Surgical Considerations of Occlusive Disease of Innominate, Carotid, Subclavian, and Vertebral Arteries *

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ATHEROSCLEROTIC occlusive lesions of the great vessels arising from the aortic arch and of the internal carotid arteries in the neck were well described by Broadbent,[1] in 1875, and Penzoldt,[15] in 1881. The significance of these lesions in patients with cerebral arterial insufficiency was also recognized by Chiari,[2] in 1905, and by Hunt,[12] in 1914, who suggested investigating the carotid arteries in all such patients. Subsequent development of certain arteriographic technics [3, 10, 16] made accurate diagnosis possible, the need for which was again emphasized by the pathologic studies of Hutchinson and Yates,[13] in 1947, and Fisher,[11] in 1951. The most significant recent advance in the knowledge of this disease was the recognition of the segmental nature of the lesions because this concept led to the application of operative procedures that had proven effective in the treatment of similar lesions occurring elsewhere, namely, the aorta and the iliac, femoral, and popliteal arteries.[6] The successful restoration of circulation by procedures directed toward the lesion itself incited considerable interest in patients with arterial insufficiency of the cerebrum and upper extremities.[3, 5, 8, 9, 14, 17] Subsequent more aggressive investigation of these problems by arteriography demonstrated operable lesions in a large percentage of the cases indicating the frequency with which the disease could be effectively treated by reconstructive operation.

Our experience with this method of therapy extends over a period of a little more than five years and includes 88 occlusive lesions of the innominate, common and internal carotid, subclavian and vertebral arteries. Accordingly this report is concerned with certain observations derived from an analysis of this experience, with particular emphasis upon surgical management and upon types of operative procedures employed for the various patterns of occlusive lesions encountered.

Clinical Material

In a series of 174 patients with manifestations of arterial insufficiency of the cerebrum and upper extremities, arteriographic studies revealed the presence of extracranial arterial occlusion in 73 (42 per cent), 63 of whom were operated upon. A total of 115 extracranial arterial occlusive lesions occurred in the latter group of patients, multiple lesions being present in approximately one half of these cases (Tables 1–3). Of the 63 patients submitted to operation ten were found to have inoperable lesions owing to the presence of

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extensive complete occlusion of the internal carotid and vertebral arteries without a patent distal segment. All of these patients had manifestations of long duration. In the remaining 53 patients the occlusive lesions were found to be segmental in nature and susceptible to restorative operations. Since this report is directed primarily toward surgical management, the observations presented here are concerned with this latter group of patients.

Pathology

The underlying etiologic factor in the great majority of these cases is atherosclerosis. Although multiple lesions are frequent, the disease in general assumes two patterns of involvement, namely, a proximal and distal form, similar to those observed in patients with arterial insufficiency of the lower extremities (Tables 2, 3).[6] In the former type, the occlusion is located in either one, two, or all of the great vessels arising from the aortic arch. The obstruction in these cases may be either complete or incomplete and may be localized to a short segment of artery near its origin, or may be more extensive and involve the major portion of their course in the neck. A particularly fortunate pathologic feature of this type of occlusion is the fact that despite the extensive nature of some of these lesions the occlusive process tends to be well localized with patency of the arterial bed beyond the distal limits of the occlusion. In the distal form of the disease the occlusive lesion usually occurs near the origin of the internal carotid or vertebral arteries and may also be incomplete or complete. In contrast with the proximal form of the disease, the occurrence of complete obstruction in this distal form is rarely well localized and usually extends well into the intracranial portions of the vessels. Such cases usually represent the more advanced forms of the disease in which thrombosis has supervened upon a partially occlusive process. For this reason most cases of this type are found to be inoperable.

TABLE 1. *Occlusive Disease of Innominate, Carotid, Subclavian and Vertebral Arteries*

Location	No. Cases	No. Explored	No. Circulation Restored
Internal carotid	64	50 (78%)	37 (74%)
Common carotid	11	9 (82%)	9 (100%)
Innominate	10	8 (80%)	8 (100%)
Subclavian	18	15 (83%)	15 (100%)
Vertebral	12	6 (50%)	3 (50%)
Total	115	88 (77%)	72 (82%)

TABLE 2. *Occlusive Disease of Innominate, Carotid, Subclavian and Vertebral Arteries*

Type Occlusion	No. Cases	No. Explored	No. Circulation Restored
Proximal			
Complete	22	20 (91%)	20 (100%)
Incomplete	17	12 (71%)	12 (100%)
Distal			
Complete	31	19 (61%)	6 (32%)
Incomplete	45	37 (82%)	34 (92%)
Total	115	88 (77%)	72 (82%)

Clinical Manifestations

The clinical features of the disease depend upon the location and extent of the lesion. Proximal involvement is characterized by manifestations of arterial insufficiency of the brain and upper extremities. Although the patient's main concern may be recurring hemiplegia, it is more often intermittent claudication of the upper extremities. Collateral circulation is usually good and the essential physical findings in these cases are limited to the vessels. Pulses may be diminished or absent in the neck and/or arm. Blood pressure in the arms may be difficult to obtain or may vary from

one side to the other. Systolic murmurs are frequently heard at the base of the neck and in the supraclavicular regions, particularly in patients with partial occlusion. In some cases collateral circulation may be less well developed, and there may be gangrene of the fingers or recurring episodes of cerebral arterial insufficiency, particularly in the presence of secondary distal occlusions of the vertebral or internal carotid arteries. The precise location and extent of the occlusive process are determined by arteriography, a detailed description of which has been presented elsewhere.[3, 4]

Distal arterial occlusion is associated predominantly with cerebral manifestations which vary according to the location and extent of obstruction. In most instances because of the limitations of collateral circulation the symptoms are more severe in these cases than in those with proximal lesions. Patients with partial occlusion of the internal carotid artery usually have transient recurrent attacks of paralysis, aphasia, paresthesia, and visual disturbances. Although recovery may have occurred in many cases by the time of admission, neurologic deficits may persist, particularly in those patients with bilateral lesions. The physical findings in these patients are limited to the ophthalmologic and neurologic disturbances when present and certain changes in the carotid arteries. A systolic murmur is heard under the angle of the jaw, and in the presence of contralateral occlusion, unilateral carotid artery compression may cause syncope and transient loss of consciousness. Arterial pulsations in the neck, throat and face are usually normal. The history of illness in patients with complete occlusion of the internal carotid artery is in general longer than in those with incomplete occlusion. Persistent neurologic disturbances, usually in the form of paralysis, are present in most of these cases. The diagnosis of complete occlusion of the internal carotid artery in the neck is usually not evident on clinical examination, although this lesion is suggested by persistent extensive paralysis and syncope by contralateral carotid compression. Vertebral artery occlusion is manifested by the clinical picture previously described as basilar artery thrombosis which consists of visual (cortical), cerebellar, cranial nerve, and bilateral motor and sensory disturbances. These symptoms may be transient in some cases and persistent in others. Due to the limitations of diagnosis in patients with the distal forms of the disease, all patients with manifestations of cerebral arterial insufficiency in whom proximal lesions are not suspected should be studied by arteriography as soon as possible after an attack of cer-

TABLE 3. *Occlusive Disease of Innominate, Carotid, Subclavian and Vertebral Arteries*

Type Occlusion	No. of Arteries Involved				
	One	Two	Three	Four or More	Total
Complete	16	4	1	1	22
Incomplete	15	9	0	2	26
Combined	0	8	4	3	15
Total	31	21	5	6	63

TABLE 4. *Occlusive Disease of Innominate, Carotid, Subclavian and Vertebral Arteries*

(Surgical Treatment)

Type of Operation	No. Cases	Circulation Restored	
		No. Cases	Per Cent
Thromboendarterectomy	37	34	92
Graft bypass	38	38	100
Exploration only*	13	0	0
Total	88	72	82

* Complete occlusion of long duration.

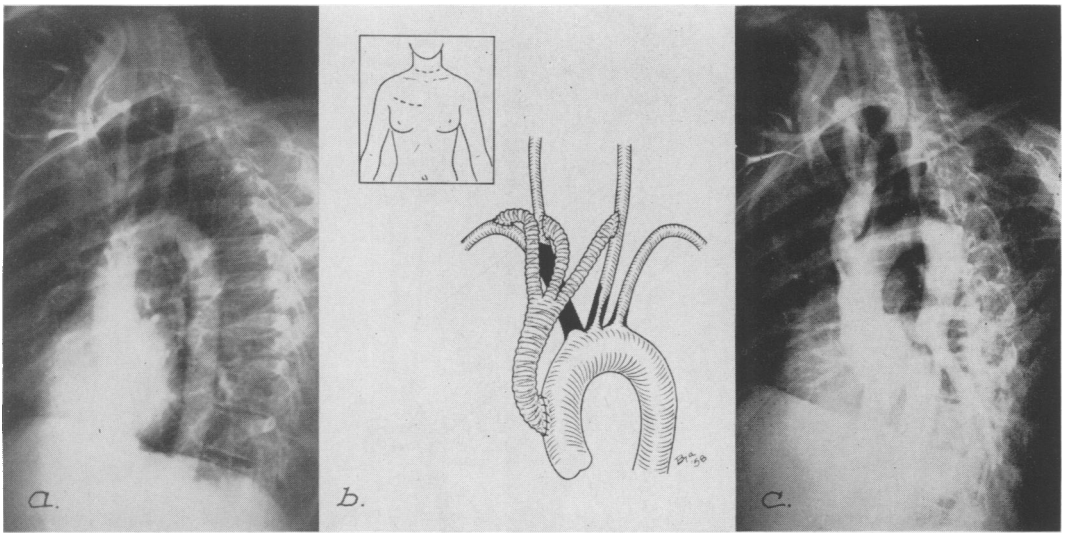

FIG. 1. Illustrations in case of multiple involvement of vessels arising from aortic arch showing application of bypass method of treatment. (a) Aortogram performed before operation showing complete occlusion of innominate artery and incomplete occlusions of left common carotid and left subclavian arteries. (b) Diagrammatic drawing showing location of incisions, extent of occlusive lesion (in black) and bypass graft. (c) Postoperative aortogram showing restoration of circulation through graft.

