Usefulness of intraoperative cortical blood flow measurement by heat clearance method for monitoring cerebral ischaemia during therapeutic carotid ligation

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SUMMARY Changes of regional cortical blood flow (rCBF) was monitored by the heat clearance method during the operation of cervical carotid ligation combined with superficial temporal artery and middle cerebral artery anastomosis for the treatment of inaccessible aneurysms of the internal carotid artery in eight patients. There were three types of rCBF responses upon closure of the internal carotid artery, with or without bypass blood flow. Based on the responses, the internal carotid artery was ligated abruptly or occluded gradually. The usefulness of the method for monitoring cerebral ischaemia for therapeutic carotid ligation is discussed.

Cervical carotid ligation is effective in the treatment of intracavernous and/or giant aneurysm of the internal carotid artery inaccessible to direct surgery.¹ However, the immediate or delayed occurrence of cerebral ischaemic complications is a serious problem.²⁻⁴ To avoid complications due to low perfusion, it is important to assess the collateral circulation after carotid ligation before and during operation. Many methods of assessment have been reported, but each has disadvantages and their reliability has not been established.

Recently, we found that measurement during the operation of regional cortical blood flow (rCBF) by the heat clearance method⁵⁻⁷ at craniotomy for combined extracranial and intracranial bypass surgery is useful for this purpose.

Material and methods

Regional CBF was monitored in eight patients who had giant or intracavernous aneurysms of the internal carotid

artery undergoing treatment by cervical carotid ligation combined with superficial temporal artery and middle cerebral artery anastomosis. Before operation, Matas test and contralateral carotid angiography were performed to assess spontaneous collateral blood supply after carotid ligation. In the Matas test, the EEG was recorded during percutaneous compression of the carotid artery for more than 15 minutes; and changes of neurological signs and EEG were studied. Cross-filling of the cerebral arteries during the compression of the carotid artery on the side of the aneurysm was studied by angiography after an injection of contrast medium into the opposite carotid artery.

Operative procedure: Under general anaesthesia, the bifurcation of the carotid artery in the neck was exposed and superficial temporal artery to middle cerebral artery anastomosis was performed through the ipsilateral frontotemporal craniotomy. One or two thermal diffusion flow probes (Plate-type, outside diameter 13 mm, Unique-Medical Co. Ltd., Komae, Tokyo, Japan) were placed on the surface of the frontal and/or temporal lobes exposed by craniotomy for superficial temporal artery to middle cerebral artery anastomosis. Attention was paid to avoid contact between large surface vessels and the probes. The probes were then covered with wet cotton pledgets, taking care not to deform the cortex. The output direct current from the thermocouple probe was amplified by an amplifier (UM meter: UM 2000, Unique-Medical Co. Ltd.) and recorded by XY recorder (Watanabe Multicorder MC 6601, Watanabe Instruments Corp.). The heating current for the thermocouple heating circuit was 20 mA and the sensitivity was adjusted as 10 μ V of probe output

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was equivalent to 1.0 cm or 3.0 cm on a recording graph. Systemic arterial pressure was monitored with a catheter inserted into the radial artery and cervical internal carotid artery pressure was monitored with a 21-gauge needle inserted into the distal part of the exposed internal carotid artery in the neck.

After the anastomosed superficial temporal artery had been temporarily occluded by a clip, the internal carotid artery was clamped just distal to the bifurcation of the common carotid artery, and the changes of rCBF and the arterial pressures were recorded. A few minutes after, the clip on the anastomosed superficial temporal artery was removed, and a further few minutes later, the clamp on the internal carotid artery was released. These procedures were repeated twice.

Based on the data obtained, ligation of the internal carotid artery was performed abruptly, or a Selverstone clamp was placed on the internal carotid artery for later gradual occlusion of the internal carotid artery.

The results of surgery were evaluated by computed tomography and cerebral angiography, performed more than two weeks after surgery.

Results

There were three types of rCBF responses to internal carotid artery occlusion. *Type A*: While the anastomosed superficial temporal artery was occluded, no change of rCBF was observed upon closure of the cervical internal carotid artery (fig 1, two cases); *Type B*: Decrease of rCBF by closure of internal carotid artery was cancelled by opening the anastomosed superficial temporal artery (fig 2, three cases), and *Type C*: Decrease of rCBF by closure of internal carotid artery was not compensated by opening the anastomosed superficial temporal artery

(fig 3, three cases). Systemic arterial pressure was not usually changed throughout the procedures. The distal internal carotid artery pressure (back pressure) was decreased to 11% to 47% of the pre-clamped level in the seven cases in which it was measured.

In the cases of Type A, the internal carotid artery was ligated abruptly: in those of Type C, it was occluded gradually with a Selverstone clamp in the post-operative period. Referring to the findings of pre-operative EEG and Matas test, angiographical cross filling and intra-operative internal carotid artery back pressure, the internal carotid artery was ligated abruptly in two cases of Type B, and in one case, the internal carotid artery was occluded gradually. In the former two cases; ligation was abrupt because the Matas test was negative, angiographical cross filling was good, reduction of distal intravascular pressure of the carotid artery during temporary carotid occlusion was less than 30% from control, and the results indirectly suggested sufficient development of spontaneous collaterals after carotid occlusion. The table summarises the results of the cases.

