one operation.

Local anesthesia was employed in the majority of the first 600 patients, but since then, general anesthesia has been employed almost exclusively because it is believed to have a number of advantages, including better oxygenation, increase in collateral cerebral circulation protecting the cerebrum from anoxia, better patient cooperation and smoother conduct of operation in general.

Associated lesions of other vessels—such as aneurysmal or occlusive diseases of the aorta and renal, superior mesenteric, iliac, femoral and popliteal arteries—requiring treatment were treated as previously described (Fig. 11).^{6, 9-12} The cerebrovascular operation was employed first in the majority of the 222 patients submitted to operation for such associated disease to prevent the recurrence or progression of stroke. These patients gave a history of transient cerebral ischemia or had residual neurologic deficits, and arteriograms demon-

stenosis of left external carotid artery. C) Arterial pressure measurements showing severe pressure gradient across stenotic lesion in left external carotid artery. D) Drawing illustrating operative procedure consisting of thromboendarterectomy of left external carotid artery with patch graft angioplasty. E) Arteriogram made after operation showing restoration of normal circulation in left external carotid artery. Immediately following operation patient noted that ringing sensation in left ear had disappeared and he had progressive improvement in other manifestations. F) Arterial pressure measurements made immediately following endarterectomy of left external carotid artery showing disappearance of pressure gradient.

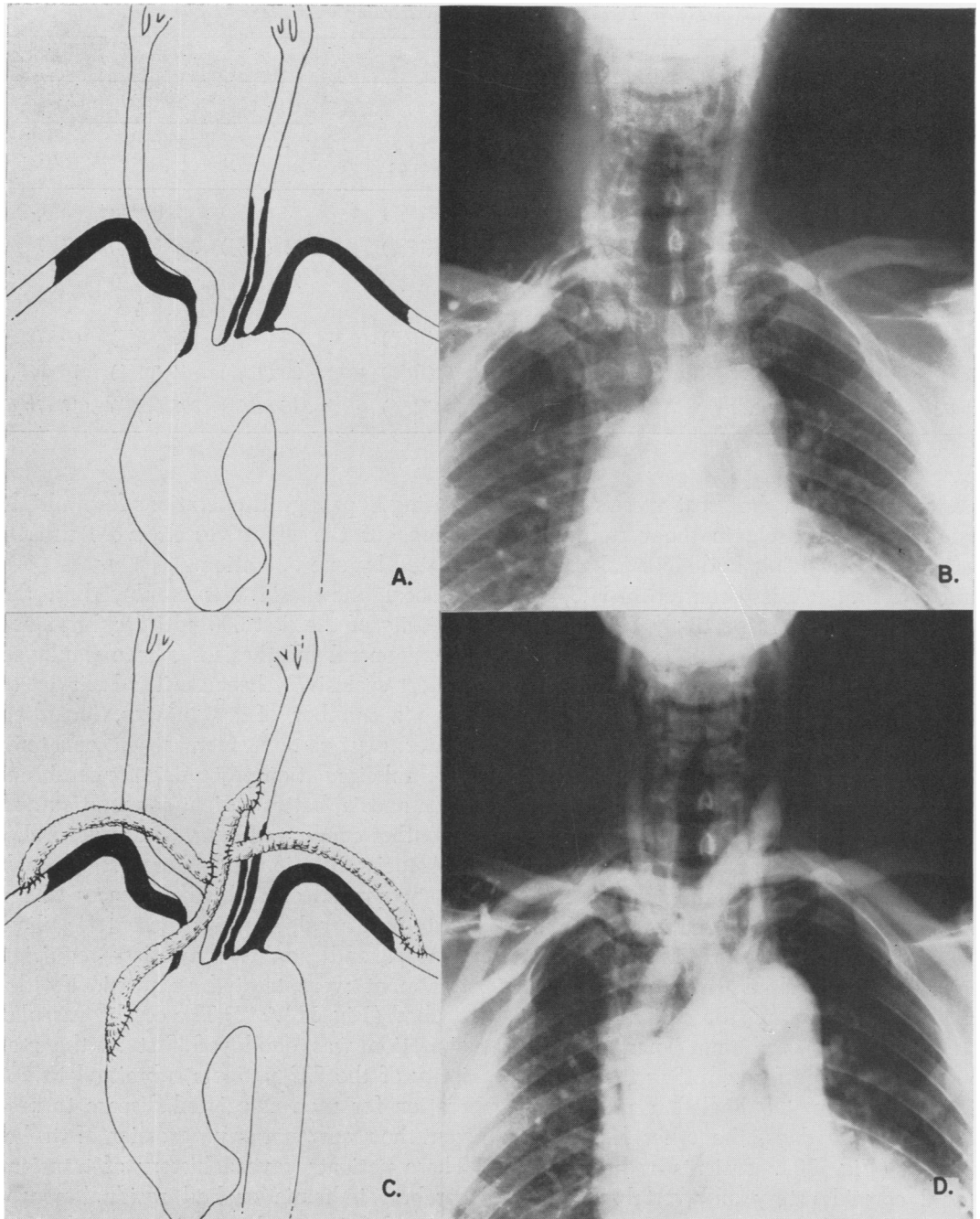


FIG. 7. Drawing (A) and preoperative arteriograms (B) showing complete segmental occlusion of both subclavian arteries and severe but incomplete occlusion of left common carotid artery in a 51-year-old white man with intermittent manifestations and both carotid and basilar artery insufficiency and intermittent claudication of both arms. C) Drawing showing operative procedure consisting of knitted Dacron bypass graft from ascending aorta to both subclavian and left common carotid arteries. D) Arteriogram made about 5 years after operation showing restoration of normal circulation through bypass graft. About 4 years after this operation patient had another operation consisting of bypass graft from abdominal aorta to both external iliac arteries for Leriche syndrome. He is now completely asymptomatic.

strated operable extracranial lesions. The cerebrovascular operation was performed as a second operation in the remaining patients. The clinical manifestations of cere-

brovascular disease occurred in these patients postoperatively, either while they were still in the hospital or during the follow-up period.

