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Acute Cerebral Revascularization:Correlation among Preoperative CBF, Collateral Flow and Surgical Outcome

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Summary : Twenty-two patients of acute cerebral revascularization were analyzed in order to evaluate various predictors related to surgical effectiveness and outcome. These patients presented sudden neurological symptoms following occlusion of the middle cerebral artery (MCA). The left MCA was involved in 8 patients, and the right in 14 patients. Prior to surgical intervention, CT scan, serial angiography, and measurement of cerebral blood flow (CBF) were performed. STA-MCA anastomosis was completed in 21 patients, and left MCA embolectomy was performed on one patient. In the 14 patients of the "effective" group, the time elapsed from onset of stroke to revascularization was an average of 19.5 hours (6-72 hours). Of these patients,7 cases has a residual CBF of 24.8±1.2ml/100g/min (45% of normal CBF). Collateral flow, as judged from the preoperative angiograms, was "good" in 4 cases, and "fair" in 10 cases. In the 8 cases of the "non-effective" group, the time elapsed prior to the restoration of flow was an average of 8.2 hours (6-16 hours). Three cases had a residual CBF of 19.5±1.1ml/100g/min. Collateral flow was "fair" in 5 cases, and "poor" in 3 cases. These results suggest that good preoperative collateral flow and residual CBF constitute the most accurate favorable predictors for the estimation of surgical effectiveness and outcome, and the time limits for acute cerebral revascularization is variable according to the degree of residual CBF supplied by collateral flow patterns.

Key words :
- acute cerebral revascularization
- cerebral blood flow
- cerebral ischemia
- collateral flow
- embolectomy
- STA-MCA anastomosis

Introduction

The role of revascularization in the acute stage of cerebral ischemia remains controversial for several reasons. Acute cerebral revascularization is beneficial in selected patients with stroke in evolution. On the other hand, it is known that this procedure may potentially lead to hemorrhagic infarction or severe brain edema.

We analyzed 22 cases of acute cerebral revascularization performed at Nakamura Memorial Hospital, in order to better understand factors related to patient selection, prognosis, surgical results, and complications. The present study attempts to evaluate various predictors related to surgical effectiveness and outcome.

Materials and Methods

This study included 22 patients (18 men and 4 women), ranging from 33 to 72 years with a mean age of 56 years. These patients presented with sudden neurological symptoms following occlusion of the middle cerebral artery (MCA). The left MCA was involved in 8 patients, and the right in 14 patients.

Prior to surgical intervention, CT scan, serial angiography, and measurement of cerebral blood

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flow (CBF) were performed. Initial CT scan of these patients revealed no demonstrable abnormality except for a small low density area (LDA) in the subcortical terminal zone in some patients. The collateral flow patterns on the cerebral angiogram were classified into three categories: "good" indicated late filling of the whole MCA complex through the leptomeningeal arteries, "fair" demonstrated late filling down to the insular segment of the MCA and delayed clearance of contrast material, "poor" indicated almost no filling of the MCA and late filling of a part of its cortical branches. Hemispheric CBF (mean CBF), measured preoperatively in 11 patients, was expressed as the mean ISI value obtained by the ^{133}Xe inhalation technique, the normal mean CBF in our laboratory being 55 ± 7.0 (S. D.) ml/100g/min.

Surgical revascularization was performed within an average of 15.4 hours (ranging from 6 to 72 hours) after the onset of stroke. Superficial temporal artery to middle cerebral artery anastomosis (STA-MCA) was performed in 21 patients, and left MCA embolectomy was performed on one patient. With regard to the effectiveness of revascularization, patients were divided into two groups, based on postoperative clinical manifestations and CT findings. The "effective" group showed postoperative improvement of neurological symptoms, in addition there was no extension of LDA to the cortex in the postoperative CT scan. The "non-effective" group showed extension of LDA to the cortex in the CT scan apart from neurological symptoms. Surgical outcome was judged according to the activity of daily living scale (ADL) 3 months following the revascularization. ADL was graded from I (normal life) to V (death).

