(RIND) in 8, and minor completed stroke (MiCS) in 3. CT scans showed the absence of a low density area (LDA) in 6 cases, spotty LDA in the basal ganglia in 6 cases, and LDA in a watershed zone in 6 cases and in the lobal cortex in 1 case. The angiographic findings showed internal carotid artery (ICA) occlusion in 12 cases, ICA stenosis ($\geq 50\%$) in 4 cases, and middle cerebral artery (MCA) occlusion in 3 cases.

In this study, the STA-MCA bypass was performed on the clinically symptomatic cases showing a disturbed response to ACZ with or without a reduction in the resting CBF on SPECT. The clinical symptoms correlated to the site of the obstructive findings as indicated by angiography.

The standard STA-MCA bypass was performed more than 4 weeks after the onset, when the neurological symptoms were stable. During the surgery, the posterior temporal or temporo-occipital artery was chosen as the recipient artery. Postoperatively, the patency of the bypass was checked by angiography within 2 weeks of the operation in all cases. Postoperative angiography performed within two weeks of the operation, showed good patency of the bypass and a retrograde filling of the middle cerebral artery through the bypass in each case.

Follow-up Study of Clinical Symptoms

The follow-up period for the 19 cases ranged from 9 months to 3.7 years (mean follow-up period: 2.1 years). During the follow-up period, none of the patients complained of recurrent clinical ischaemic attack.

LCBF Measurement

The LCBF was measured during surgery by the thermal diffusion technique using a flow probe with a Peltier stack [6, 22] on the precentral gyri during surgery. After opening the dura, before anastomosis, the LCBF was first measured at normocapnia ($PaCO_2$; 37.6 ± 2.4 mmHg). Next, to investigated the CO_2 CVR, the LCBF was measured at hypocapnia ($PaCO_2$; 29.8 ± 4.4 mmHg) induced by hyperventilation and the LCBF was measured continuously. After completing the anastomosis, the LCBF and CO_2 CVR measurements were carried out in the same manner.

CO_2 CVR was calculated as a percentage of the change in LCBF per millimeter of mercury decrease in $PaCO_2$, expressed as a percentage in the change per millimeter of mercury (relative CO_2 reactivity) [26]. The mean arterial blood pressure (MABP) was maintained at 90–112 mmHg with no significant change before and after bypass at any $PaCO_2$.

SPECT Studies

SPECT studies were performed in all cases with ^{123}I N-isopropyl-p-iodoamphetamine (IMP) not only at the resting stage, but also at the ACZ activation stage before surgery and at 1 month after surgery. The resting images were analysed in comparison to the primary occipital visual cortex. The ACZ activation images were estimated using subtracted SPECT images, which were obtained by subtracting the resting SPECT images from the ACZ activation SPECT images. The response to ACZ on SPECT was divided into two groups. The one with a normal response to ACZ, and the other with a disturbed response to ACZ compared to the response of the healthy side.

LCBF and CO_2 CVR of Normal Controls

For the control study, we used the same technique and protocol to examine LCBF and CO_2 CVR values at the inferior frontal gyri in five patients with non-ruptured aneurysms. The mean age in these cases was 59.7 years; two patients were male and three were female. There were no remarkably abnormal findings on the CT scan in these five cases. Form these control cases, the average LCBF (mean $\pm$ SD) was determined to be 65.0 ± 15.3 ml/100 g/min (MABP; 102.0 mmHg, $PaCO_2$; 37.4 mmHg) and the average CO_2 CVR (mean $\pm$ SD) was 3.26 ± 0.58%/mmHg.

Statistical Analysis

The physiological data were compared by a two-tailed paired or non-paired Student's t test. The value of $p < 0.05$ was taken as the threshold for statistical significance. All values are reported as means $\pm$ standard deviation.

