

Surgical Treatment for Occlusive Disease of the Carotid Artery

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It is acknowledged that atherosclerotic lesions of the carotid bifurcation causing stenosis or complete occlusion can produce neurologic symptoms and deficits. These lesions can either decrease cerebral blood flow or be the source of cerebral emboli.

Since 1954, when Eastcott, Pickering and Rob³ reported a successful reconstruction of a stenotic internal carotid artery, operations on these lesions have become common.^{2, 5, 6, 7, 8, 9, 11, 13, 15, 16} Endarterectomy is the preferred method of reconstructing the vessel but considerable debate remains as to technical details which include: choice of anesthetic; monitoring of jugular venous blood gases; value of shunts during occlusion of the vessels, and the necessity for a patch graft to enlarge the lumen of the vessel. Indications for the operation and timing, particularly during the acute phase of the stroke, have also been frequently discussed. In addition, the ability of reconstruction to produce long term relief of neurologic symptoms and to increase longevity has been questioned. An answer to most of these questions will require a controlled study of a large number of patients treated with or without operation.¹

It is important that results of surgical management are carefully evaluated to form a basis for future studies and treatment. Results of 227 carotid artery reconstructions with significant atherosclerotic occlusive lesions in 205 consecutive patients were carefully analyzed. Operations were performed at the University of Rochester Medical Center between January 1, 1961 and June 30, 1966.

Materials and Methods

The 205 patients in this study conformed to the usual pattern of patients with atherosclerotic lesions. There were 121 men and 84 women. The youngest was 42 and the oldest 85 years of age with 91 of the patients in the 60-70 age range. There were 33 patients (16%) with diabetes mellitus. A history of hypertension or blood pressure recordings greater than 150/90 mm. Hg were observed in 103 (50%) of the patients. There were 44 patients (21%) with electrocardiographic evidence of arteriosclerotic heart disease. Symptomatic peripheral arterial disease or aneurysms were at some time present in 41 or 20% of the patients. Serum cholesterol levels were available on 99 patients, of which 66 demonstrated levels greater than 275 mg. per cent.

Symptoms. The patients were classified on the basis of their histories and neurologic examinations. They were considered either: 1) "asymptomatic"; 2) subject to

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transient cerebrovascular ischemic attacks (TIA's) without significant residual deficits; 3) victims of rapidly "progressive" neurologic deficits or 4) patients with "completed" strokes as manifested by fixed neurologic deficits.

There were 20 patients who underwent operation for asymptomatic carotid artery lesions. The lesions were recognized in nine patients during the routine evaluations or treatment of strokes related to lesions of the contralateral carotid artery. Seven patients drew the attention of their physicians to the lesions by complaining of a "buzzing," "whistling," or "noise" in the neck. Bruits were discovered at the time of a routine physical examination in the remaining 4 asymptomatic patients. Operation was recommended as a prophylactic measure if the patients were under 55 years of age, if the lesion caused at least a very significant (70%) decrease in diameter of the carotid artery as seen on angiograms, or if they were to undergo major unrelated operations.

There were 167 patients who suffered TIAs thought to be related to the carotid artery lesions for which operations were performed (Table 1). In addition to the 120 patients whose indication for operation was TIAs, eleven of 18 patients with progressive strokes and 36 of 69 patients with completed strokes gave histories of previous transient neurologic symptoms which were consistent with involvement of the same carotid artery.

Symptoms usually related to carotid arterial lesions were observed in 88% of the patients. These included either ipsilateral eye symptoms, or contralateral motor and sensory symptoms, or speech difficulties or all three. The ipsilateral eye symptoms consisted of transient scotomata, blurred vision, or transient blindness and occurred in 35% of the patients. Contralateral motor or sensory symptoms consisted of transient weakness, paralysis, numbness, or paresthesias and were observed in 63% of the patients.

Speech difficulties consisted of transient motor or expressive aphasia and occurred in 22% of the patients. Speech symptoms occurred only if the involved artery supplied the dominant cerebral hemisphere. Other symptoms such as dizziness, syncope, headache, seizures, and confusion were observed in the 12% of TIA patients who had no classic symptoms.