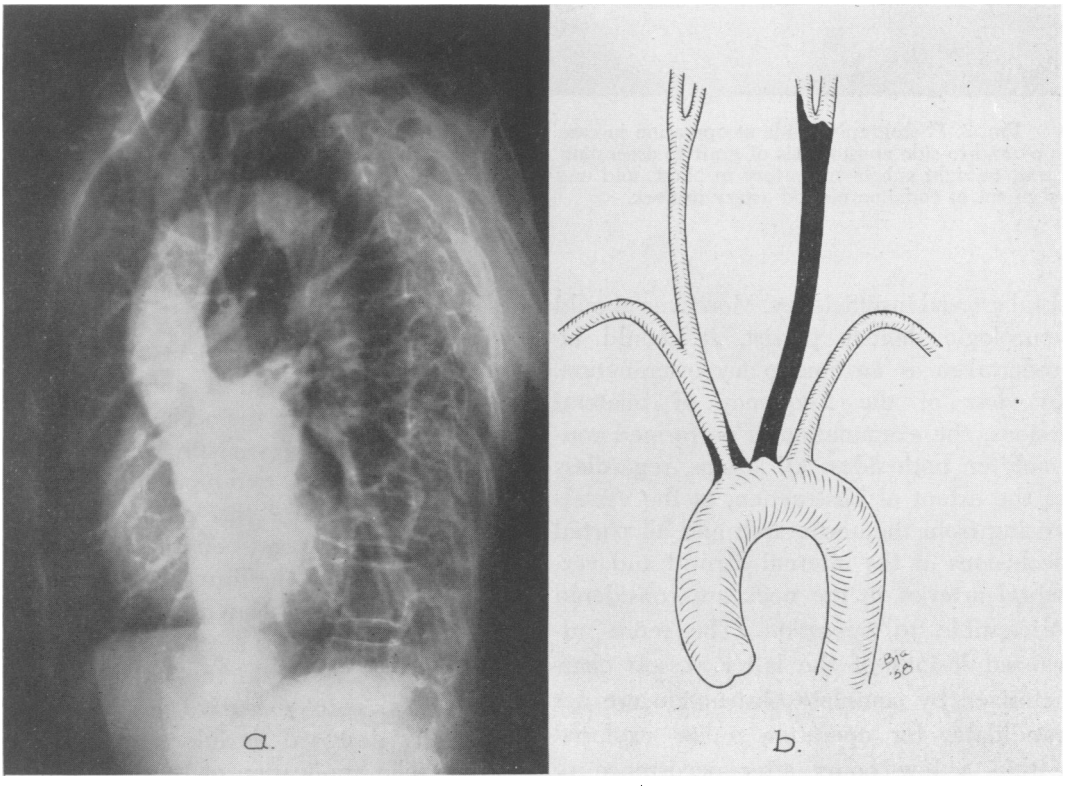

FIG. 2. (a) Preoperative aortogram in patient with incomplete occlusion of innominate artery and complete occlusion of left common carotid artery. (b) Diagrammatic drawing showing extent of occlusive lesions (in black).

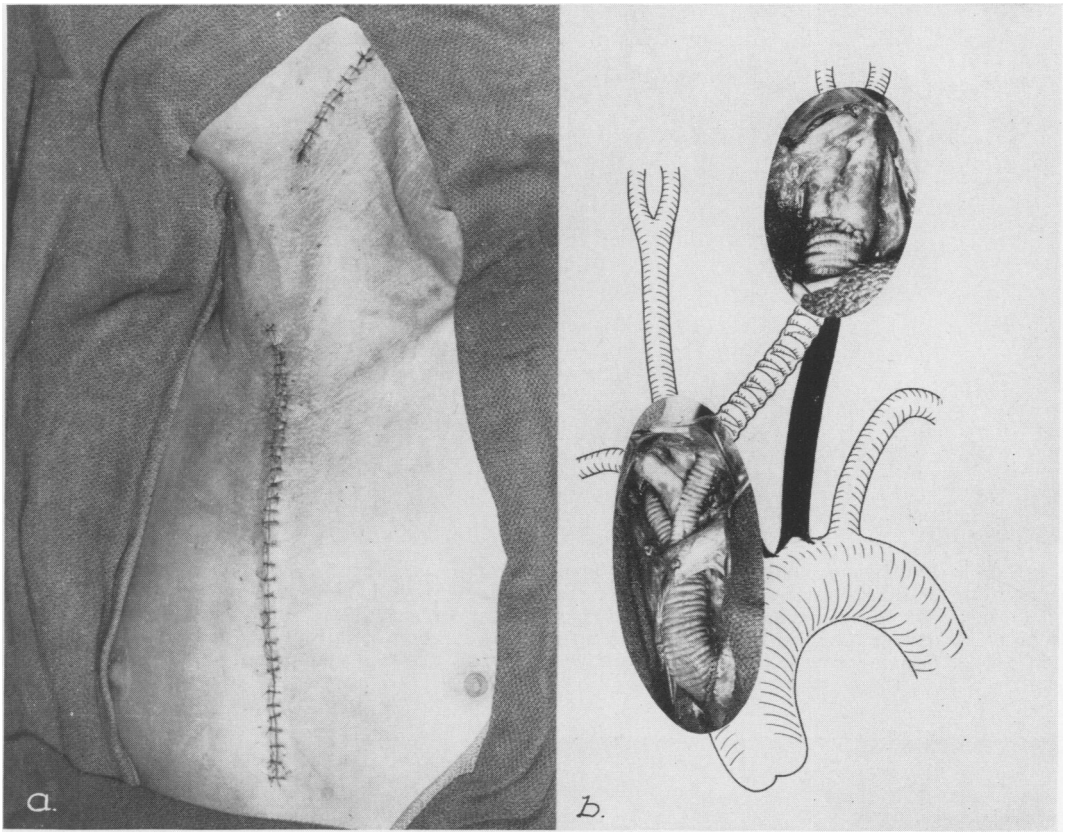

FIG. 3. Photographs made at operation in case shown in Figure 2 showing (a) incisions employed and (b) end-to-side anastomosis of graft to ascending aorta proximal to occlusions, end-to-side anastomosis of graft to right subclavian artery in chest, and end-to-side anastomosis of graft to endarterectomized distal segment of common carotid artery in neck.

ebral arterial insufficiency. Moreover, should neurologic deficits persist, it should be undertaken as an emergency examination. In view of the frequency of bilateral lesions, the examination is performed routinely on both sides. All lesions, regardless of the extent of obstruction, in the vessels arising from the aortic arch and all partial occlusions of the internal carotid and vertebral arteries in the neck are considered susceptible to operation. The more advanced lesions of the latter vessels characterized by complete obstruction are not candidates for operation unless explored within a few hours after occurrence of manifestations of complete obstruction.

Treatment

Treatment in these patients was directed toward restoration of a normal pulsatile blood flow distal to the occlusion to relieve symptoms or to prevent progression of the disease. In general two types of procedures were employed for this purpose, namely, endarterectomy and end-to-side bypass graft (Table 4). The former was applied in the treatment of lesions that were discrete and well localized to a relatively short segment of artery while the latter was employed for more extensive lesions using a specially designed flexible knitted dacron tube.[7] The application of these procedures was also dependent in large measure upon