Results

Tables 1 and 2 give a summary of the clinical data of both groups. In the 14 patients of the "effective" group (**Table 1**), the time elapsed from onset of stroke to revascularization was an average of 19.5 hours (ranging from 6 to 72 hours). Of these patients, 7 cases had a residual CBF of 24.8 ± 1.2ml/100g/min (45% of normal CBF). Collateral flow, as judged from preoperative angiograms, was good in 4 cases, and fair in 10 cases. The ADL of these patients was I in 9 cases, II in 5. No surgial complications were noted. Postoperatively, two patients showed angiographic evidence of spontaneous reopening of occluded vessels without hemorrhagic infarction or brain edema.

Table 1 Summary of clinical data in "effective" group

Case No.	Age(yrs) Sex	Neurological grade	Preop. Angiography		mean CBF(ISI) (ml/100g/min) ^{133}Xe-inhalation	Surgical Revascularization			ADL*
			Occlusion site	Collateral flow		Procedure	Time to flow restoration	Hemorrhagic infarction	
1	53 M	major	Rt-MCo	good	25.0	STA-MCA	18	—	II
2	67 M	major	Lt-MCo	fair	25.4	STA-MCA	6.5	—	II
3	61 M	major	Lt-MCo	fair	24.1	STA-MCA	6	—	I
4	63 M	minor	Rr-MCo	good	25.2	STA-MCA	10	—	I
5	33 F	major	Rt-MCo	good		STA-MCA	8.5	—	II
6	62 M	major	Rt-MCo	fair		STA-MCA	72	—	II
7	46 M	major	Lt-MCo	fair		STA-MCA	10	— re-open	II
8	47 M	major	Lt-MCo	fair		STA-MCA	6	— re-open	I
9	48 F	major	Lt-MCo	fair		STA-MCA	44	—	I
10	59 M	major	Rt-MCo	fair		STA-MCA	9	—	I
11	52 M	major	Rt-MCo	fair	24.4	STA-MCA	38	—	I
12	59 M	minor	Rt-MCo	fair		STA-MCA	15	—	I
13	47 M	major	Rt-MCo	good	26.6	STA-MCA	18	—	I
14	60 M	major	Rt-MCo	fair	22.7	STA-MCA	12	—	I
Mean	54.9				24.8±1.2		19.5 (hrs)		

ADL*: I (normal), II (unassisted), III (partially assisted), IV (totally assisted), V (dead)

Table 2 Summary of clinical data in "non-effective" group

Case No.	Age(yrs) Sex	Neurological grade	Preop. Angiography		mean CBF(ISI) (ml/100g/min) ^{133}Xe-inhalation	Surgical Revascularization			ADL*
			Occlusion site	Collateral flow		Procedure	Time to flow restoration	Hemorrhagic infarction	
15	47 M	major	Lt-MCo	poor		MCA-Embolectomy	10	+++ re-open	V
16	55 M	major	Lt-MCo	fair		STA-MCA	6.5	+ re-open	III
17	49 F	major	Lt-MCo	fair		STA-MCA	8	− re-open	II
18	60 M	major	Rt-MCo	poor	18.5	STA-MCA	6.5	−	III
19	72 M	major	Rt-MCo	poor		STA-MCA	5.5	+ re-open	III
20	70 F	major	Rt-MCo	fair		STA-MCA	7	−	III
21	62 M	major	Rt-MCo	fair	19.4	STA-MCA	16	−	II
22	64 M	major	Rt-MCo	fair	20.7	STA-MCA	6	−	II
Mean	59.5				19.5±1.1		8.2(hrs)		

ADL*: I (normal), II (unassisted), III (partially assisted), IV (totally assisted), V (dead)

On the other hand, in the 8 cases of the "non-effective" group (**Table 2**), the time elapsed prior to the restoration of flow was 8.2 hours on the average (ranging from 6 to 16 hours). Three cases had a residual CBF of 19.5±1.1ml/100g/min. Collateral flow was fair in 5 cases, and poor in 3 cases. The ADL of these patients was II in 3 cases, III in 4, and V in 1. One patient who underwent emergency embolectomy died due to massive hemorrhagic infarction with severe brain edema. Three patients who underwent STA-MCA anastomosis showed angiographic findings of spontaneous reopening of occluded MCA. Of these 3 patients, two cases showed a small volume of hemorrhagic infarction on CT scans.