In patients operated upon because of TIAs, the severity of the problems and the desire for immediate treatment by the majority of patients is reflected in an analysis of the time of onset, time of the last, and frequency of the small strokes prior to operation (Table 2). Forty per cent of these patients became symptomatic within 3 months prior to operation; 53% were having multiple attacks at intervals of less than 3 weeks; 66% suffered their last attacks within 1 month of operation. Single episodes were experienced by only 13% of patients and the single attacks occurred more than 6 months prior to operation in only 2%.

Of patients with progressive or completed stroke, 54% gave histories of previous TIAs (Table 3). Since complete histories could not always be obtained from very ill patients, it is likely that even more than 54% experienced previous attacks. Thirty-six per cent of patients with previous episodes experienced their first attack less than 3 months prior to the final episode. The attacks were multiple and occurred at intervals of less than 12 months in 72% of the patients. Sixty-eight per cent experienced their last TIA within 1 month of their major stroke.

All patients with progressive strokes were operated upon within 13 days of onset of continuing neurologic deficits. Fifty-seven per cent of patients with completed strokes were operated upon within a week of onset of deficits and an additional 22% within 1 to 4 weeks after onset. Only 21% had fixed deficits of greater than 1 month's duration.

TABLE 1. *Neurologic Symptoms in 167 Patients with TIA's and Significant Occlusive Disease of at Least One Carotid Artery*

Symptoms	TIA's Only	TIA's Prior to Progression	TIA's Prior to Completion	Total	% Patients
Classic	(103)	(11)	(33)	(147)	(88)
Ipsilateral Eye	47	4	7	58	35
Contralateral Motor or Sensory	71	8	27	106	63
Speech	21	5	11	37	22
No Classic Symptoms	(17)	(0)	(3)	(20)	(12)
Other					
Dizziness	24	0	6	30	18
Syncope	12	0	0	12	7
Headache	4	0	1	5	3
Seizures	5	0	1	6	4
Confusion	2	0	2	4	2

Bruits and Ophthalmodynamometry. The neck was carefully examined for the presence of bruits.¹⁰ Bruits associated with stenosis of the internal carotid artery were best heard in the triangle bounded by the mandible, sternocleidomastoid muscle and the thyroid cartilage.

Ophthalmodynamometry was performed in the majority of patients. The test was considered positive if there was more than a 20% difference in diastolic or systolic pressures in the central retinal arteries of the two eyes or if these pressures were less than 50% of the brachial pressures in the supine position.

The results of both a careful examination for bruits and ophthalmodynamometry were available in 118 instances in which the carotid artery was known to be at least partially occluded (Table 4). Definite bruits were heard 75% of the time and ophthalmodynamometry was positive in 63%. However, ophthalmodynamometry was positive in the absence of a bruit 14% of the time. Therefore, one or both of the tests were positive in 89% of the examinations. This also means, of course, that in 11% the diagnosis of arterial occlusive disease required angiography or exploration of the vessels.

Electroencephalography. Electroencephalograms were obtained on 88 patients prior to operation (Table 5). Fifty-one per cent of patients demonstrated at least some minor abnormality of their tracing.

These abnormalities usually consisted of intermittent mild to moderate focal slowing in the mid-temporal and central areas. Sixteen patients had follow-up EEGs after operation. In 11 of this group there was an increase in mean alpha frequency. This was thought to reflect increased cerebral blood flow following operation.¹²

Angiography. Angiography was performed to visualize all four extracranial cerebral vessels prior to 141 operations. Single vessel angiograms were obtained in another 27 patients. No angiograms were obtained in 59 patients early in the course of the study. Considerable information is obtained from visualization of all four vessels and it is now routinely performed. Lesions of the arteries were considered significant if they caused a greater than 30% narrowing of the diameter of the internal carotid artery as seen on the A.P. and Lateral angiograms, or by examination of the removed atherosclerotic core.

Operation. The operations were performed by the attending and resident staff

TABLE 2. *TIA's Prior to Operations in 120 Patients Operated on for History of TIA's*

TIA's	Number of Patients	Percentages
First		
0-3 mo.	48	40
3-12 mo.	33	28
>1 yr.	39	33
Frequency		
q. 0-7 days	29	24
q. 1-3 wks.	35	29
q. 1-12 mo.	41	34
Isolated		
<6 mo.	13	11
>6 mo.	2	2
Last		
0-7 days	44	37
1-4 wks.	35	29
1-12 mo.	39	33
>1 yr.	2	2

of the University of Rochester Medical Center. Eighty-two per cent of operations were performed by either C. G. R. or J. A. DeW.