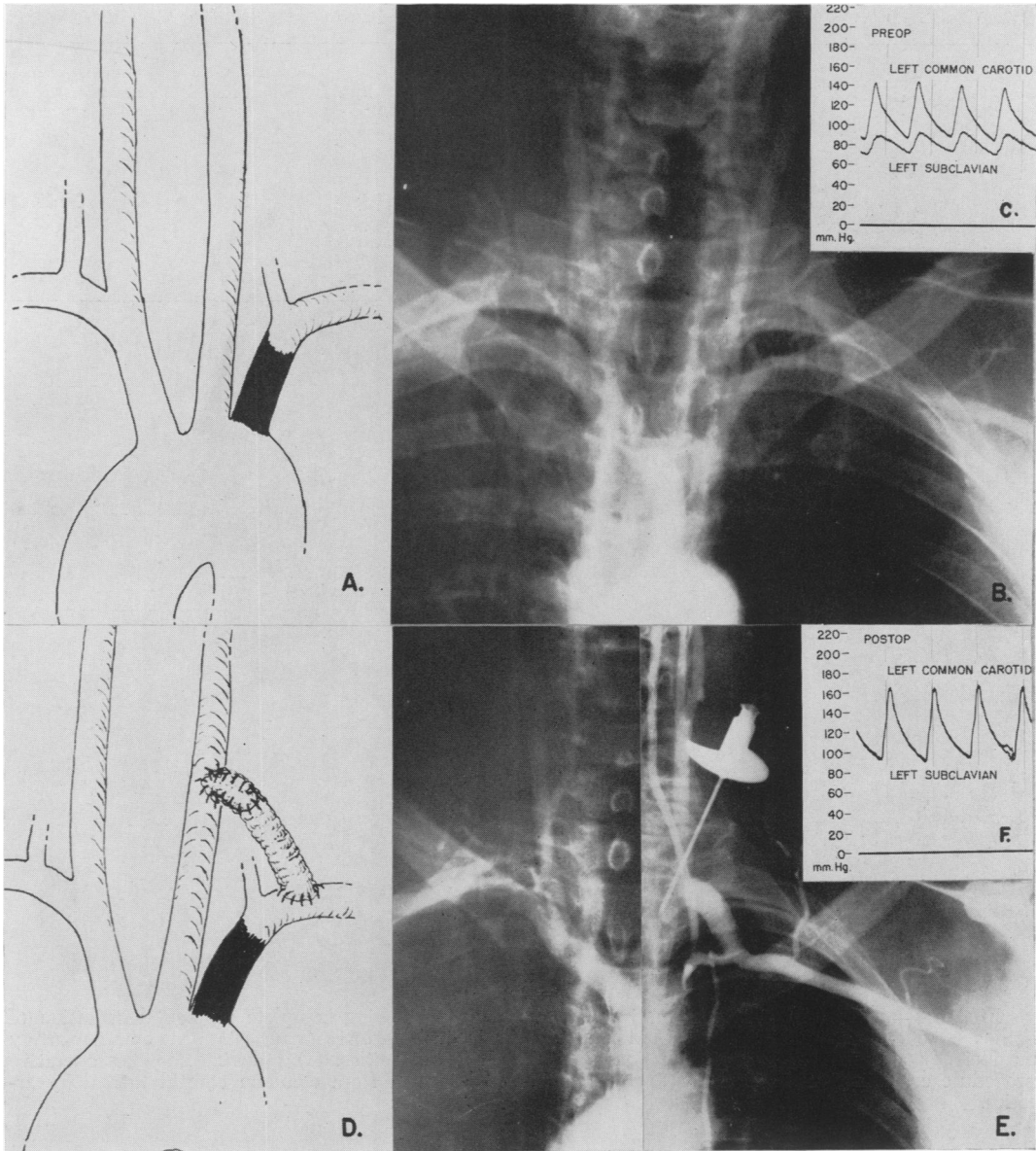


FIG. 8. Drawing (A) and preoperative arteriogram (B) showing complete segmental occlusion of left subclavian artery in a 48-year-old white man complaining of intermittent claudication of left arm associated with occasional episodes of dizziness, visual disturbances and "blackout spells." C) Arterial pressure measurements showing severe pressure gradient across lesion in left subclavian artery. D) Drawing showing operative procedure consisting of Dacron bypass graft from left common carotid to left subclavian artery. E) Arteriogram made 1 year after operation showing restoration of normal circulation in left subclavian artery through bypass graft. Patient has remained completely asymptomatic since operation more than 3 years ago. F) Arterial pressure measurements made immediately after completion of bypass graft showing elimination of pressure gradient.