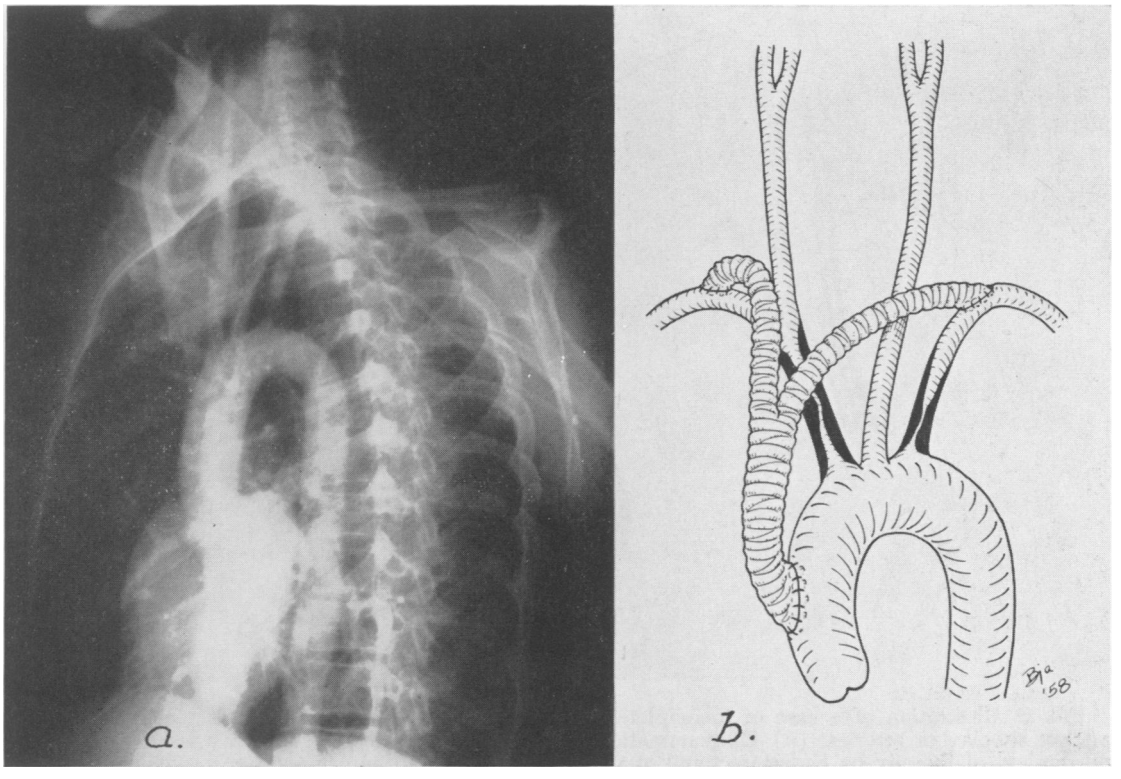

FIG. 4. (a) Preoperative aortogram showing well localized incomplete occlusions of innominate and left subclavian arteries. (b) Diagrammatic drawing showing extent of lesions (in black) and method of bypass employed.

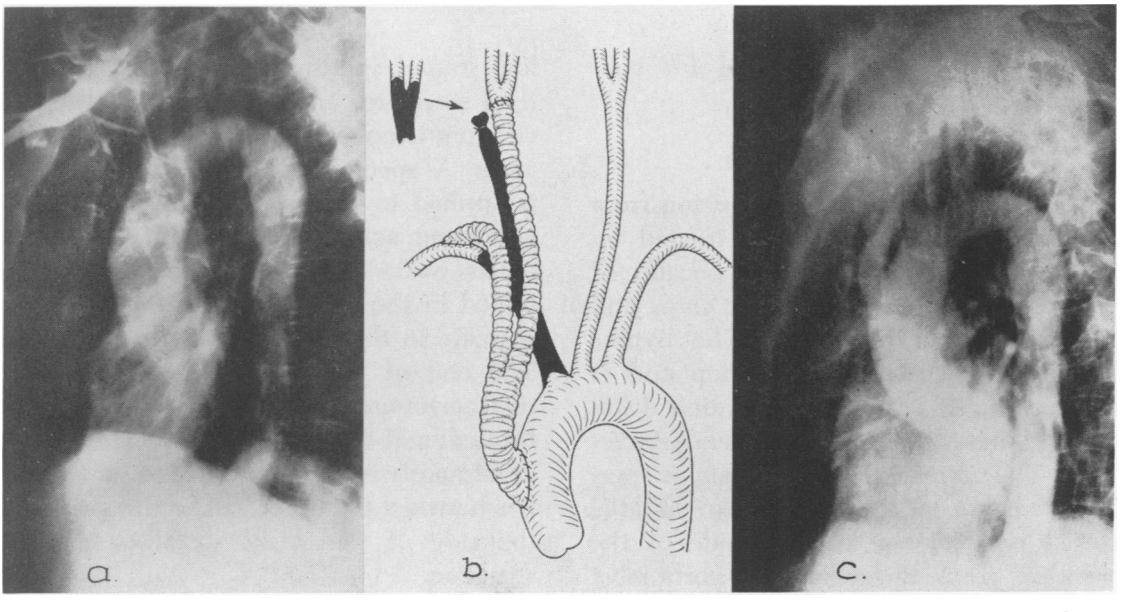

FIG. 5. (a) Aortogram showing complete occlusion of innominate artery. (b) Diagrammatic drawing showing extent of occlusion (in black) and bypass graft attached to ascending aorta by end-to-side anastomosis and to right subclavian artery by similar anastomosis and by end-to-end anastomosis to endarterectomized distal segment of common carotid artery. (c) Postoperative aortogram showing restoration of circulation through bypass graft.

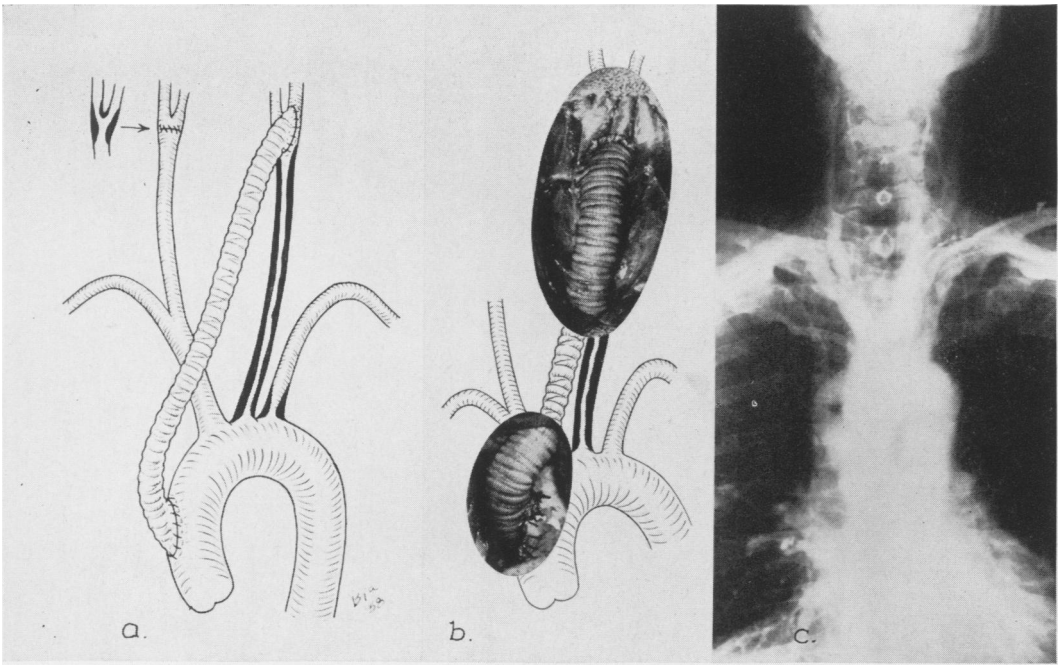

FIG. 6. Illustration of a case of incomplete occlusion of right internal carotid, left common carotid and left subclavian arteries. (a) Diagrammatic drawing showing extent of occlusive lesions (in black) and method of therapy by endarterectomy of right common carotid and bifurcation by means of bypass graft from ascending aorta to left common carotid near bifurcation. (b) Photographs at operation showing end-to-side anastomosis of graft to ascending aorta proximal to occlusion and end-to-side anastomosis of graft to side of bifurcation of common carotid artery. (c) Postoperative aortogram showing restoration of circulation in both carotid arteries.

the location of the lesion and for convenience is discussed separately.

Proximal Occlusions

Lesions of the great vessels arising from the aortic arch are preferably treated by employing the bypass principle, because of the extent of occlusion in these cases and the simplicity of operation.[5] The bypass procedure requires less dissection and is more certain of restoring circulation distal to the diseased segment than endarterectomy. The proximal anastomosis is performed between the end of a suitable arterial replacement and the side of the ascending aorta, the segment of aorta most accessible for this purpose. The exposure for this part of the operation is obtained through either a small second intercostal right anterior thoracic incision or a midline sternal splitting incision. The mediastinal structures are separated and the pericardium is opened to expose the ascending aorta. A specially designed curved clamp is applied to the anterolateral wall of the ascending aorta, thus excluding a portion of its wall. Thus, with circulation maintained in the aorta, a longitudinal incision is made in the excluded segment of aorta. The end of the graft is then sutured to this aortotomy using a simple continuous through-and-through suture. The distal anastomosis is performed in the same manner between the other end of the graft and the side of the vessel distal to the obstruction.

The actual location of the distal anastomosis is dependent upon the extent, location and number of vessels involved in the occlusive process. Multiple involvement of

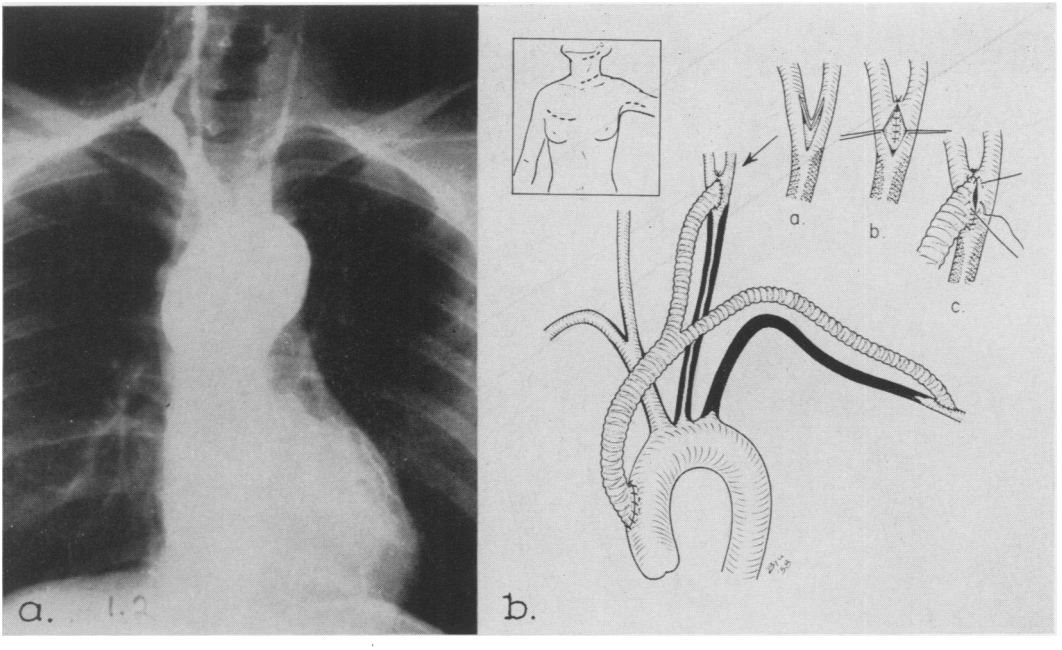

FIG. 7. (a) Preoperative aortogram showing occlusion of left common carotid and left subclavian arteries. (b) Diagrammatic drawings showing incisions employed, extent of occlusive lesions (in black) and method of bypass.