A general anesthetic was used for 196 operations of which 9, early in the study, were accompanied by total body cooling to esophageal temperatures of 31-32° Centigrade. A local anesthetic was used in 31 operations early in the study. Operations are now routinely performed under general anesthesia with maintenance of the blood pressure at normotensive or even slightly hypertensive levels.

The operations were performed through a transverse incision along a skin crease at the level of the thyroid cartilage. The anterior facial vein was divided and the carotid bifurcation mobilized—taking care to avoid injury to the hypoglossal nerve. A longitudinal arteriotomy was made over the atherosclerotic plaque beginning at the distal end of the common carotid artery and extended along the postero-lateral side of the internal carotid artery to the end of the palpable plaque. In some instances, the incision was initially made through only the

adventitia and outer media to enable placement of stay sutures and partial performance of the thromboendarterectomy before the vessels were occluded. Care was taken to remove all of the shreds of media and to carefully cut the atherosclerotic intima at the point where it fuses with normal intima. Five thousand units of heparin were injected into the distal carotid artery after occlusion of the vessels and 50 mg. of protamine sulfate were given intravenously following closure of the arteriotomy. The total time of occlusion was less than 10 minutes in 25% of the operations and greater than 20 minutes in 10% of the operations but the usual time was between 10 and 20 minutes. Internal shunts were used on only 14 occasions when technical problems arose which would prolong the period of occlusion beyond 25 minutes. Patch grafts of autogenous jugular vein were used on two occasions, short saphenous vein grafts on 6 occasions. In four instances redundant artery was excised and an end-to-end anastomosis performed between the common carotid artery and the

TABLE 3. *TIA's Prior to Onset of Progressive or Completed Stroke*

	No. of Patients	%
No TIA's	40	46
Previous TIA's	47	54
Onset TIA's		
<3 mo.	17	36
3-12 mo.	6	13
>1 yr.	24	51
Frequency		
q. 0-7 days	6	13
q. 1-3 wks.	16	34
q. 1-12 mo.	13	26
Isolated		
<6 mo.	4	9
>6 mo.	8	17
Last TIA's		
<1 mo.	32	68
1-12 mo.	8	17
>1 yr.	7	15

internal carotid artery. Small rubber tissue drains were left through stab wounds in the subcutaneous tissue for a period of 24 hours. No anticoagulants were used in the postoperative period.

Patients without complications were discharged from the hospital 3 to 5 days following operation and were then seen periodically for evaluation. It was possible to establish direct contact (or confirm the death of) 99% of the patients within 6 months of the termination of this study.

Surgical Results

Patency. Information concerning patency of the operated carotid arteries was available in 98 cases. The carotid artery was found patent in 36 instances by direct information provided by angiography, exploration or autopsy. In an additional 56 instances improvement in retinal artery pressures as measured by ophthalmodynamometry provided indirect information that the vessels were patent. Direct information revealed that in the remaining 6 cases carotid arteries were thrombosed. There were 15 in whom both ophthalmodynamometry and direct information indicated that the vessels were patent. There were four in whom both ophthalmodynamometry and direct information indicated that the vessels were acutely thrombosed. Ophthalmodynamometry was not falsely positive in the presence of carotid artery patency nor falsely negative in the presence of acute thrombosis as verified by angiography or postmortem examination.

Early Clinical Results. The results of operation during the first 30 postoperative days for patients with asymptomatic lesions or with a history of TIAs are, in general, very similar (Table 6).

Seventy-four per cent became or remained asymptomatic. Transient weakness of the opposite extremities beginning immediately after operation and lasting for 1 to 2 days was observed in 13% of patients.

TABLE 4. *Bruits and Ophthalmodynamometry in Carotid Arterial Occlusive Disease*

Bruit	Ophthalmodynamometry	Number of Patients	%
Present	Positive	58	49
Present	Negative	31	26
Absent	Positive	16	14
Absent	Negative	13	11
		118	100

At the end of this early followup period, therefore, 87% were without neurologic symptoms or deficits. Three deaths occurred and were all related to major cerebral infarctions. It should be noted that the incidence of worsening or death was significantly lower in those patients operated upon for asymptomatic lesions. Worsening was known to be associated with thrombosis of the carotid arteries in three patients but worsening also occurred in the presence of patent reconstructions in 5 additional patients.