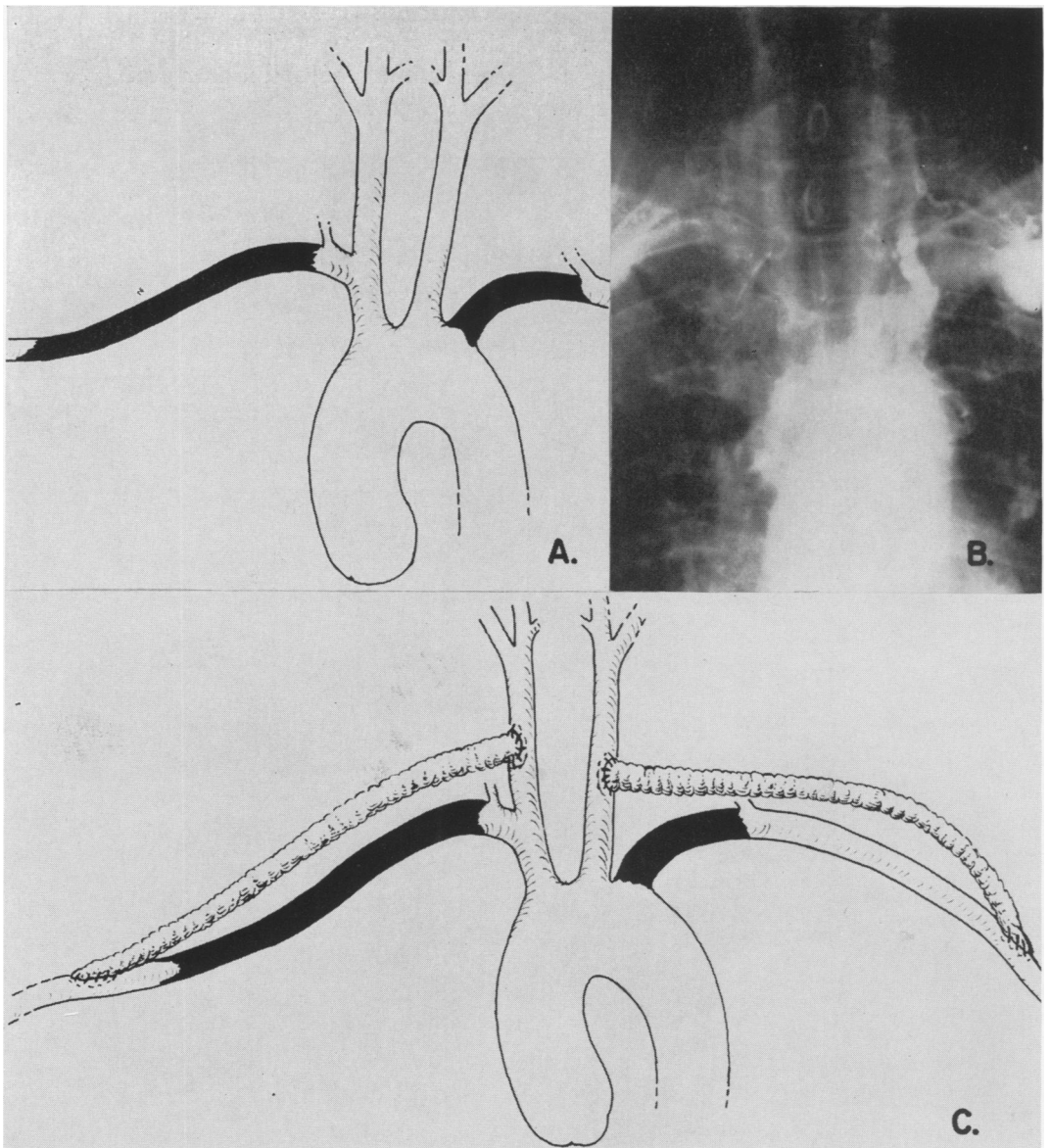


FIG. 9. Drawing (A) and preoperative arteriogram (B) showing complete segmental occlusion of both subclavian arteries in a 56-year-old white woman with progressive manifestations of basilar artery insufficiency and intermittent claudication of both upper extremities. C) Drawing showing operative procedure consisting of bilateral end-to-side Dacron bypass graft from common carotid to axillary arteries.

Results

The results of operation were analyzed and are presented with emphasis upon neurologic function and patient survival. The various factors which may influence either of these were analyzed and are presented accordingly.

Functional Results

The functional results are classified as *early* (the condition at the time of discharge from the hospital) and *late* (the neurologic functional change after operation at the time of the last follow up, or at the time of death). Most noteworthy is the

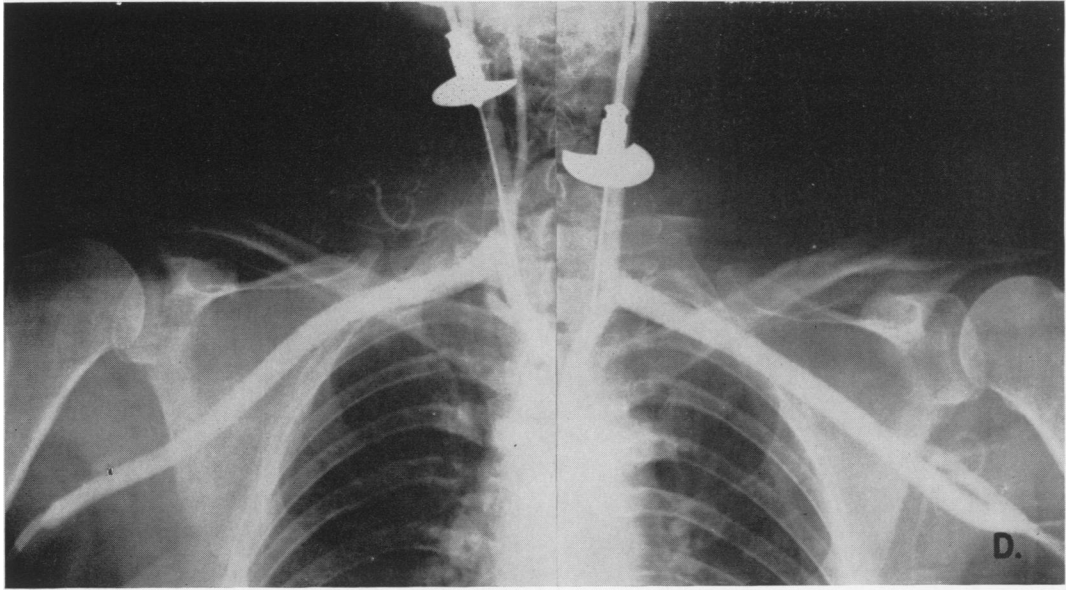


FIG. 9. D) Arteriogram made about 1 year after operation showing restoration of normal circulation through bypass grafts. Patient has remained completely asymptomatic.