the vessels arising from the aortic arch is frequent and to bypass all of the lesions

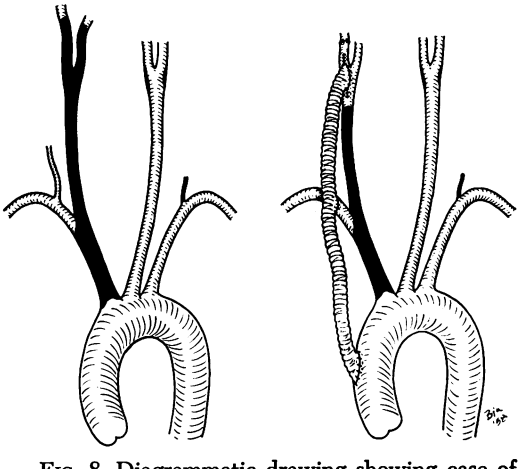

FIG. 8. Diagrammatic drawing showing case of complete occlusion involving innominate, right common carotid, right internal and external carotid, and left vertebral arteries. Extent of lesions is shown (in black) on left, and diagram on right shows end-to-side anastomosis of graft to ascending aorta proximal to occlusion, side-to-side anastomosis of graft to right subclavian artery, and end-to-side anastomosis of graft to endarterectomized distal segment of common carotid artery.

a bifurcated or trifurcated graft may be required (Fig. 1). In such cases the end of the aortic segment of the graft is sutured to the side of the ascending aorta, as previously described, and the ends of the limbs of the graft are sutured to the sides of the involved vessels distal to the occlusion. When the obstruction is incomplete and well localized to the origins of the vessels, the anastomoses may be performed in the chest through an exposure provided by a sternal splitting incision (Fig. 2, 3). In other cases the occlusive process is more extensive and in order to get beyond the entire diseased segment, the distal anastomoses are performed in the vessels at the base of the neck through a low collar incision with the graft drawn retrosternally through a tunnel made by blunt dissection connecting the thoracic and cervical incisions (Fig. 1). In cases in which the occlusion is limited to the innominate artery without involvement of its bifurcation, circulation may be restored in the right com-

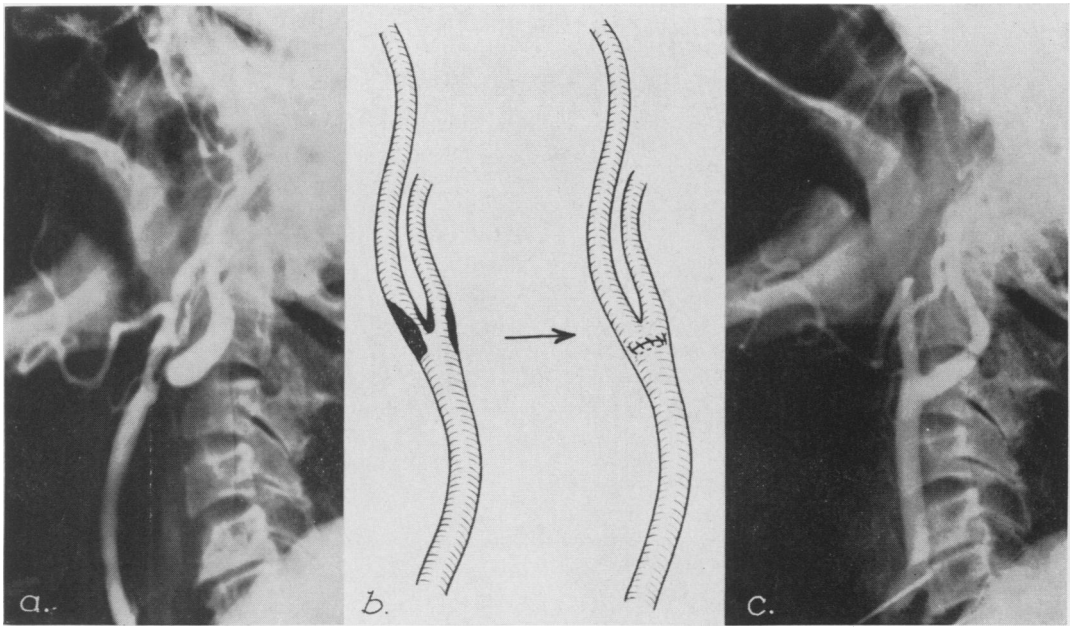

FIG. 9. Illustrations in case of incomplete occlusion of internal carotid artery showing application of endarterectomy. (a) Preoperative arteriogram showing incomplete occlusion of short segment of internal carotid artery. (b) Diagram showing extent of lesion on left and arterial incision on right employed for endarterectomy. (c) Postoperative arteriogram showing restoration of normal arterial channels.

mon carotid and right subclavian arteries by attachment of the distal end of the graft to the subclavian artery (Fig. 4). In other cases of innominate artery occlusion in which the obstruction involves the origins of both the subclavian and right common carotid arteries, a bifurcation graft is required with separate anastomoses of the limbs of the graft to each artery (Fig. 1). Occlusion of the common carotid arteries frequently involves the proximal segment of internal carotid artery producing partial occlusion of this vessel (Fig. 2, 3, 5, 6). In such cases, the obstruction is removed from the distal common carotid artery and the internal carotid artery by the technic of endarterectomy. The distal end of the tube bypassing the common carotid artery is then sutured to the distal end or to the side of the endarterectomized segment of common carotid artery (Fig. 2, 3, 5, 6). Under these circumstances a separate incision is employed for exposure of the common carotid artery at its bifurcation and the graft is brought up through a tunnel made by blunt dissection from the lower collar incision in the neck. Various other combinations of multiple occlusive lesions may be encountered, but application of these principles of the bypass graft may be effectively employed to restore normal circulation in the distal arterial bed (Fig. 7, 8).

Internal Carotid Artery

Occlusions of the internal carotid artery may be treated either by endarterectomy or by the use of the bypass graft. Whenever possible the former is considered preferable because of the simplicity of the operation. Fortunately it is usually possible in well localized incomplete occlusive lesions. In other cases, however, in which the lesion is more extensive and involves a long segment of artery or has produced considerable intramural destruction of the vessel, the end-to-side bypass procedure is more suitable than endarterectomy.

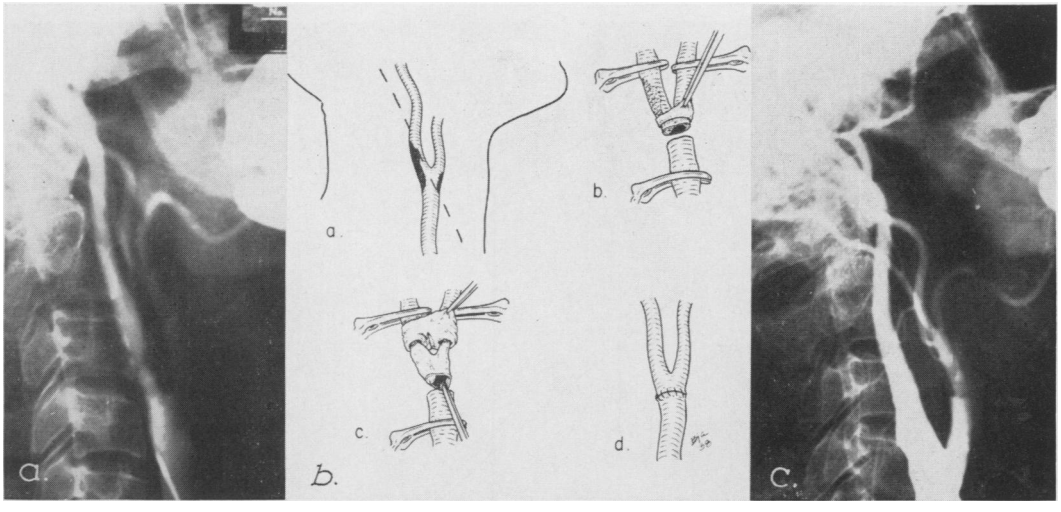

FIG. 10. (a) Preoperative arteriogram showing incomplete occlusion of internal carotid artery beginning at its origin and extending distally for approximately 2.5 cm. (b) Diagrammatic drawing showing extent of occlusive lesion and method of endarterectomy. (c) Postoperative arteriogram showing restoration of circulation in internal carotid artery.