Results

LCBF Alteration Before and After Bypass

At normocapnia ($PaCO_2$; 37.6 mmHg), the average LCBF was 45.7 ± 11.2 ml/100 g/min before surgery, which was significantly reduced in comparison to the control cases ($p < 0.05$). After bypass, the mean LCBF increased significantly ($p < 0.05$) to 59.3 ± 13.0 ml/100 g/min (Fig. 1). At hypocapnia (mean $PaCO_2$; 29.9 mmHg), the average LCBF was 49.1 ± 14.1 ml/100 g/min before surgery, which then significantly ($p < 0.05$) increased to 61.0 ± 17.4 m/100 g/min after bypass.

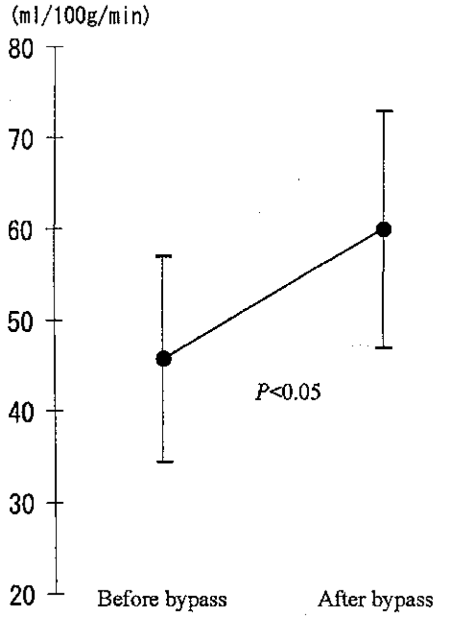

Fig. 1. Comparison of local cerebral blood flow before and after bypass

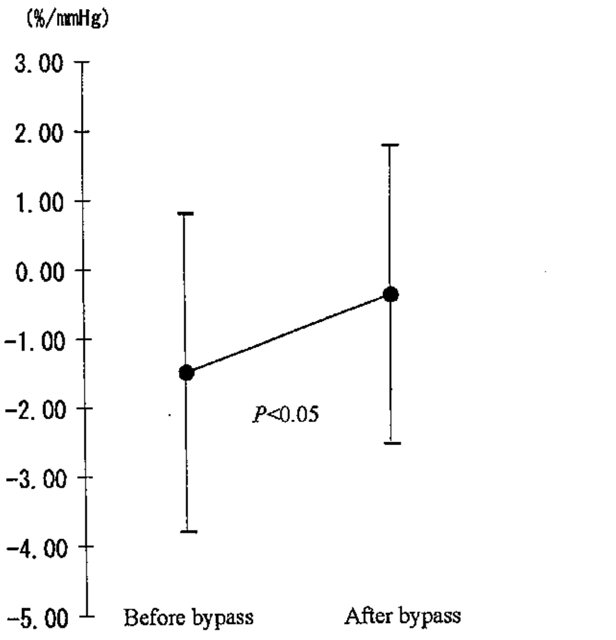

Fig. 2. Comparison of CO_2 cerebrovascular reactivity before and after bypass

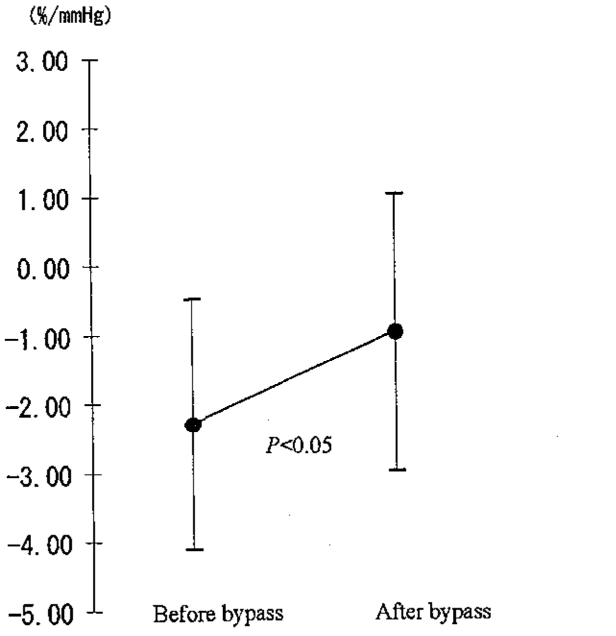

Fig. 3. Comparison of CO_2 cerebrovascular reactivity before and after bypass in the cases pre-operatively showing the inverse steal phenomenon