observation that progressive improvement occurred with time; many patients who were significantly improved but not asymptomatic at the time of discharge from the hospital continued to improve over a period of weeks or months until they became completely asymptomatic. Thus, among the original group of 440 patients with manifestations of persistent progressive or completed stroke, 65 per cent were better, but only 16 per cent were asymptomatic at the

time of discharge from the hospital (Table 2). During the follow-up period, however, of 407 patients who survived operation, 81 per cent became better and 45 per cent became completely asymptomatic (Table 3).

A highly significant finding was the fact that only 44 patients (5%) of those surviving operation in the entire series either had recurrent neurologic difficulties or worsening of residual neurologic deficits (Table 3). Thus, this form of treatment

TABLE 11. Results at Time of Follow Up or at Time of Death According to Location of lesions treated

Artery Treated	No. Patients	Results					
		Deaths	Worse	No Change	Better		
Improved	Asymp-tomatic				Total		
External carotid	8	1 (12%)	1 (12%)	1 (12%)	2 (25%)	4 (50%)	6 (75%)
Internal carotid	526	118 (22%)	37 (7%)	47 (9%)	111 (21%)	331 (63%)	442 (84%)
Internal carotid and vertebral	57	8 (14%)	3 (5%)	3 (5%)	14 (25%)	37 (65%)	51 (90%)
Vertebral	84	13 (15%)	2 (2%)	10 (12%)	17 (20%)	55 (66%)	72 (86%)
Great vessel	86	11 (13%)	2 (2%)	6 (7%)	11 (13%)	67 (78%)	78 (91%)
Total	761	151 (20%)	45 (6%)	67 (9%)	155 (20%)	494 (65%)	649 (85%)