To summarize the above results, the time elapsed prior to the restoration of flow apparently had no relation to outcome (**Fig. 1**). The outcome of patients

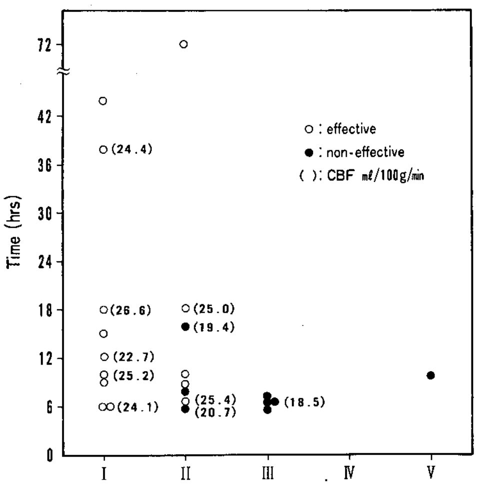

Fig. 1 Correlation of outcome with the time to restoration of flow. The time to restoration of flow was not a good predictor of outcome.

who underwent acute cerebral revascularization 12 hours or more after onset, was satisfactory without complications if the residural CBF supplied through collateral circulation was above 25ml/100g/min (**Fig. 1**). The correlation of outcome with collateral flow and residual CBF is presented in **Fig. 2**. Good

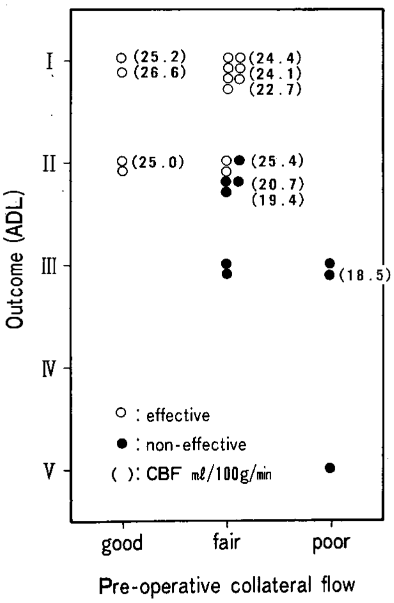

Fig.2 Correlation of outcome with collateral flow and residual CBF. Good collateral flow as judged by the preoperative angiogram and residual CBF indicated by ^{133}Xe inhalation technique was a good prognostic factor.

collateral flow as judged by the preoperative angiogram and residual CBF was an effective prognostic factor (**Fig. 3, 4**). The correlation of collateral flow with residual CBF is presented in **Fig. 5**. The degree of collateral flow had some relation to the degree of residual CBF in the ischemic brain tissue.

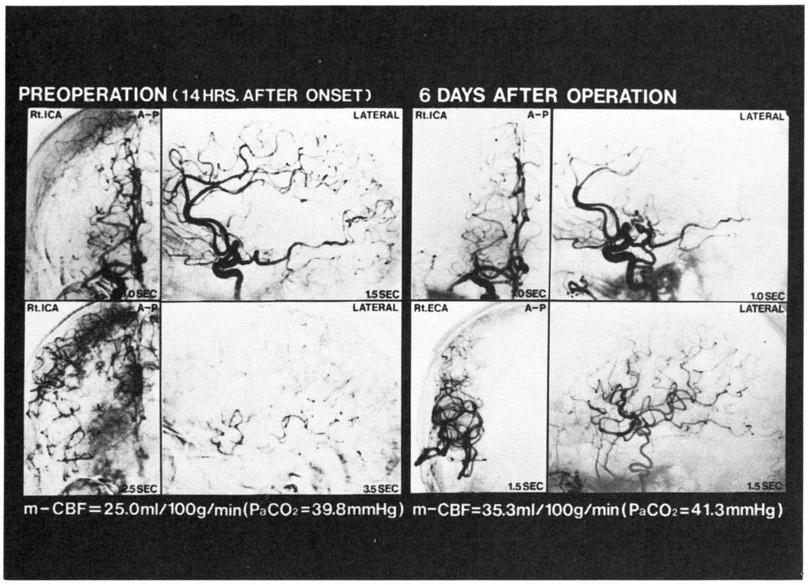

Fig. 3 Case 1 Left : preoerative angiograms showing occlusion of the right MCA and good collateral flow through the leptomeningeal arteries at the venous phase. Right : postoperative angiograms 6 days after surgery showing extensive filling of the MCA via a patient STA-MCA anastomosis.