There were no complications due to low perfusion after operation, but an embolism occurred in one case. In this case, a 31-year-old woman with an intracavernous carotid aneurysm, superficial temporal artery to middle cerebral artery anastomosis was performed with application of a Selverstone clamp to the right internal carotid artery. The clamp was advanced to about 80% occlusion of the internal carotid artery on the 2nd postoperative day. The patient tolerated this procedure well and no

Fig 1 Recording of the Type A response. Regional cortical blood flow shows almost no change by occlusion of the internal carotid artery and anastomosed superficial temporal artery.

Fig 2 Recording of the Type B response. Regional cortical blood flow (rCBF) and internal carotid artery stump pressure decrease by closure of internal carotid artery, but the decrease of rCBF recovers by opening the anastomosed superficial temporal artery, particularly in the frontal region.

neurological changes ensued. However, early the next morning, left hemiparesis and dysarthria occurred and angiography showed embolic stenosis in the stem of the right middle cerebral artery. After physical therapy, she was discharged with mild weakness of the left upper extremity.¹⁵

Disappearance of rapid and marked enhancement with contrast medium in the aneurysmal cavity on computed tomography, and failure to demonstrate the aneurysm on cerebral angiography after surgery suggested that the aneurysms were thrombosed.¹ Development of collateral flow through surgical bypass was demonstrated on cerebral angiograms in all cases where the examination was performed.

Discussion

In the Cooperative Study of Intracranial Aneurysms

and Subarachnoid Hemorrhage,³ the incidence of ischaemic neurological complications after carotid occlusion was 233/814 (28.6%); the rate was higher in older patients than in younger patients, higher with abrupt ligation (34%) than with gradual occlusion (25%), and significantly higher with internal carotid occlusion (49%) than with common carotid occlusion (28%). Recently, Heros *et al*¹⁶ indicated that the rates of ischaemic complications of cervical carotid ligation reported in the literature ranged from 7% to about 50%, with an average about 25%, and, of these, roughly half were serious and permanent. Two factors have been considered as the main causes of cerebral ischaemic complications; one is low perfusion and the other is thrombo-embolism.³

To avoid ischaemic complication due to low perfusion, the technique of gradual occlusion of the carotid artery and/or the combined surgery of

Fig 3 Recording of the Type C response. The decreases of rCBF and internal carotid artery stump pressure by closure of internal carotid artery do not recover by opening of the anastomosed superficial temporal artery.

extracranial and intracranial bypass have been employed. The effectiveness of gradual occlusion of the carotid artery to aid the development of a collateral circulation and to prevent acute ischaemic complication was demonstrated in the cooperative study and by others.³⁻¹⁰ Many kinds of instrument, for example the Selverstone clamp, or the Crutchfield clamp, have been developed for this purpose. Extracranial and intracranial bypass surgery, especially superficial temporal artery and middle cerebral artery anastomosis, is a relatively simple and safe procedure, and can contribute a significant blood flow to the ischaemic cerebral hemisphere. It is logical to believe that this procedure is effective in preventing

acute ischaemia in patients with marginal collateral circulation. Furthermore, extracranial and intracranial bypass may be even more effective in preventing late ischaemic complication after carotid ligation,⁴ for the bypass blood flow would increase later in the follow-up period, in response to the demands of the brain.¹¹ Based on the view, extracranial and intracranial bypass surgery has been usually combined before carotid ligation following the development of microsurgical techniques in recent years.¹²⁻¹³

However, a few reports have appeared recently in which ischaemic complication occurred occasionally in cases of gradual carotid occlusion combined with superficial temporal artery and middle cerebral