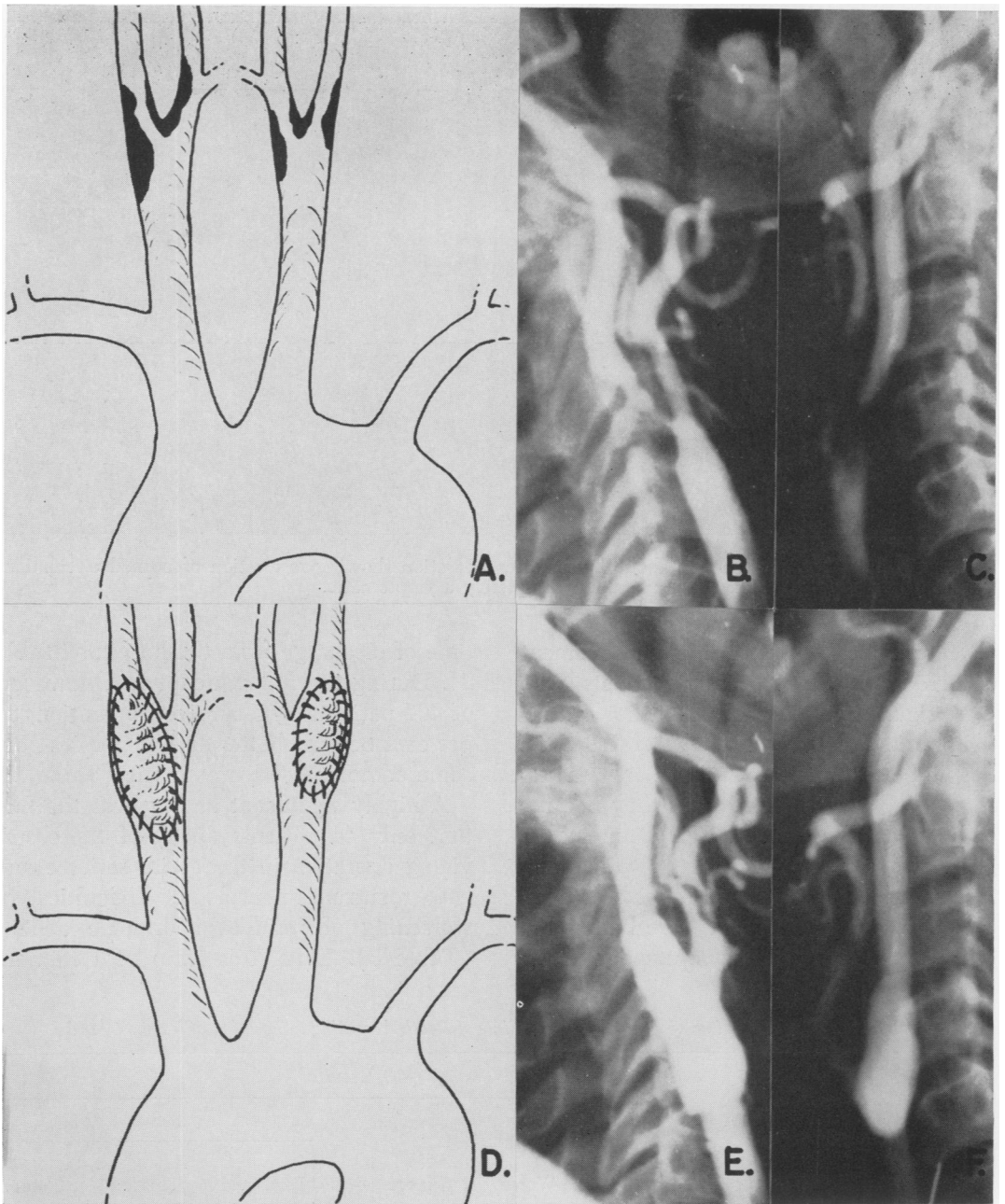


FIG. 10. Drawing (A), preoperative right carotid arteriogram (B) and preoperative left carotid arteriogram (C) showing severe stenosis of both internal carotid arteries in a 67-year-old white man complaining of intermittent episodes of diplopia, transient blindness and headaches over a period of about two months prior to admission. D) Drawing showing operative procedure consisting of thromboendarterectomy with patch graft angioplasty of both carotid arteries. E) Arteriograms made about 6 months after operation showing restoration of normal circulation in both internal carotid arteries. Patient has remained completely asymptomatic.

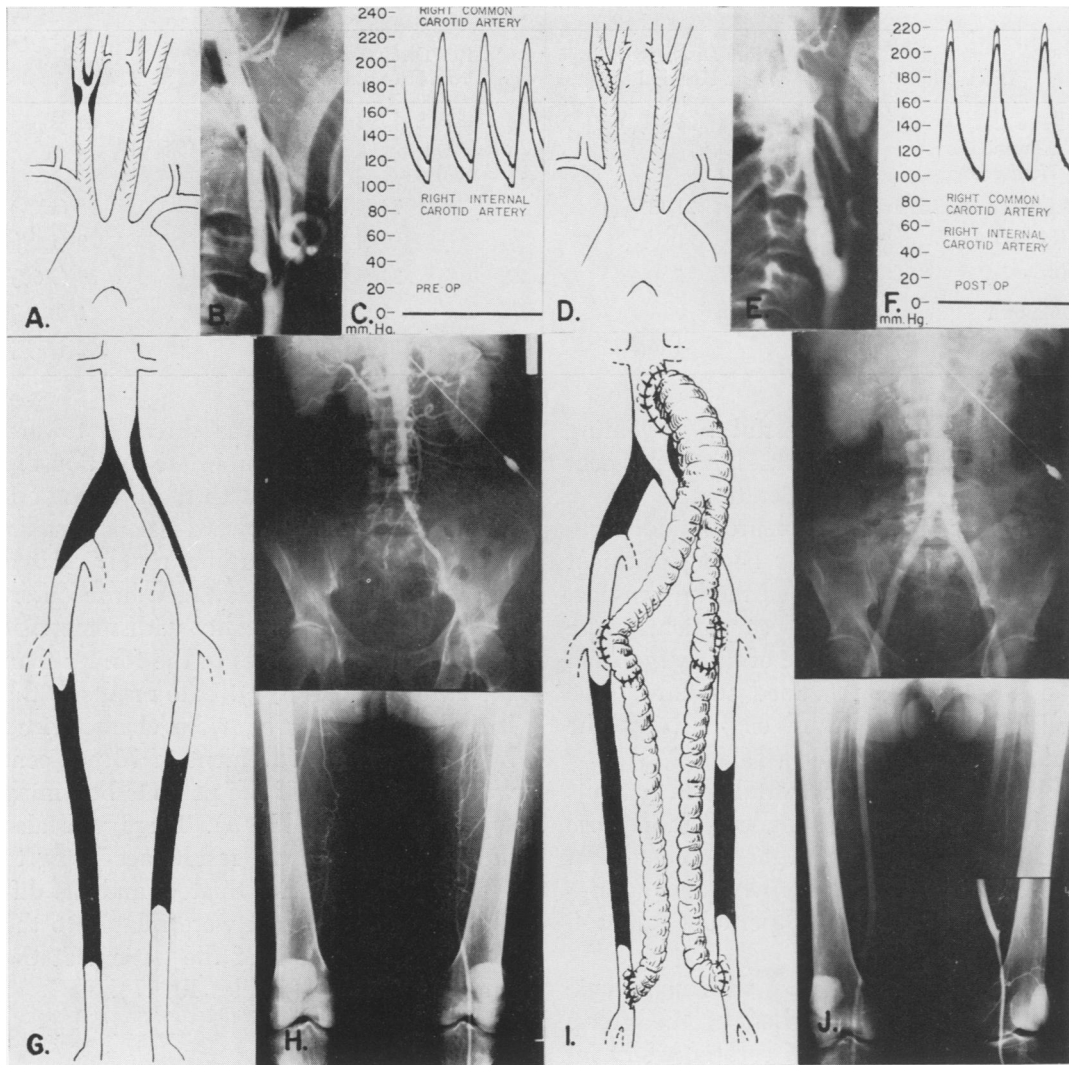


FIG. 11. Drawing (A) and preoperative right carotid arteriogram (B) showing severe stenosis of right internal carotid artery in a 50-year-old white male patient with complaint of intermittent episodes of blurring of vision, some numbness in left upper extremity and intermittent claudication of lower extremities. C) Arterial pressure measurements showing severe pressure gradient across lesion in right internal carotid artery. D) Drawing of operative procedure consisting of thromboendarterectomy with patch graft angioplasty of common and internal carotid arteries. E) Arteriogram made after operation showing restoration of normal lumen and circulation in right internal carotid artery. F) Arterial pressure measurements made immediately following operation showing elimination of pressure gradient in internal carotid artery. G) Drawing and H) aortogram showing segmental complete occlusion of right common iliac and both superficial femoral arteries and incomplete occlusion of left common iliac artery. I) Drawing illustrating operative procedure consisting of Dacron bypass graft from abdominal aorta to both common femoral arteries and both popliteal arteries. J) Aortogram made after operation showing restoration of normal circulation. Patient has remained asymptomatic since operation almost 2 years ago.