CO_2 CVR Alteration Before and After Bypass

Before bypass, the average CO_2 CVR value was -1.50 ± 2.30%/mmHg, indicating that the CO_2 CVR for patients with ischaemic CVD is severely disturbed. In 15 cases (79%), the CO_2 CVR value was below 0%/mmHg, with, this condition being known as the inverse steal phenomenon. After bypass, the average CO_2 CVR increased significantly ($p < 0.05$) to -0.40 ± 2.16%/mmHg (Fig. 2). Fifteen cases showed a postoperative improvement in CO_2 CVR values in each case Among the 15 cases showing the inverse steal phenomenon before bypass, four cases resolved the inverse steal phenomenon immediately after bypass.

The average CO_2 CVR value for the cases pre-operatively showing the inverse steal phenomenon improved significantly after bypass (Fig. 3). But the CO_2 CVR value for the cases with no pre-operative inverse steal phenomenon did not show any significant improvement in the postoperative CO_2 CVR value (Fig. 4).

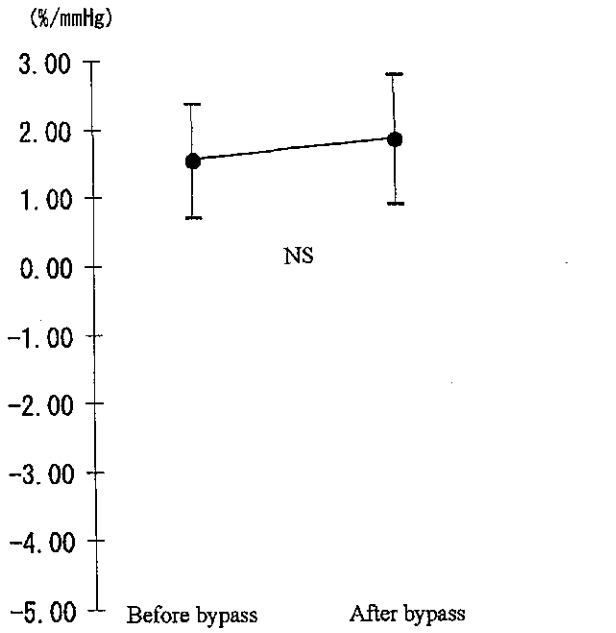

Fig. 4. Comparison of CO_2 cerebrovascular reactivity before and after bypass in the cases without preoperative inverse steal phenomenon

CO_2 CVR and SPECT Studies

Before surgery, 13 cases showed a reduction in the CBF on the affected side on resting SPECT. In addition, in the ACZ challenging stage, all 19 cases showed a disturbed response to ACZ. At 1 month after bypass, the resting SPECT findings were improved in 14 cases, and no change was observed in 5 cases. A normal response to ACZ was observed in 6 cases and a disturbed response was observed in 13 cases. The average postoperative CO_2 CVR value of the cases showing a normal ACZ response on the postoperative SPECT

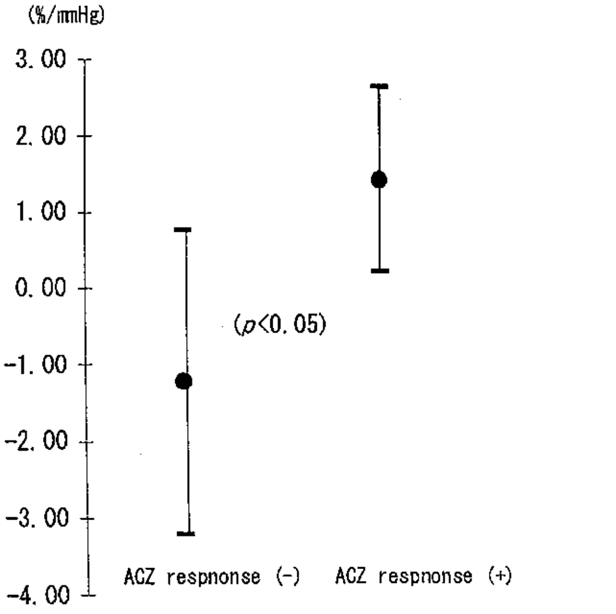

Fig. 5. Comparison of postoperative CO_2 cerebrovascular reactivity according to the acetazolamide response on postoperative single photon emission computed tomogrphy. (*ACZ* Acetazolamide)