Usefulness of intraoperative cortical blood flow measurement

Table Summary of the cases

Cases	pre-op.		at op.		Carotid occlusion	post-op. (2 w after CO)		
	Matas test	CAG cross filling	ICA stump pressure (% decrease)	Cortical BF change closed STA open STA		Neurologic complication	CT CE in aneurysm	CAG collateral via STA
1	—	+	44%↓	↓↓ ↓	gradual	hemiparesis (embolization)	+ → —	+++
2	—	++	33%↓	↓↓ ↓	gradual	—	+ → —	++
3	—	+	—	↓↓ ↓	gradual	—	+ → —	+++
4	+	+	47%↓	↓↓ ↓	gradual	—	+ → —	—
5	—	++	—	↓ ↓	abrupt	—	+ → —	++
6	—	++	11%↓	↓ ↓	abrupt	—	+ → —	+
7	—	+	23%↓	↓ ↓	abrupt	—	+ → —	+
8	—	++	27%↓	↓ ↓	abrupt	—	+ → —	++
Pre-op.:	pre-operative assessment					Cortical BF change by CO: change in cortical blood flow by		
at op.:	intra-operative assessment					temporary occlusion of the carotid artery		
post-op.:	(2 w after CO): postoperative assessment more than 2 weeks after carotid occlusion					closed superficial temporal artery; change during closure of the anastomosed superficial temporal artery		
Matas test:						open superficial temporal artery; change during opening of the anastomosed superficial temporal artery		
—;	no neurological signs and abnormal finding on electroencephalogram (EEG) evoked by compression of the carotid artery with aneurysm for 15 minutes					↓; no significant change in cortical blood flow		
+	neurological signs and/or abnormal finding on EEG evoked by the compression					↓; mild reduction in cortical blood flow (reduction of thermocouple voltage was less than 20 μV from control)		
CAG cross filling:	degree of cross filling of the cerebral arteries on contralateral carotid angiogram during ipsilateral carotid compression					↓↓; marked reduction in cortical blood flow (reduction of thermocouple voltage was more than 20 μV from control)		
—;	no cross filling					CT: CE in aneurysm; changes of contrast enhancement in the aneurysm on CT		
+	fair cross filling (one additional major vessel well opacified or two additional major vessels faintly opacified by the compression)					+ → —; preoperative contrast enhancement in aneurysm disappeared after carotid occlusion		
++;	good cross filling (two or more additional major vessels well opacified by the compression)					CAG: collateral via superficial temporal artery; development of collaterals through anastomosed superficial temporal artery on carotid angiogram		
Internal carotid artery stump pressure (% decrease):	percent reduction in mean intravascular pressure of the carotid artery following temporary proximal carotid occlusion					+; fair		
						++; good		
						+++; marked		

artery anastomosis; thromboembolism was considered to be the cause of such cerebral ischaemia.⁸⁻¹⁴ As mentioned above, we also encountered a cerebral thrombo-embolic complication in a patient with an intracavernous carotid aneurysm who was treated by gradual occlusion of the internal carotid artery combined with superficial temporal artery and middle cerebral artery anastomosis.¹⁵ Based on available evidence, we have suggested that in the presence of a sufficient collateral blood supply after combined extracranial and intracranial bypass surgery, abrupt internal carotid artery ligation may reduce the risk of thrombo-embolic complications.

As to low cerebral perfusion caused by carotid ligation, Miller *et al* indicated that about 80% patients will tolerate acute occlusion of one internal carotid artery but 20% will not.¹⁶ In order to ligate the carotid artery safely, it is necessary to assess the collateral circulation after carotid ligation before and during operation. For this purpose, there exist numerous examinations and tests: EEG-Matas test,^{10,16} angiography for cross filling,¹⁷ ophthalmodynamometry,¹⁰ ophthalmoplethysmography,¹⁸ intravascular balloon-Matas test,¹⁹ Doppler flowmetry with compression test,²⁰ regional cerebral

blood flow study with radioisotope,^{16,17} electromagnetic flow measurement,²¹ back pressure measurement of the internal carotid artery,^{10,17} etc. Though every method for the assessment has some advantages, it also has some defects and problems. In recent years when extracranial and intracranial bypass surgery has become routinely combined with this treatment, the development of collateral circulation after carotid ligation and anastomosis needs to be evaluated after bypass surgery. A new reliable method for this assessment is required.

Regional blood flow measurement with thermal diffusion flow probe (heat clearance method) was originally developed by Gibbs in 1933.²² Many have improved the method, and the modern technique using thermocouples has been widely applied, mainly in the experimental studies. The advantages of the method for regional blood flow measurement are (1) it is a simple and easy technique using small apparatus, (2) the ability to measure regional blood flow dynamically and continuously, (3) the method is non-invasive when a plate-type probe is used, (4) it is not necessary to use radioisotope. These advantages indicate that this method is suitable for clinical intra-operative measurement of the regional blood

flow of tissues. However, there are few reports of clinical use of this method for cerebral circulation,^{23, 24} except in experimental conditions. There has been no report of practical application of this method except for recent studies by Carter *et al.*^{25, 26} They applied this technique using a Peltier stack in the neurosurgical field and indicated that intraoperative evaluation of rCBF with this method may be of value in estimating the safety of temporary occlusion of the major cerebral vessel for bypass or aneurysm surgery. In the present paper, we demonstrated the practical usefulness of the rCBF measurement by the heat clearance method for monitoring the development of collateral blood supply after carotid ligation.

The disadvantage of the method is inaccuracy in quantitative measurement and difficulty in expressing regional blood flow data as absolute values (such as ml/100 g/min). However, this method is useful enough to check whether a decrease of rCBF during carotid ligation occurs or not, and whether it may be compensated by opening bypass flow. Another weak point of this method is that the measurement is limited to the exposed cortical surface during bypass surgery. Furthermore, ischaemia in the deeper regions cannot be detected by cortical blood flow measurement with plate-type flow probes. However, the ischaemia caused by internal carotid artery occlusion occurs mainly in the middle cerebral artery territory where craniotomy is performed for superficial temporal artery and middle cerebral artery anastomosis, and low perfusion caused by internal carotid artery occlusion usually takes place diffusely, though thrombo-embolic ischaemia may occur locally in a small region, that is perforator vessel infarction. It is concluded that rCBF measurement by the heat clearance method at craniotomy for combined superficial temporal artery and middle cerebral artery anastomosis offers sufficient information regarding ischaemia caused by internal carotid artery ligation.

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