TABLE 12. *Causes of Death in Patients Submitted to Operation*

Disease	Before Discharge From Hospital	After Discharge From Hospital	Total
Stroke	25 (3%)	39 (5%)	64 (8%)
Thrombosis	19 (2.3%)	26 (3.2%)	45 (5.5%)
Hemorrhage	6 (0.7%)	13 (1.6%)	19 (2.3%)
Other cardiovascular	21 (2.6%)	78 (9.6%)	99 (12%)
Cancer	0	9 (1.1%)	9 (1.1%)
Other	5 (0.6%)	24 (3.0%)	29 (3.6%)
Unknown	0	1 (0.1%)	1 (0.1%)
Total	51 (6.3%)	151 (18.6%)	202 (25%)

may be considered successful in preventing further neurologic difficulties in 95 per cent of the cases surviving operation.

Among patients with neurologic disturbances, those classified as having transient cerebral ischemia obtained the best results, since 86 per cent of these patients were asymptomatic at the time of discharge from the hospital and remained so during the follow-up period, thus emphasizing the value of early operation (Tables 2, 3).

Although operative mortality in patients with acute strokes was higher than in those with chronic strokes, a higher percentage of the former became improved and asymptomatic in the follow-up period (Tables 4, 5).

Among the entire series with neurologic disturbances, a comparison of the group having manifestations of carotid artery insufficiency with those having manifestations of vertebral-basilar artery insufficiency revealed little difference in operative mortality, but a significantly higher percentage of the latter group became asymptomatic in the follow-up period (Tables 6, 7). This may be because the former group included a higher percentage of patients with transient symptoms at the time of operation while the latter group included a higher percentage of patients with completed strokes and with residual deficits at the time of operation.

A comparison of the group of patients

in whom operation was directed toward lesions located in appropriate relationship to the manifestations with those whose operation was directed toward lesions in other arteries, considered inappropriately related to the manifestations, revealed little difference in operative mortality with somewhat better functional results in the former than the latter (Tables 8, 9). Late results in the latter group, however, were characterized by significant improvement in 76 per cent with more than half the patients becoming asymptomatic (Table 9). There was also little difference in the results according to the location of lesions treated, and the differences that did exist were related to the neurologic condition of the patient at the time of operation (Tables 10, 11).

Survival

Death occurred in 51 patients (6.3%) before discharge from the hospital and after discharge in 18.6 per cent (Table 12). The most common cause, accounting for about half of all deaths, was associated cardiovascular disease. It is significant that death from cerebrovascular disease occurred in only 64 patients (8%), 25 (3%) during the period of hospitalization and 39 (5%) during the follow-up period. Of 812 surgically treated patients, 93.7 per cent survived operation, 85 per cent survived for 1 year, and 75 per cent were alive at the time of follow up.

Data regarding mortality, survival, severity of neurologic manifestations and presence of associated disease were organized in life-table form. For comparison, life tables were also constructed for a comparable standard population, adjusted for sex and age, from information provided by the census report of the U. S. Public Health Service for 1960.¹³ Although the study encompasses a period of almost 11 years and follow up is virtually complete, the majority of patients were treated during the latter half of the period. Thus, in order that the comparison may be more significant statistically, the tables considered survival only up to five years. In Figure 12 the abscissa represents years of survival and the ordinate (L_x), the number remaining alive at each year adjusted to 1,000 initial population. In this series 67.6 per cent of the patients survived up to 5 years, while 87.2 per cent of the normal population would have been expected to survive. The period of greatest risk is the first few weeks after operation because the mortality during this period accounts for one third of the difference in the 5-year survival of the two groups.

The most important factors influencing survival were associated heart disease and the presence of a neurologic deficit at the time of operation. The 5-year mortality rate in patients with arteriosclerotic heart disease was twice—and that of patients with hypertensive heart disease two and one-half times—that in patients without hypertension or heart disease (Fig. 1, 13). It is significant that the survival rate of patients without hypertension and heart disease closely approximates that expected from the normal population, and the slight difference largely constitutes the initial 3 per cent mortality in the treated group (Fig. 1, 14). The survival rate of patients with uncomplicated hypertension closely approximated that of patients without hypertension or heart disease. Finally, the 5-year survival

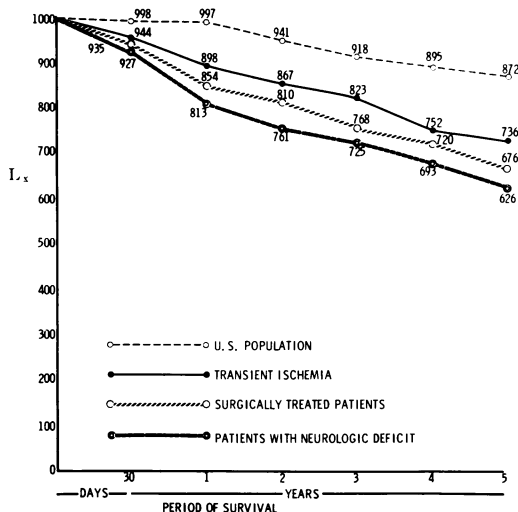


FIG. 12. Graph showing comparison of survival of patients treated for cerebral arterial insufficiency with comparable population adjusted for 1,000 initial population.

rate was 10 per cent better in patients submitted to operation for transient cerebral ischemia than in those who had neurologic deficits at the time of operation (Fig. 12).