The carotid arteries are exposed through either a circular incision over the carotid artery bifurcation following the skin lines of the neck or an oblique incision just anterior to the sternocleidomastoid muscle. Operation is performed under local anesthesia to prevent cerebral depression and reduction in blood pressure and to permit close observation of any neurologic changes during operation. Injury to the hypoglossal, vagus, and auricular nerves and the lower branch of the facial nerve is avoided. The internal carotid artery is temporarily clamped and the patient observed for five minutes. In most cases collateral circulation is adequate to maintain normal function during operation and temporary occlusion does not produce neurologic deficits. Under these circumstances the operation is performed without employing methods designed to protect the cerebrum during operation. Patients with complete contralateral internal carotid artery occlusion usually require support during operation and methods employed for this purpose are discussed later.

Endarterectomy of the internal carotid artery may be performed by several methods, although the principle involved is the same in all approaches. The atheromatous lesion involves the inner layers of the arterial wall and predominantly the intima. Endarterectomy consists of entering the tissue plane between the diseased layer and the normal outer arterial wall and removing the atheromatous mass. In the actual performance of the operation, several factors that may lead to failure deserve careful consideration, namely, luminal narrowing resulting from closure of the arteriotomy and incomplete removal of the disease. To prevent luminal constriction following operation, endarterectomy is preferably performed through a transverse incision in the relatively large common carotid artery just proximal to its bifurcation. This incision is made through the anterior half of the circumference of the common carotid artery in the treatment of discrete lesions of one centimeter or less in length (Fig. 9). The proper plane of dissection is entered and the normal outer layers of the distal segment are retracted from over the lesion, and as normal intima

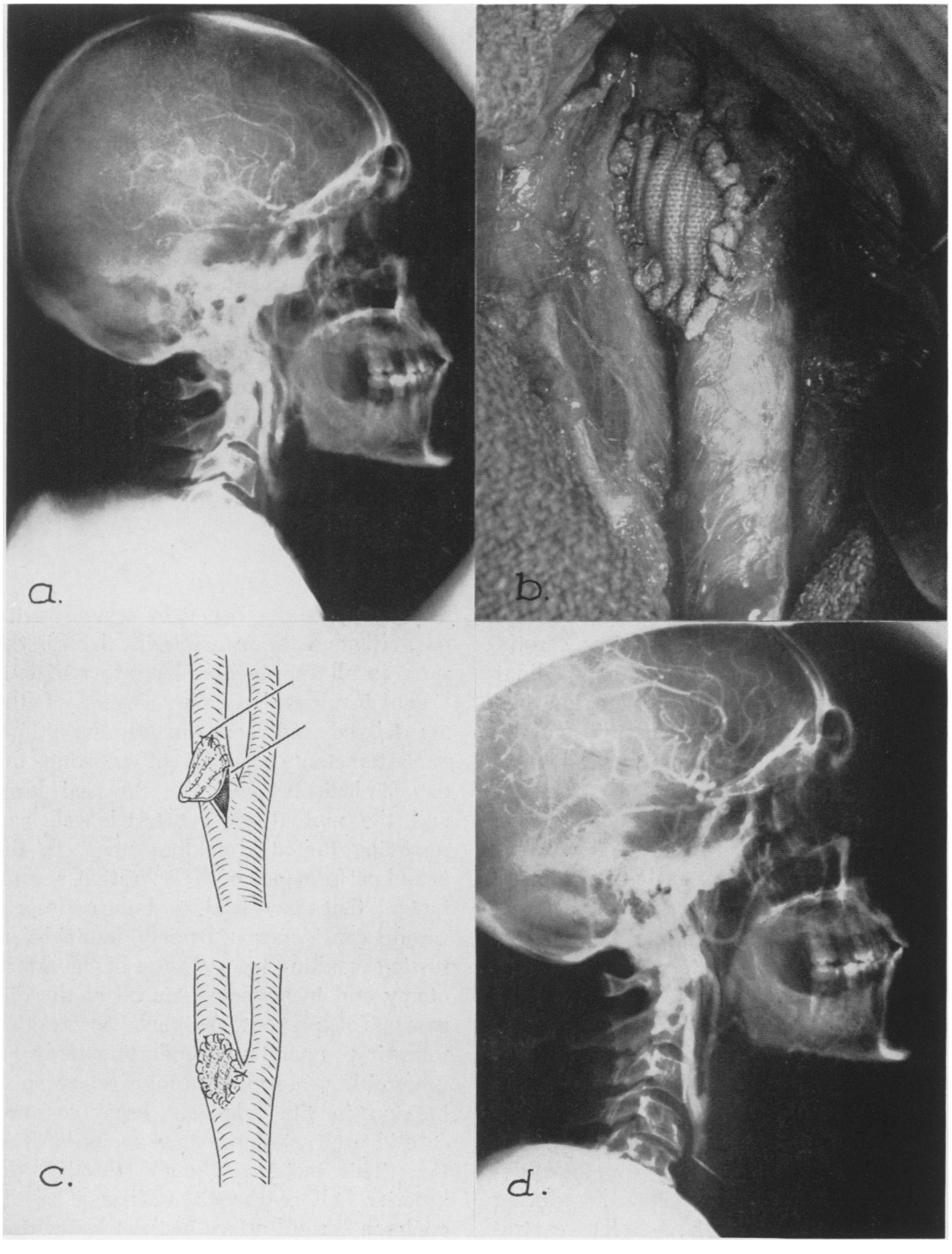

FIG. 11. Illustrations in case of internal carotid artery occlusion showing method of applying patch in arterial closure following endarterectomy. (a) Preoperative carotid arteriogram showing partial occlusion of right internal carotid artery. (b) Photograph taken at operation showing patch in place. (c) Diagrammatic drawing showing method of applying patch. (d) Postoperative arteriogram showing restoration of circulation.

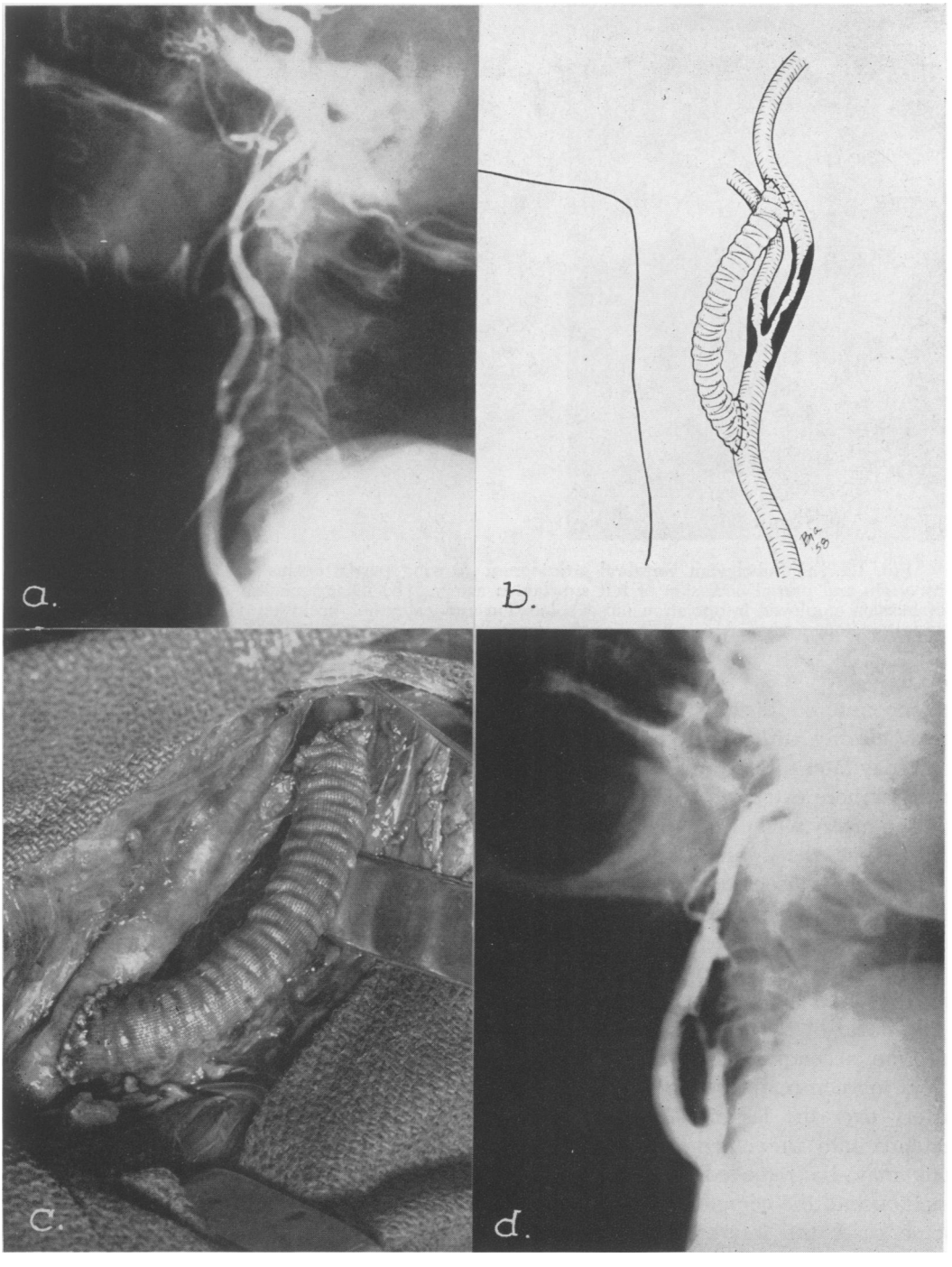

FIG. 12. (a) Preoperative arteriogram showing extensive incomplete occlusion of internal carotid artery. (b) Diagrammatic drawing showing extent of occlusive lesion (in black) and bypass graft. (c) Photograph made at operation showing end-to-side anastomosis of graft to common carotid artery below occlusion and internal carotid artery above lesion. (d) Postoperative arteriogram showing restoration of circulation through graft.