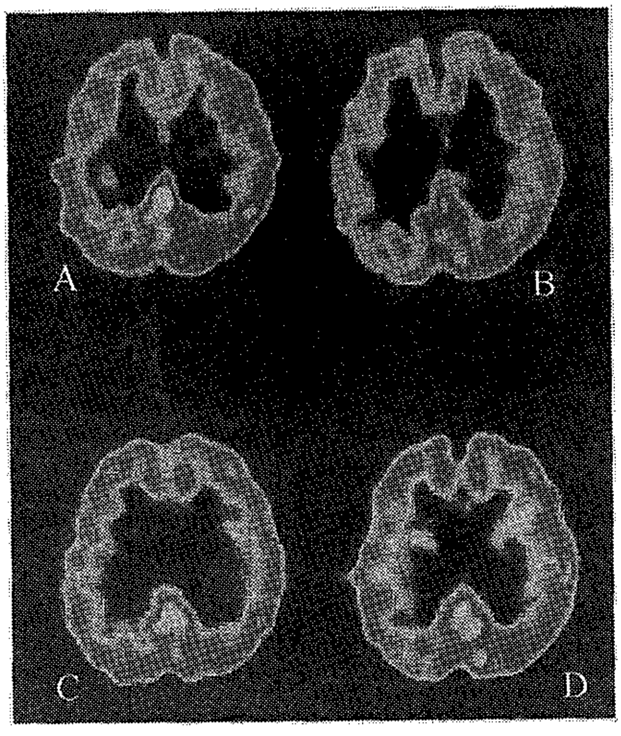

Fig. 6. Single photon emission computed tomography (*SPECT*) findings of 54-year old male complaining of transient left hemiparesis. (A) SPECT at resting before bypass showing the relative hypoperfusion area in right cerebral hemisphere. (B) SPECT at acetazolamide (*ACZ*) challenge before bypass showing the poor response to ACZ in right cerebral hemisphere. (C) SPECT at rest after bypass showing the improvement of the blood flow. (D) SPECT at ACZ challenge after bypass showing the improvement of the response to ACZ

study was 1.43 ± 1.21%/mmHg, which was significantly higher than the average CO_2 CVR value of the cases showing a disturbed ACZ response on the postoperative SPECT studies (Fig. 5).

Illustrative Case

A-54-year-old male visited our hospital complaining of transient left hemiparesis. CT-scan showed no LDA. A right carotid angiogram showed an occlusion at the origin of the right internal carotid artery. The SPECT findings for this patient showed a relative hypoperfusion and poor response to ACZ in the right cerebral hemisphere before surgery (Fig. 6A, B). The patient underwent an STA-MCA bypass. The LCBF value was 54 ml/100 g/min before bypass and increased to 67 ml/100 g/min after bypass ($PaCO_2$; 34.5 mmHg, MABP; 100 mmHg). The CO_2 CVR value was -3.42%/mmHg before bypass, and after bypass, this value improved to -1.61%/mmHg. The patency of the bypass was confirmed by postoperative angiography. At 1 month after the bypass, SPECT showed the improvement of the resting CBF and ACZ response (Fig. 6C, D). This change was comparable to the intra-operative change in CO_2 CVR level.

Discussion

Since the report of the International Co-operative Study of Extracranial/Intracranial Arterial Bypass [9], this type of surgery has usually been performed on symptomatic patients with severe cerebral perfusion reduction or limited capacity for vasodilatation based on an examination of the CBF study [3, 5, 7, 18, 24]. We have reported the usefulness of the bypass for ischaemic CVD from various aspect [10, 11, 12]. This study is to report the effects of the bypass on CO_2 CVR values in patients with haemodynamic crisis based on LCBF and CO_2 CVR studies during surgery, as well as SPECT studies of ACZ activation before and at 1 month after surgery.