Discussion

The observations derived from this experience support the conviction, which we have long held, that the great majority of patients with cerebral arterial insufficiency resulting from extracranial segmental occlusive lesions can be successfully treated by surgical methods with highly gratifying results. This is evidenced by the fact that 95 per cent of the patients survived operation, the great majority of whom resumed normal activities during the long follow-up period. There is evidence too that recurrence of cerebrovascular insufficiency was prevented in a high proportion of cases, since only 5 per cent of the patients became worse and late deaths from this cause accounted for only 5 per cent of the cases.

The fact that the operative mortality is highest in patients with acute strokes has raised some question about the desirability of performing early operation under these

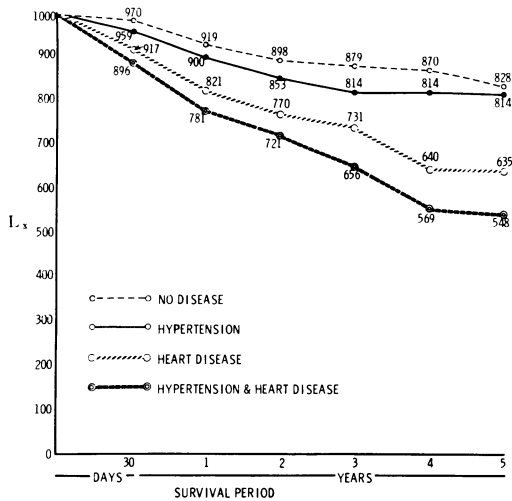


FIG. 13. Graph showing comparison of survival of patients treated for cerebral arterial insufficiency according to presence of hypertension and heart disease.

circumstances. It has been suggested that there is great danger of producing hemorrhage in the ischemic portion of the brain following restoration of normal circulation in the arterial bed supplying this part of the brain. Our experience would suggest that although this may be true its occurrence is relatively rare, with an incidence of less than 1 per cent. Moreover, there is greater danger of death and permanent ischemic damage to the brain from delay in restoration of normal circulation. This viewpoint is supported by the fact that in the natural course of the disease there is a relatively high mortality, probably over 20 per cent, during the initial attack¹²—indeed significantly higher than our operative mortality—and by the fact that the long-term results in our surgically-treated series were even better in this acute group than in the chronic cases.

Particularly significant, and supporting our concept of the totality of cerebral blood flow, are the observations demonstrating the beneficial results obtained following surgical treatment of occlusive lesions involving arteries not appropriately related to the

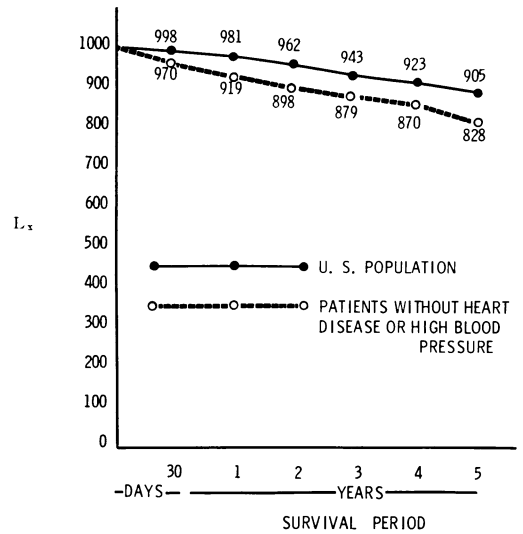


FIG. 14. Graph showing comparison of survival of patients with hypertension or heart disease treated for cerebral arterial insufficiency with comparable population.

clinical manifestations.³ Increasing experience has demonstrated that the classic patterns of clinical and neurologic disturbances frequently do not reflect the exact nature, site and extent of involvement of the occlusive process in the extracranial arterial bed. It has been found, for example, that in some patients having intermittent ischemic episodes characterized by clinical manifestations of occlusion of the internal carotid artery, complete arteriographic studies may reveal the responsible and surgically correctible lesion to be in the vertebral arteries (Fig. 5). On the other hand, in patients with characteristic manifestations of basilar artery insufficiency, complete arteriographic studies may reveal the responsible and surgically correctible lesion to be in the internal carotid arteries (Fig. 3). There are several reasons for these apparent discrepancies in the correlation of clinical manifestations with the site and extent of the occlusive lesions; most important are the frequency of multiple involvement and the presence of collateral circulation. The brain receives its arterial

blood supply from four major arterial systems—the two vertebral and two internal carotid arteries—and these two systems may communicate with each other through two major sources of collateral circulation—an extracranial source, mainly from branches of the external carotid and thyrocervical arteries, and an intracranial source through the circle of Willis. The compensatory nature of this often rich source of collateral circulation resulting from the gradual onset of occlusive disease has not been fully appreciated and deserves emphasis in both better understanding and proper surgical management of this problem.

Obviously, collateral circulation is the essential factor in this concept of the totality of cerebral blood flow. The fact that an acute occlusion of a major artery may produce immediate ischemic damage to the tissues it supplies, while gradual occlusion of this same artery may cause little or no ischemic disturbance because of the compensatory development of collateral circulation, has long been well known. Under the latter circumstances ischemic disturbances are manifested only when the collateral circulation is inadequate to meet the demands which may be placed upon it by the tissues which it supplies. This, of course, is the well-known explanation for intermittent claudication of the lower extremities and it is equally applicable to the brain.