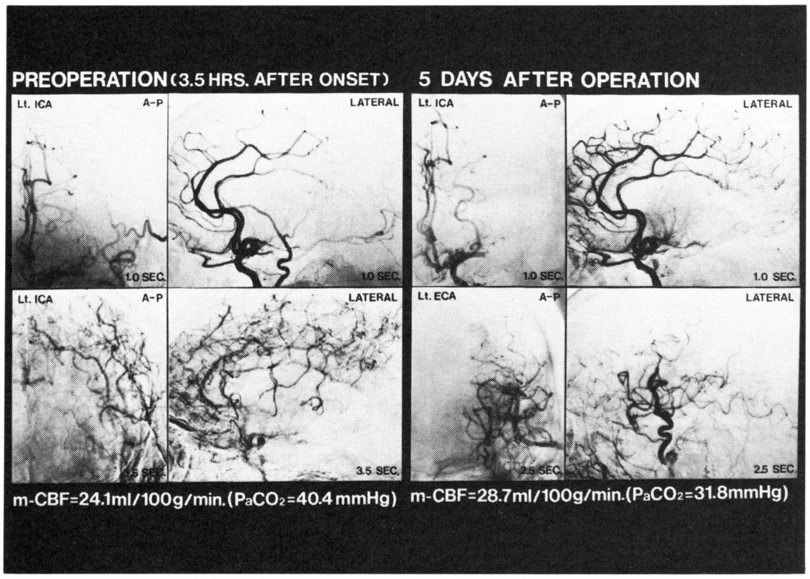

Fig. 4 Case 3 Left : preoperative angiograms showing occlusion of the left MCA with fair collateral flow. Right : postoperative angiograms 5 days after surgery showing extensive filling of the MCA through a dilating STA.

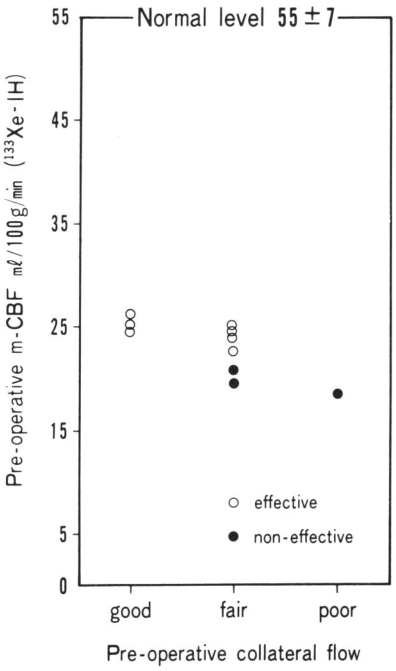

Fig. 5 Correlation of collateral flow and residual CBF. The degree of collateral flow had some relation to the degree of residual CBF in the ischemic brain tissue.

Discussion

The development of cerebral infarction seems to be a function of the residual CBF and the duration of ischemia[5]. When CBF decreases to less than "the flow threshold of electrical failure"[1], early restoration of flow will lead to complete recovery without cerebral infarction if ischemic brain tissue remains viable. As yet, however we have no sure way of determining whether or not any brain tissue remains viable in the early stage following ischemic stroke.

However, measurement of residual CBF may serve as an indicator of brain tissue viability. In the present study, LDA (core of infarction) on the CT scan extended from a subcortical terminal zone[7] due to lack of the collateral supply, in patients with hemispheric CBF of about 25 ml/100 g/min (ISI value) as indicated by the ^{133}Xe inhalation technique. This level of mean CBF (about 45 % of normal value) supplied through collateral circulation seems to imply the critical CBF level below which cerebral infarction would take place. In collaterally perfused brain tissue, some of the ischemic low flow areas surrounding the core of infarction are considered to be the "ischemic penumbra" (viable, but functionally depressed brain tissue due to inadequate perfusion)[8].

Based on animal studies of cerebral ischemia, it is generally thought that the human brain can tolerate ischemia for no more than 6 hours. This critical time limit may be unrealistic for acute cerebral revascularization, since most patients are neither brought to the hospital nor definitively diagnosed in the initial 6 hours after onset of stroke[4]. However, as demonstrated in **Fig. 1**, the time elapsed prior to restoration of flow did not predict the outcome. Furthermore, in many cases, restoration of flow was delayed far longer than 6 hours without producing hemorrhagic infarction or brain edema. The time limits for acute cerebral revascularization may be variable according to the degree of residual CBF supplied by collateral flow patterns (**Fig. 6**).