The early results of operation for patients with progressive and completed strokes were similar. Forty-five per cent improved following operation and some were without any significant neurologic deficits (Table 7). Twenty-three per cent of patients were unchanged from preoperative states. Progression of strokes was observed in 32% of the patients. Death occurred in 23%. Of 20 fatalities, 17 were due to complications of major strokes. Two deaths were due to pulmonary emboli and two were

TABLE 5. *Electroencephalograms in Carotid Arterial Occlusive Disease*

Type of Case	Abnormal	Normal	
Asymptomatic	11	4	
TIA's	17	28	
Progressive	1	2	
Completed	16	9	
		45	43

TABLE 6. *Early Results in Asymptomatic and TIA Groups*

Group	Asymptomatic	Transient Weakness	Symptoms & Deficit	Died
Asymptomatic (20)	17 (85%)	2 (10%)	1 (5%)	0 (0%)
TIA's (120)	86 (72%)	16 (13%)	14 (12%)	3 (3%)
(140)	103 (74%)	18 (13%)	15 (11%)	3 (2%)

TABLE 7. *Early Results in Progressive and Completed Strokes*

Group	Improved	Same	Worse	Died
Progressive (18)	9 (50%)	0 (0%)	9 (50%)	7 (39%)
Completed (69)	30 (44%)	20 (29%)	19 (28%)	13 (19%)
87	39 (45%)	20 (23%)	28 (32%)	20 (23%)

secondary to myocardial infarctions. Progression was associated with known thrombosis of the carotid artery in four patients but the vessel was patent in the six others from whom this information was available.

Other minor complications were observed following the 227 operations. Five patients developed wound hematomas which required evacuation. One patient developed a wound infection requiring drainage. Twenty-two patients developed transient weakness of the tongue with deviation toward the operated side presumably secondary to traction on the hypoglossal nerve during operation.

The high mortality rate and lack of improvement in the majority of patients with completed strokes prompted further analysis of this group (Table 8). Of patients operated upon within 24 hours of onset of completed stroke, 34% improved but 53% worsened and 34% died. If patients were operated upon from 1 to 13 days after onset, 47% were improved, but 24% worsened and 15% died. When patients were operated upon more than 2 weeks after onset of strokes, 45% improved, 15% worsened and none died.

There were 32 vessels completely occluded by thrombus at the time of operation. There was direct information concern-

ing the patency of vessels following operation in only 22 patients. In 12 patients in whom patency could not be re-established 34% improved nevertheless, 17% worsened but lived, and 50% died within 8 months of operation. Of 10 patients in whom blood flow was re-established 70% improved; 10% worsened but lived and 20% died in the hospital. One patient in whom flow could not be re-established was found to have a hemorrhagic infarct at autopsy, and one patient in whom flow was re-established had cerebral infarction without hemorrhage demonstrated at autopsy.

Late Results. Of 205 patients operated upon 181 survived hospitalization and it was possible to closely follow 179 for periods ranging up to 5½ years. Forty-eight per cent were followed for longer than 2 years and 16% for longer than 4 years. There were 46 late deaths, of which 16 were due to myocardial infarctions, 11 to strokes, three to cancer, and 16 to miscellaneous or unknown causes.

Late results were analyzed according to operative procedures. Neurologic deficits were graded and recorded at time of last followup or just prior to death. Mild deficits were those which did not prevent the patient from carrying out all activities including work. Moderate deficits were those that

limited at least some activities of daily living or intellectual abilities. Those with severe deficits required care or supervision in all activities.

Twenty operations were performed for asymptomatic carotid artery stenosis (Table 9). There were no neurologic symptoms related to the stenosis in 19 patients during the followup period. The one patient who worsened immediately following operation continued to have a moderate deficit. New symptoms related to lesions of other extracranial or intracranial lesions appeared in two patients. There were two late deaths, one of which followed thrombosis of the opposite carotid artery.

One hundred twenty operations were performed for TIAs. There were three early deaths. Preoperative symptoms were relieved in 81 instances and fewer symptoms were noted in an additional 21 instances. When worsening appeared immediately following operation, there were no or mild related deficits in four patients, moderate deficits in six and severe deficits in one patient at time of late followup. There were new unrelated cerebrovascular lesions observed following 28 procedures and 27 late deaths.