Another important conceptual consideration, supported by the observations derived from this analysis of our surgical experience, concerns the significant distinction between viability and function. It has long been recognized that tissues may tolerate and survive relatively long periods of certain degrees of ischemia. Although function may be abolished during this time, with return of adequate arterial blood flow and oxygenation, there may be complete return of normal function. While brain tissue may be more sensitive to oxygen lack, it can survive certain degrees of ischemia even

though function during the ischemic period is completely abolished. It would also appear that gradual, chronic and repeated periods of ischemia may even increase the tolerance of the tissues to oxygen lack. This distinction between viability and function of cerebral tissue is further indicated by our experience with many patients having severe manifestations of depressed cerebral function, characterized by progressive or even stable neurologic defects over a relatively long period of time, who obtain complete restoration of normal cerebral function following restoration of normal circulation.

It is apparent from these observations that the classical approach to this problem, based upon the belief that the site and extent of the arterial occlusion may always be determined by a well-defined pattern of clinical manifestations, is no longer acceptable. More recently these conceptual considerations concerning the critical level of the totality of cerebral blood flow in relation to neurological deficit, the role of collateral circulation and the distinction between viability and function of cerebral tissue have instigated a more exacting evaluation of each case, with complete angiographic studies regardless of the nature and severity of symptoms.³ This approach, as evidenced by our experience, has revealed many operable lesions which would not have been detected by clinical and neurologic evaluation or by angiography limited to the arterial segment suggested by the clinical manifestations. To be sure, a careful clinical and neurologic study of the patient remains essential and in many cases will provide a reasonably accurate evaluation of the problem. In a large proportion of cases, however, the only means by which a precise diagnostic evaluation of the problem can be made, particularly in relation to the application of surgical therapy, is by complete angiography of both the extracranial and intracranial arterial systems.

Finally, this analysis of our experience suggests that surgical treatment provides a means not only of obtaining relief of symptoms and preventing further attacks of cerebral ischemia but also of prolonging life. In the entire series of follow-up studies, extending from 1 to 11 years, significant improvement occurred in 85 per cent of the patients, about two thirds of whom were completely asymptomatic. Furthermore, late deaths from recurrent cerebrovascular insufficiency occurred in only 5 per cent of the cases. Particularly significant is the fact that the 5-year survival rate in patients without associated cardiovascular disease approximates that of a comparable standard population.

Summary

This report is concerned with an analysis of our experience with the surgical treatment of 812 patients with manifestations of cerebrovascular insufficiency in whom follow-up studies have been made from 1 to 11 years. Current follow-up studies are available on over 99 per cent of the cases.

Ages of the patients ranged from 20 to 85 years with the highest incidence in the sixth and seventh decades. The ratio of men to women was 5:2. Hypertension was present in slightly more than one half, and both hypertension and heart disease in about one third, of the cases. Associated aneurysmal or occlusive arterial disease was present in slightly more than one half the cases and required surgical treatment in 27 per cent.

Arteriosclerosis or atherosclerosis was the predominant underlying pathologic lesion producing occlusion. The most frequent location of the occlusive lesions for which operation was performed was at the bifurcation of the common carotid and origin of the internal carotid arteries (almost 70 per cent of cases). Next in frequency were those located in the great vessels arising from the aortic arch, the vertebral arteries, and those involving both internal carotid

and vertebral arteries. There was multiple arterial involvement in 75 per cent of the cases.

On the basis of clinical manifestations the patients were classified into four categories:

1) Forty-eight patients with little or no neurologic disturbance but with other manifestations of occlusive lesions, 98 per cent of whom remained asymptomatic during the follow-up period.

2) Transient cerebral ischemia; among 324 patients, 89 per cent were improved and 86 per cent remained asymptomatic during the follow-up period.

3) Persistent progressive stroke; among 34 patients, 86 per cent were improved and 53 per cent remained asymptomatic during the follow-up period.

4) Completed stroke; among 406 patients, 80 per cent were improved and 44 per cent were asymptomatic during the follow-up period.

Particularly noteworthy is the fact that progressive improvement occurred with time following operation; among 440 patients with manifestations of persistent progressive or completed stroke, 65 per cent were better but only 16 per cent will be asymptomatic at the time of discharge from the hospital, whereas during the follow-up period 81 per cent became better and 45 per cent became asymptomatic.

Among patients with neurologic disturbances, those classified as having transient cerebral ischemia obtained the best results; 86 per cent remained asymptomatic during the follow-up period.

Of special interest are those patients with multiple arterial involvement in whom the occlusive lesion considered appropriately related to the neurologic manifestations was inoperable, but in whom operation was directed to the remaining operable lesions in order to increase blood flow to the involved portion of the brain through collateral circulation. Late results in this group of pa-

tients were characterized by significant improvement in 76 per cent with more than half the patients becoming asymptomatic.

The total operative mortality in the series was about 6 per cent and death in the subsequent follow-up period occurred in 18 per cent. Death from cerebrovascular insufficiency occurred in only 3 per cent of the early deaths and 5 per cent of the late deaths.

Follow-up studies indicate strongly that surgical treatment prolongs life in these patients. While the 5-year survival rate in the total series was 67.6 per cent, as compared with about 87 per cent in the normal population, this rate is also influenced by factors such as the presence of associated cardiovascular disease and types of neurologic deficits. For example, patients with no associated cardiovascular disease had a 5-year survival rate almost equal that of the normal population. Furthermore, the patients operated upon for transient cerebral ischemia had a 5-year survival rate 10 per cent better than that of patients who had neurologic deficits at the time of operation.

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