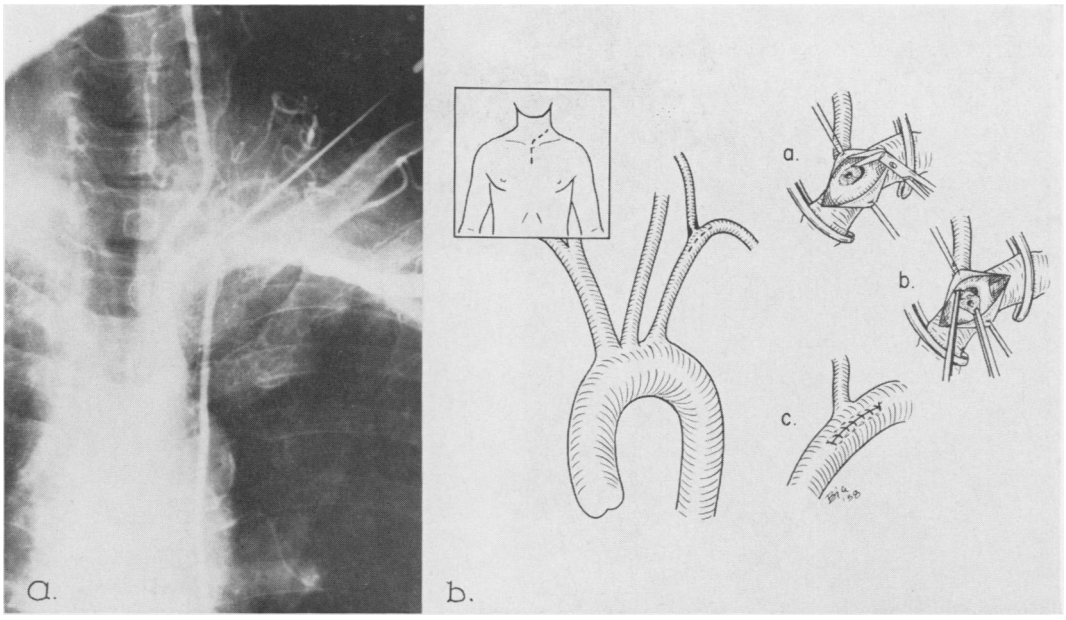

FIG. 13. (a) Subclavian vertebral arteriogram showing partial occlusion of left vertebral artery at its origin and partial occlusion of left subclavian artery. (b) Diagrammatic drawing showing location of incision employed in operation (inset), location and extent of occlusion (in black), and method of endarterectomy.

is encountered distally the lesion breaks away cleanly without leaving an elevation that may later dissect and produce obstruction. In more extensive lesions the common carotid artery well proximal to the occlusive process at the bifurcation is preferably completely transected, since this maneuver permits greater freedom in retraction of the normal outer layer over the occlusive process (Fig. 10). Arterial continuity is then restored by end-to-end anastomosis.

Removal of the atheromatous mass may also be accomplished through a longitudinal incision made in the internal carotid artery over the lesion. When the disease extends into the common carotid artery, this may be removed by extending the incision into the common carotid artery. In some cases the internal carotid artery is large enough so that longitudinal closure can be accomplished without significant narrowing of the lumen. In other cases, however, longitudinal closure may produce narrowing that leads to obstruction and failure of operation. Under these circumstances normal lumen may be maintained by suturing a patch made of knitted dacron around the edges of the arteriotomy (Fig. 11). This procedure actually increases the circumference of the arterial lumen by a distance equal to the width of the patch.

Experience at the present time is insufficient to determine which method of endarterectomy is best suited to lesions at this level. It would appear that all the methods described have a place in the treatment of this disease owing to the variations in the local pathologic features of the occlusive process that may be encountered, and it is therefore desirable to be familiar with all of them. Regardless of the procedure employed, arteriography should be performed at the completion of operation in order to assure that all the disease has been removed and effective arterial lumen has been provided.

The end-to-side bypass operation, as previously indicated, is employed in patients

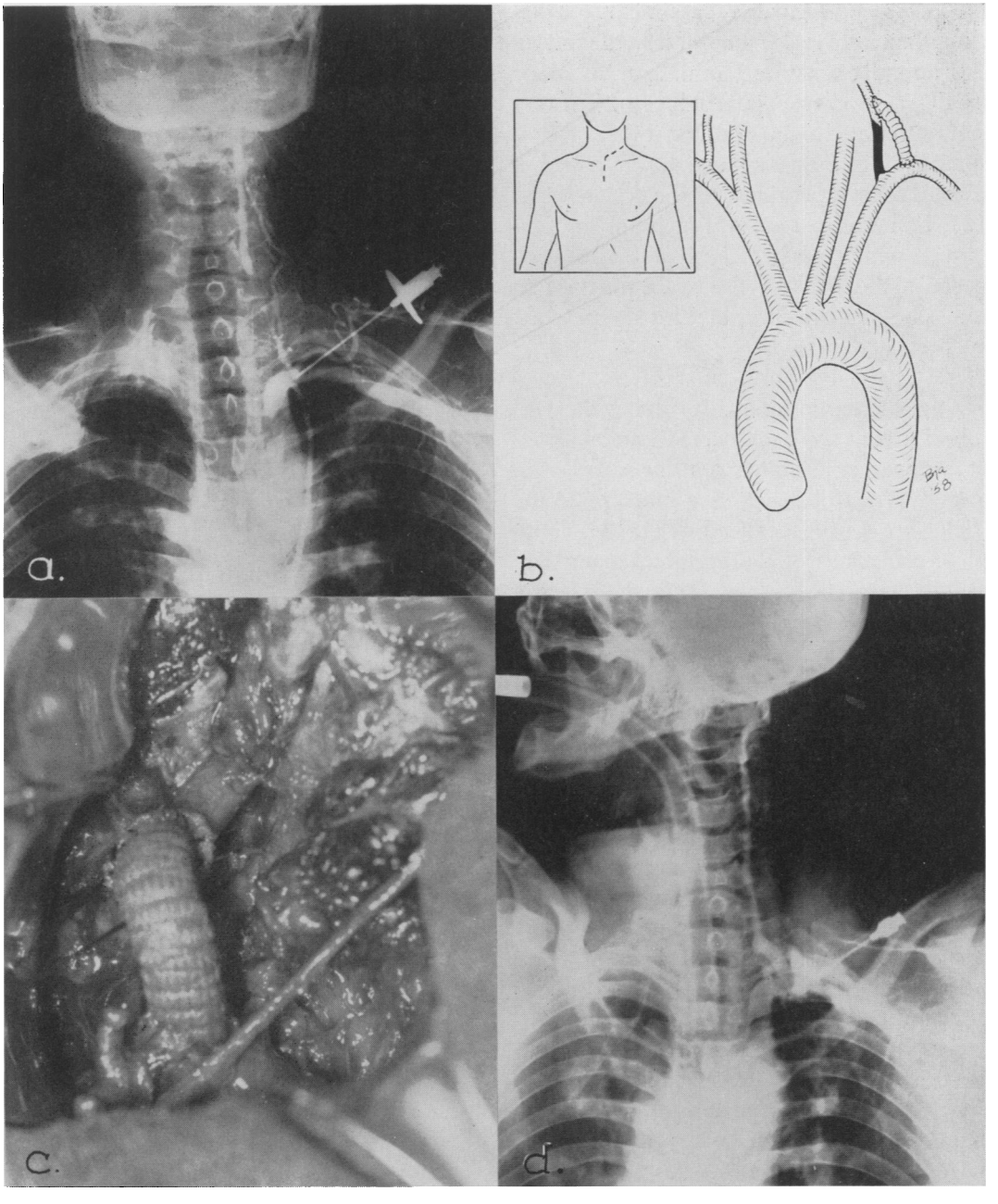

FIG. 14. Illustration in case of vertebral artery occlusion showing application of bypass method of treatment. (a) Preoperative arteriogram showing segmental complete occlusion of vertebral artery. (b) Diagrammatic drawing showing location of incision (inset), extent of occlusion (in black), and bypass graft. (c) Photographs made at operation showing end-to-side anastomosis of graft to subclavian artery proximal to occlusion and to vertebral artery distal to occlusion. (d) Arteriogram after operation showing functioning bypass graft.

with the more extensive lesions. The technic of its performance is similar to that described above. One end of a small knitted dacron graft is sutured to an opening made in the side of the internal carotid artery distal to the lesion and the other end is sutured in a similar manner to the common carotid artery proximal to the lesion (Fig. 12). Longitudinal arterial incisions are employed without fear of luminal constriction because the ends of the graft function in the same manner described for the patch.

Vertebral Artery

Atherosclerotic lesions involving the vertebral artery are usually small and located at or near its origin from the subclavian artery. When obstruction is incomplete the occlusion is well localized (Fig. 13). Complete occlusions of the vertebral artery are usually more extensive although in some cases the obstruction may be segmental with a patent segment proximal to its course in the cervical vertebral transverse processes (Fig. 14). Both the incomplete occlusions and the segmental complete occlusions are amenable to operative treatment. Although occlusion at this level is frequently bilateral, operation may be required only on one side since adequate blood flow through one normal sized vertebral artery may be sufficient to support basilar artery circulation.