Following 18 operations for progressive strokes, there were seven early deaths. No or mild neurologic deficits occurred in three, moderate in six, and severe in two patients when last seen. Two patients developed new symptoms of cerebrovascular insufficiency and three died late.

There were 69 operations for completed strokes. There were 14 operative deaths. Of the survivors 29 had no or mild deficits, 15 moderate deficits, and 11 severe deficits. New symptoms were observed in nine instances and there were 14 late deaths.

Discussion

Analysis of earlier cerebrovascular symptoms in patients with progressive or completed strokes provided interesting informa-

TABLE 8. *Early Results of Thromboendarterectomy for Completed Strokes as Related to Time from Onset of Stroke to Surgery*

Time	Operations	Improved	Same	Worse	Death
<24 hours	15	5 (34%)	2	8 (53%)	5 (34%)
1-13 days	34	16 (47%)	10	8 (24%)	5 (15%)
> 2 weeks	20	9 (45%)	8	3 (15%)	0 (0%)

tion previously mentioned but worthy of re-emphasis. Fifty-four per cent of patients gave histories of TIAs consistent with vascular insufficiency secondary to carotid artery lesions that finally produced major strokes, raising the possibility that the major catastrophe might have been prevented in a significant percentage of these patients by surgical therapy following the warning sign of the little stroke or TIA.

Some helpful information regarding the screening of patients for operable carotid artery lesions can be inferred from this series: 1) patients with operable carotid artery lesions frequently give histories of TIAs with at least one of the classic symptoms [ipsilateral visual disturbances, or contralateral motor or sensory disturbances, or speech difficulties]. Only 12% of 167 patients with transient ischemic attacks did not have at least one of the classic symptoms. 2) Bruits are very frequently heard in the presence of a significant carotid occlusion—75 per cent in this study. A bruit proved to be even more diagnostically valuable than previously thought (Peart and Rob). This is undoubtedly due to increased experience. The stethoscope must be placed over the carotid bifurcation. The bruit of carotid stenosis is higher pitched and louder than a transmitted murmur from aortic stenosis, as heard in the lower neck. 3) Ophthalmodynamometry may be more helpful in evaluating patients with suspected carotid artery stenosis than is generally appreciated. Although the test was positive in only 63%, it was positive in the absence of a bruit in 14 per cent. Ophthalmodynamometry was positive or a bruit was heard

TABLE 9. *Late Results*

Category	Number of Procedures	Operative Death	Related Neurologic Sx			Early Worsening Late Neurologic Deficits			New Sx	Late Death
			None	Fewer	Same	None or Mild	Mod-erate	Severe		
Asymptomatic	20	0	19	—	—	0	1	0	4	2
TIA's	120	3	81	21	4	4	6	1	28	27
Total	140	3	100	21	4	4	7	1	32	29

in 89 per cent when carotid artery occlusions were greater than 30%. Angiogram or exploration of the artery are, of course, the definitive means for detection of a carotid lesion. Also significant lesions may be present in the absence of classic symptoms, in the absence of bruits, or with a negative ophthalmodynamometric test. The knowledge however, that with significant carotid artery stenosis almost 90% of patients will have classic symptoms and that almost 90% will have bruits or positive ophthalmodynamometry provides some guidelines for the selection of patients for arteriography.

There is agreement that reconstruction of carotid arteries in selected asymptomatic patients or in patients with recurrent neurologic deficits is beneficial. Over 80% of patients will be asymptomatic or improved.^{2, 7, 16} Long-term beneficial results followed in 125 of 140 or 89% of patients operated upon. The operation can be performed with low mortality. The mortality rate of 2% is acceptable in the face of ages and overall conditions of patients operated upon. The worsening of neurologic status following operation and permanent late neurologic deficits or death which followed in 11 of 140 (8%) of operations is of concern. The reasons frequently given for these complications are prolonged occlusion of the carotid artery, embolization from the carotid bulb during or following operation, or postoperative thrombosis. The routine