It is desirable that some adjunctive treatment could help prolong the period of ischemia which could be tolerated by the human brain. As yet, however, no such adjunctive treatment has been firmly established. In the present study, hypervolemic hemodilution[10] was used to improve collateral perfusion to ischemic regions of the brain. Among the various available forms of medical treatment, a combination of volume expansion, hemodilution and barbiturate administration might further improve cerebral circulation and prolong the period that the brain could tolerate ischemia without damage[4]. The final outcome in each patient reflects the interaction of various parameters, including the time elapsed prior to the restoration of flow, residual CBF, collateral flow patterns and adjunctive treatment. **Fig. 2** demonstrates that collateral flow was the most important prognostic factor. "Good" collateral flow is necessary in order to prevent irreversible cell dam-

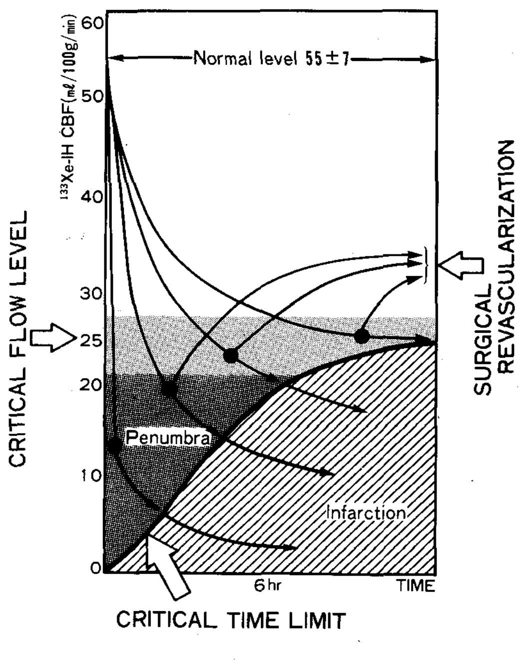

Fig. 6 Time limits for acute cerebral revascularization and ischemic thresholds. The time limits for acute cerebral revascularization may be variable, the more satisfactory the collateral flow, the more prolonged a time limit may be set for surgical intervention.

age in the compromised neuronal cells. Accordingly, collateral flow has also been found to be the best predictor of outcome in the emergency embolectomy for acute occlusion of the MCA [6].

From our surgical results, indications for acute cerebral revascularization can not yet be definitively decided neuroradiologically. A few guidlines may, however, be suggested: (1) when cerebral angiography shows "good" collateral circulation and initial CT scan shows no abnormal density areas except for a spotty LDA in the subcortical terminal zone, then acute restoration of flow is likely to prevent the extension of ischemic infarction without complications. (2) On the other hand, when angiographical collateral circulation is "poor" and LDA extending to cortical structure is revealed on CT scan, acute revascularization may cause development of hemorrhagic infarction or brain edema.

In this study, a single patient who underwent emergency embolectomy for occlusion of MCA with poor collateral circulation, had severe hemorrhagic infarction with brain edema after surgery. In principle, early restoration of high blood flow to an area of brain ischemia may improve functional recovery without any stealing from normal adjacent areas[3)4)] Yet, restoration of high blood flow to severely ischemic brain tissue has a high potential for leading to serious hemorrhagic infarction[2) 4)] . On the other hand, the initial amount of blood delivered by the STA-MCA anastomosis may not be sufficient to support an entire hemisphere; it may, however, be sufficient to maintain normal function in approximately 100 gm of brain tissue, or to keep viability in approximately 250 gm of brain tissue until the collateral blood supply through the dilating STA can be increased by metabolic demand[3)4)9)]. This limited improvement of perfusion pressure immediately after STA-MCA anastomosis may lessen the potential for serious postoperative complications.

Conclusions

(1) In the present study, it was demonstrated that if revascularization of ischemic stroke in the acute stage is performed, collateral blood flow patterns of the preoperative cerebral angiogram reflect to some degree the residual CBF, and constitute a good predictor for the estimation of surgical effectiveness and outcome. (2) The time limits for acute cerebral revascularization may be variable according to the degree of residual CBF supplied by collateral flow patterns and, therefore, the more satisfactory the collateral flow, the more prolonged the time limit may be set for surgical intervention.

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