Endarterectomy is employed in the treatment of small incomplete occlusions. Because of the small size of the vertebral artery and the possibility of lumen constriction resulting from arteriotomy closure, endarterectomy of this artery is preferably performed through an incision made in the larger subclavian artery opposite the origin of the vertebral artery (Fig. 13). The atheromatous lesion usually involves the intima of the subclavian artery surrounding the orifice of the vertebral artery. A plane of dissection is developed under the involved intima of the subclavian artery and extended under the lesion into the vertebral artery. The atheromatous mass is removed by retracting the normal layers. Arterial continuity is restored by closing the subclavian artery.

The more extensive lesions are treated by end-to-side bypass. One end of the graft is sutured to the vertebral artery distal to the lesion and the other end is sutured to the subclavian artery proximal to the lesion (Fig. 14). The vessels involved in these cases are usually exposed through a small supraclavicular incision. In some patients, however, the vertebral artery arises within the mediastinum, and under these circumstances, a combined cervicothoracic incision splitting the sternum to the level of the third rib in the midline is required.

Supportive Measures During Operation

Successful application of these operative procedures are dependent upon careful consideration of a number of factors in the conduct of the operation other than those directed toward restoration of circulation. These include particularly anesthesia, control of peripheral arterial blood pressure, and measures to protect against cerebral ischemia during temporary arrest of cerebral circulation. In the majority of patients with moderate to severe neurologic disturbances, the occlusion is located in the internal carotid or vertebral arteries. In most of these patients, local anesthesia is preferably employed in order to minimize the risk of operation and to detect neurologic change during the period of temporary arrest of circulation. Cerebral depressant drugs, opiates, and barbiturates should not be used or should be administered in small quantities. Most patients with proximal occlusive lesions have adequate collateral cerebral circulation. For this reason, and since thoracotomy is usually required, light general anesthesia is employed in patients with obstruction at this level.

Early in our experience it was believed that cerebral protection by the use of hypo-

thermia or temporary shunts would be required in patients with incomplete obstruction during the period of arterial occlusion. Despite application of a combination of these methods in our second case of partial occlusion of the internal carotid artery, ischemic damage manifested by transient weakness of the left hand occurred. Further experience clearly demonstrated that such measures were unnecessary unless carotid compression before operation or temporary carotid occlusion during operation produced cerebral disturbances. The period of arterial occlusion in our experience has ranged from five to thirty minutes, and in the presence of reasonably normal blood flow in the contralateral artery, collateral circulation, presumably developed by partial occlusion, was sufficient to maintain normal function during this time. Severe cerebral arterial insufficiency evident by transient convulsive phenomena and loss of consciousness was produced by digital compression of the carotid artery on the side with partial occlusion of the internal carotid artery in seven cases and the common carotid artery in one case. Contralateral internal carotid artery occlusion was present in all of these patients and was complete in six and incomplete in two of them. Temporary shunts were successfully employed in those patients with contralateral complete occlusions of the internal carotid artery. In the remaining two cases, the non-critical contralateral incomplete internal carotid artery occlusion was removed first. The resulting increase in cerebral circulation permitted safe operation on the other side without special measures for cerebral protection.

The temporary shunts employed in these cases were of two types requiring different methods of application. One of the shunts consisted of a No. 14 Bardex catheter with a 14-gauge needle attached to each end. At operation, one end of the shunt is inserted into the common carotid artery proximal to the region of operation and the other end is inserted into the internal carotid artery distal to the field of operation (Fig. 15). The needles are held in place with small purse string sutures placed in the adventitia of the artery. With the shunt functioning, operation is performed as previously described. After blood flow is restored in the arterial channels, the needles are removed and bleeding controlled by a single small suture in the vessel over the puncture site.

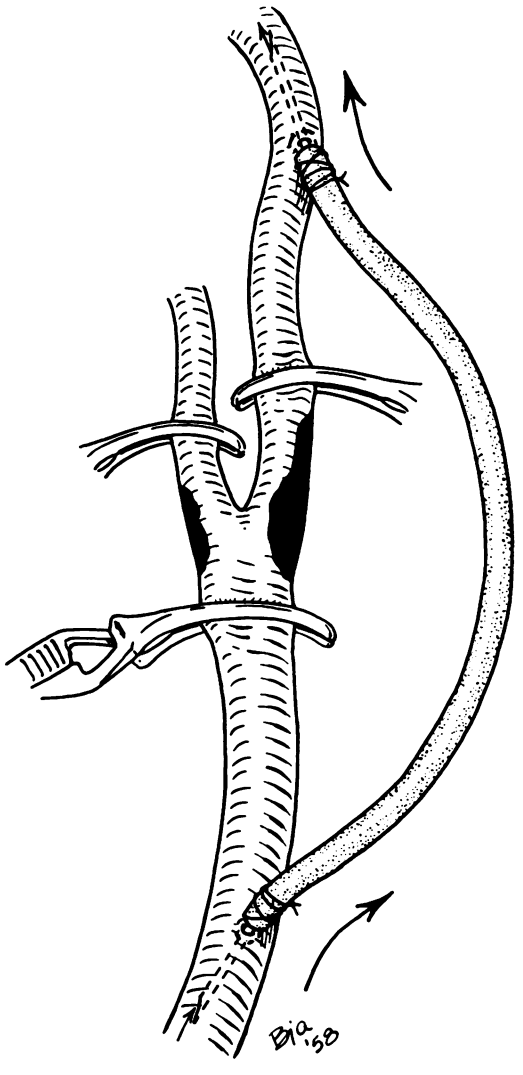

FIG. 15. Drawing illustrating method of temporary external bypass employing small catheter with attached needles.

The other type of temporary shunt, which under some circumstances is preferable, consists in the use of a soft No. 14 polyethylene tube approximately 10 cm. in length. A silk suture is securely tied around the midpoint of the tube. With temporary proximal occlusion of the common carotid artery an opening is made in the internal and common carotid artery in the region of the lesion (Fig. 16). One end of the shunt is inserted into the lumen of the internal carotid artery distal to the lesion and the other end into the common carotid artery proximal to the lesion in the same manner that a "T" tube is inserted into the common bile duct. While circulation is arrested in the region of operation by circumferential tightening of the artery against the tube employing umbilical tapes which had previously been looped around the arteries, blood flow from the common to the internal carotid artery is maintained through the shunt. Endarterectomy or bypass graft may then be performed as previously described. Following completion of either of these procedures the arteriotomy through which the tube had been inserted is partially closed at each end and interrupted sutures are placed in the remainder of the incision but left untied. Using the suture which had been previously tied around the tube, the shunt is quickly withdrawn from the artery as a "T" tube is removed from the common bile duct. The untied sutures in the arterial wound are pulled taut and circulation is restored while these are being tied (Fig. 16).

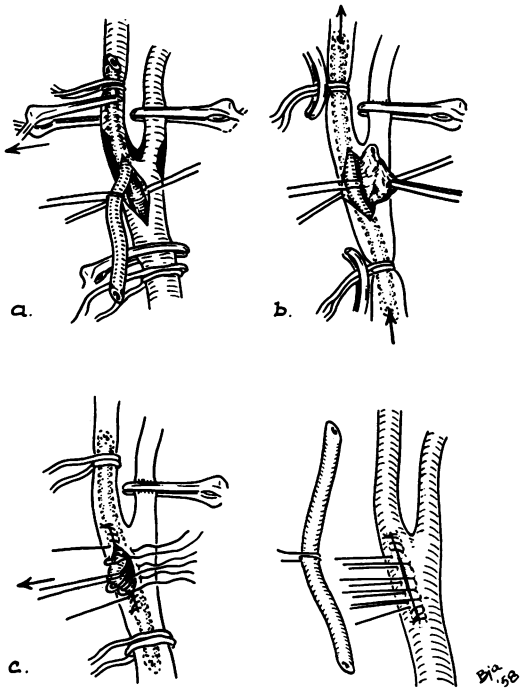

FIG. 16. Diagrammatic drawings illustrating endarterectomy employing internal shunt. (a) A longitudinal incision is made over or immediately proximal to lesion and flexible tube is inserted, each end separately, as in insertion of a "T" tube. (b) With bleeding in region of operation controlled by tightening tapes previously placed around artery proximal and distal to arterial opening, endarterectomy is performed by entering cleavage plane between disease and normal outer layer of artery and removal of atheromatous mass. (c) Partial closure of arterial opening is performed at both ends of incision and interrupted sutures are placed but not tied in remainder of incision. Removal of shunt is started by traction on string tied to center of tube. (d) After removal of shunt, circulation is immediately restored in artery and bleeding is controlled by placing traction on sutures which are subsequently tied.

Depression of arterial blood pressure below the patient's normal level may result either in thrombotic progression of the occlusive process or an increase in cerebral ischemia. Peripheral arterial blood pressure may be reduced in these patients by the use of central nervous system depressant drugs, carotid sinus stimulation and hemorrhage during operation. For this reason opiates and barbiturates should be avoided or given only in small doses as preoperative medication and rarely used after operation. The depressant systemic effects of procaine should also be avoided by employing less than 60 cc. of a 1 per cent solution containing epinephrine. Care should be exercised to avoid its intravenous injection. During operation, blood loss is carefully replaced and the tissues surrounding the carotid bifurcation should be injected with procaine solution to prevent bradycardia

and hypotension. When the latter reflexes occur despite these measures, small doses of atropine and neosynephrine may be given intravenously. During the period of arterial occlusion, peripheral systolic blood pressure may be elevated to 200 mm. Hg using a continuous intravenous drip of dilute neosynephrine solution both to increase blood flow through collateral channels and to prevent sudden drop in blood pressure from blood loss or neural reflex. As a result of these considerations, operation was successfully performed in all cases without producing cerebral damage during operation except in the second case previously described.