use of local anesthesia with or without shunts during the period of occlusion is advocated to avoid dangerously long periods of occlusion.^{8, 13, 14} Complications may occur early after operation despite these precautions.^{2, 13, 14} Increased cerebral blood flow provided by general anesthesia and the ease of operation convinced us that local anesthesia was not the anesthetic of choice. The point was further emphasized when operative death resulted from pulmonary edema developing during thromboendarterectomy under local anesthesia. Postoperative carotid artery thrombosis occurred in less than one-half of the patients who worsened following operation. It is our feeling that embolization from the plaque or thromboendarterectomized segment and thrombosis are the most frequent causes of worsening and that increased experience with careful surgical technic can prevent the complications. Ophthalmodynamometry appears the quickest and most reliable method of evaluating neurologic deficits in the recovery room; total thrombosis of the carotid artery consistently results in a decrease of ophthalmic artery pressure making early re-operation possible.

Results of operation for progressive or completed strokes were significantly different than for asymptomatic and TIA groups. Patients with progressive or evolving strokes are particularly difficult.^{2, 11} Although nine of 18 demonstrated some early improvement following operation, only

TABLE 10. *Late Results*

Category	Number of Procedures	Operative Death	Related Neurologic Deficits			New Sx	Late Deaths
			None to Mild	Mod-erate	Severe		
Progressive	18	7	3	6	2	2	3
Completed	69	14	29	15	11	9	14
Total	87	21	32	21	13	11	17

three returned to a normal existence and seven died following operation. It is our feeling that operation should not be advised for these patients unless further controlled studies indicate the superiority of operative over nonoperative management.

Patients with completed strokes still are a challenge. In thirty of 69 patients early improvement followed operation and 29 were able to return to a near normal existence. On the other hand, 28% became worse and 19% died in the early postoperative period. It is apparent from Table 8 that the percentage of patients improved by operation increases if operation is performed at least 24 hours following the onset of an acute stroke, and that worsening and death rates are significantly decreased if operation is deferred more than 2 weeks. The groups listed in Table 8, however, are not comparable. One does not know how many patients who underwent operation less than 24 hours following acute strokes would have survived to have an operation 2 weeks or even 2 days later. It is known that the chances of relieving total thrombosis of the carotid artery are significantly decreased if operation is delayed for longer than 2 days.^{2, 14} Although not encountered in our experience, there is good evidence that increasing the blood flow to an infarcted brain may result in hemorrhagic infarction contributing to the increased surgical mortality.^{4, 14} One controlled study of acute strokes indicates that patients operated upon 2 weeks following the event

have a higher improvement rate but also a higher early mortality rate than patients treated without operation.¹ Until further information is available we have adopted the following policy. Operations are advised for patients with stable strokes which are not profound, are of less than one day duration, and who demonstrate total thrombosis of carotid arteries. Patients with completed strokes and significant stenoses of carotid arteries are advised to have operations at least 2 weeks following onset of strokes.

Although the hemodynamically significant lesions are segmental, arteriosclerosis is a generalized disease. The fact is reflected in the long-term followup of these patients. Neurologic symptoms appropriate to involvement of other extracranial or intracranial arteries appeared following 43 of the 227 (19%) operations. In addition at least 11 of the 46 late deaths were due to myocardial infarction.

Conclusions

Experiences with 227 operations for carotid arterial occlusive disease on 205 patients performed between January 1, 1961 and June 30, 1966 were analyzed.

1. Patients with operable occlusive lesions of carotid arteries demonstrated the following:

- a) Appropriate neurologic symptoms and deficits. Eighty-eight per cent of patients with transient neurologic symptoms complained of either unilateral

visual disturbances, contralateral motor and sensory changes or speech difficulties.

- b) A bruit was heard over the carotid bifurcation or ophthalmodynamometry demonstrated a reduced retinal artery pressure in 89% of patients.

2. Eighty-nine per cent of patients with asymptomatic lesions or transient ischemic attacks demonstrated significant improvement in related neurologic symptoms or were normal at last followup. The operative mortality rate was 2%.

3. Operation is not indicated in patients with progressing strokes because of long-term poor results and high mortality.

4. There was improvement in 44% of patients operated upon for completed strokes. The best results and lowest mortality were achieved if the operation was performed more than 2 weeks after the onset of the stroke. Patients with total thrombosis should be operated upon within 1 day of onset, if the stroke is not profound.

5. Ophthalmodynamometry was valuable in the diagnosis and follow-up of patients with carotid occlusive lesions.

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