Results

The results of operation varied with the location and extent of the lesion. Circulation was restored in all cases with occlusion of the great vessels arising from the aortic arch regardless of the extent of the occlusion (Table 2). Among the group with incomplete obstruction of the distal vessels, circulation was restored in all but three cases, one with internal carotid and two with vertebral artery occlusion (Table 2). Of particular interest is the fact that circulation was restored in six cases with complete obstruction at this level, five internal carotid artery and one vertebral artery, all having segmental occlusion. In the remaining cases in this group of distal complete occlusion, the lesion was of long duration and the obstructive process was found to extend into the intracranial portion of the vessel.

Severe cerebral arterial insufficiency manifested by coma and extensive paralysis was present before operation in three cases. These patients were submitted to emergency operation, and although circulation was restored in one or more of the occluded arteries, the degree of brain damage was already too extensive to permit recovery and the patients finally died of extensive cerebral infarction. Death was due to myocardial infarction in two patients, one operated upon for gangrene of the fingers and the other for mental obtundity and recurrent convulsions. Death in the remaining case was due to hemorrhage resulting from infection and disruption of the suture line ten days after operation.

The remaining 57 patients recovered from operation and circulation was restored in one or more of the occluded vessels in 47 of them. The functional response to treatment in these cases varied according to the location of the lesion and the condition of the patient before operation. All patients with lesions of the great vessels arising from the aortic arch were completely relieved and the majority of patients with lesions of the internal carotid or vertebral arteries were either relieved or significantly improved. Cerebral circulation was made worse in only one case. This patient, treated early in the series, developed recurrent occlusion and hemiplegia with aphasia twenty-four hours after endarterectomy of the internal carotid artery performed through a longitudinal incision. Persistent residual paralysis occurring before operation was completely relieved in eight and improved in five patients. Progressive hemiplegia with aphasia of eighteen hours' duration was completely relieved in one patient. Residual visual defects were improved in two cases and completely relieved in four patients. Complete relief occurred from other symptoms: aphasia in five, vertigo in four, headache in three, ear noise in two, syncope in one, and claudication of the arm in 17 patients. Transient attacks of paralysis have not recurred since operation in 13 patients who had completely recovered from such attacks before operation.

Operation was performed in the first patient in this series over five years ago and all patients have been followed since

discharge from the hospital with arteriograms having been performed in most of them. The success achieved by operation has been well maintained in all but four cases. Death has occurred in two patients, one from myocardial infarction and the other from acute arterial insufficiency resulting from internal carotid artery occlusion on the side opposite the operative site. Recurrent occlusion has occurred in two patients. Endarterectomy had been performed for occlusion of the left common carotid artery in one and end-to-side bypass graft had been employed in the other for occlusion of the internal carotid artery. Both of these cases were treated early in the series employing technics no longer considered suitable.

Discussion

The atherosclerotic lesion is a progressive process which eventually consumes the arterial lumen producing arterial obstruction and arterial insufficiency. The limitation of collateral circulation imposed by the frequency of multiple lesions in patients with arterial insufficiency of the cerebrum and upper extremities casts considerable doubt upon therapy not directed toward the lesion itself. For example, 20 per cent of the patients in this series of cases were referred for operative treatment because satisfactory anticoagulant therapy had either not improved or had not prevented progression of the disease. Moreover, five patients developed cerebral arterial insufficiency while their prothrombin times were being maintained at levels less than 10 per cent of normal by dicumerol administered because of previous myocardial infarction. The successful results obtained by arterial reconstructive operations in the relief of persistent neurologic defects and in the prevention of recurrent attacks in these cases demonstrate the superiority of surgical therapy directed toward the lesion itself.

Our experience would suggest that in approximately 40 per cent of patients with arterial insufficiency of the cerebrum and upper extremities the occlusive process is segmental in character and therefore amenable to surgical treatment. It is reasonable to assume that this incidence would be higher in cases representing an earlier course of the disease. The greatest opportunity for restoration of circulation occurs early when the lesion is segmental in nature. The limitations of diagnosis by clinical means are such that extracranial arterial involvement should be suspected in all of these cases and accurate localization of the obstruction obtained by performing arteriography.

In general, two types of surgical procedures may be employed, namely, thromboendarterectomy and the bypass graft. Our experience would suggest that each of these methods is useful and effective and is indicated in accordance with the nature and extent of the occlusion (Table 4). Indeed, in some circumstances a combination of both methods may be necessary. Although these lesions tend to assume recognizable patterns, considerable variations exist in the pathologic features of the occlusive process ranging from well localized, fairly discrete, partially occlusive lesions to extensive intramural as well as intraluminal involvement. In the former case in which the occlusive process is well localized to a relatively short segment of vessel with minimal medial and adventitial mural involvement, thromboendarterectomy may be satisfactorily performed to achieve restoration of normal circulation. In the latter form of the disease, in which there are extensive and destructive mural atherosclerotic changes, the bypass graft is considered the procedure of choice, owing to its simplicity, ease of application, and efficacy of restoring normal circulation in the arterial bed distal to the occlusive process. In still other instances application of both of these prin-

ciples of treatment may be desirable. This is especially indicated in instances in which the occlusive process involves the full extent of the common carotid arteries as exemplified by the cases illustrated in Figures 3, 5, and 6. Thus, each of these methods may be effectively employed, but their successful application is dependent upon their utilization under appropriate circumstances. Moreover, it is not always possible to determine which of these procedures should be used on the basis of the preoperative arteriographic findings. Final decision in this regard often rests with the actual findings at operation and for this reason one should be prepared to employ either or both methods in accordance with these observations.

Summary

1. Arteriography was performed in 174 patients with arterial insufficiency of the cerebrum and upper extremities. Extracranial arterial occlusion was demonstrated in 73 patients (42 per cent), 63 of whom were submitted to operation. Of the 115 lesions occurring in the latter cases and located in the internal carotid, vertebral, innominate, common carotid, and subclavian arteries, 88 lesions were explored surgically and 75 obstructive lesions occurring in 53 patients were found to be segmental in nature and amenable to restorative operation. The remaining patients had extensive complete occlusion of the internal carotid or vertebral arteries, and in view of the duration of occlusion these cases were not considered operable.

2. The proximal forms of the disease were evident clinically by the manifestations of arterial insufficiency of the cerebrum and upper extremities. The distal occlusions were manifested by cerebral arterial insufficiency. Due to the limitations of accurate localization of the lesion on clinical grounds, all patients were studied by means of arteriography. Lesions occurring in the great vessels arising from the aortic arch were operable regardless of the location and extent of occlusion. Incomplete occlusions of the internal carotid and vertebral arteries were similarly amenable to operation. Complete occlusions of the latter vessels were rarely operable unless explored soon after onset of symptoms.

3. Treatment of these cases was directed toward restoration of normal circulation, and to achieve this objective two types of procedures were employed, endarterectomy and end-to-side bypass graft. Endarterectomy was employed in the treatment of well localized lesions and the more extensive occlusions were bypassed using a suitable arterial substitute. Endarterectomy was performed in 37 lesions and graft bypass was employed in the treatment of 38 lesions. A pulsatile circulation was restored in the treatment of 72 lesions. Circulation was restored in all cases with lesions involving the great vessels arising from the aortic arch, 97 per cent of those with operable lesions of the internal carotid artery, and 60 per cent of those with occlusions of the vertebral artery.

4. Severe cerebral arterial insufficiency manifested by coma and paralysis was present before operation in three of the cases and although circulation was restored in one or more of the occluded vessels, death occurred from irreversible ischemic brain damage. Two patients died of myocardial infarction following operation and one from hemorrhage. All patients with lesions of the great vessels were completely relieved and the majority of patients with lesions of the internal carotid and vertebral arteries were either relieved or improved. These patients have been followed to periods of over five years and the success achieved by operation has been well maintained.

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Discussion

Dr. Champ Lyons: Dr. Lilly, members and guests, I certainly want to congratulate Dr. Cooley on his beautiful presentation of the possibilities of restoration of cranial flow.

We have been interested in this problem and confirm almost in detail exactly what he said. The complete occlusions have a much poorer prognosis for restoration of flow. At the present time, we would feel that a patient who enters in coma, with a vascular accident should not be explored, but apart from coma and severe circulatory failure, we think all of these patients should be explored.

Our experience with sudden acute occlusion lasting beyond 48 hours has been somewhat better apparently than Dr. Cooley's. We had one patient who was aphasic and had paralysis for ten days in whom we were able to extract the clot and restore flow with complete recovery.

In another patient who was seen four days after a complete occlusion, restoration of flow was associated with transient cerebral edema and increased spinal fluid pressures, but recovery was ultimately complete.

Dr. Cooley: Thank you, Dr. Lyons, for your discussion.

We do not refuse to operate on patients in coma with these lesions. As a matter of fact, Dr. Crawford has operated successfully upon patients in coma and had them wake up on the operating table when the restoration was complete. Thank you.