With the inverse steal or Robin Hood phenomenon, areas with intact CO_2 responsiveness will constrict during hyperventilation (hypocapnia) and shunt blood to the more damaged areas where CO_2 responsiveness is lost [2]. There was a decrease in the regional cerebral perfusion pressure in symptomatic arterial trunk occlusion followed by the dilatation of cerebral arterioles distal to the occlusion site. In our 19 cases, 15 cases (79%) showed evidence of the inverse steal phenomenon. These cases also showed severe haemodynamic compromise on the pre-operative SPECT study with ACZ challenge. Widder *et al.* have reported an improvement in CO_2 reactivity in cases where a non-surgically treated ICA occlusion is necessary a few months after the ICA occlusion [21]. After revascularization or endarterectomy, the CO_2 response significantly increased postoperatively, returning to normal [14, 15]. Bishop *et al.* have reported that CO_2 reactivity significantly improves from 0%/mmHg before bypass to 2.5%/mmHg 3 months after the EC/IC bypass [5]. In our study, the average CO_2 CVR value improved from −1.50%/mmHg to −0.40%/mmHg immediately after bypass, which was a statistically significant change. However, this postoperative value was not within normal range. At 1 month after bypass, our SPECT study showed a normal response to ACZ in 6 cases (32%). Therefore, the CO_2 CVR value had already improved significantly immediately after bypass in some cases, and more improvement could be observed during the long-term postoperative period.

In the 15 cases with pre-operative inverse steal phenomenon, the CO_2 CVR values improved to a statistically significant degree immediately after bypass, and the inverse steal phenomenon in four cases (21%) was resolved immediately after bypass. There was also an improvement in the CO_2 CVR values in patients without the pre-operative inverse steal phenomenon, but this improvement was not statistically significant. Our data suggest that the STA-MCA bypass is more useful for CO_2 CVR, particularly in patients with more severely disturbed CO_2 CVR values before surgery. Kuroda *et al.* have also reported that cases showing a pre-operative reduced response to ACZ on SPECT that are treated with bypass surgery show an improvement in the cerebrovascular reactivity during the postoperative course [13].

The cerebrovascular ability to increase the CBF beyond the resting state or the capacity to respond to a physiological challenge such as CO_2 or ACZ has been termed as the "cerebrovascular reserve capacity" [18]. There is a close and highly statistically significant correlation between CO_2-induced and ACZ-induced vasomotor reactivity, indicating a strong similarity between the vasodilative effects of CO_2 and ACZ in the cerebral arteries [17]. The effect of the ACZ was similar to the hypercapnia. We did not measure the LCBF at the hypercapnic stage so as to avoid the steal phenomenon in the ischaemic region including the ischaemic penumbra which had lost the CO_2 reactivity. In all of our 19 cases, the response to ACZ was disturbed pre-operatively, and the CO_2 CVR values measured during surgery were extremely low. There was a good correlation between the results of the SPECT studies with ACZ challenge and the CO_2 CVR studies estimated from the LCBF values at normocapnia and hypocapnia in our series. In the group of cases showing a normal postoperative ACZ response, the average CO_2 CVR value was 1.43 ± 0.20%/mmHg, which was significantly high compared to the average CO_2 CVR value of the cases showing a disturbed ACZ response on the postoperative SPECT study. The ACZ response on SPECT at 1 month after bypass also correlated with the CO_2 CVR value measured after bypass intra-operatively. In this study, we evaluated the cerebral haemodynamics in a very small area during surgery using the LCBF measurement technique. The most of the cases, however, the LCBF and CO_2 CVR values measured during surgery reflected the haemodynamics of the cerebral hemisphere shown on SPECT. The primary reason for the above might be that all of our 19 cases showed severe haemodynamic compromise as indicated by the pre-operative SPECT study.

A negative cerebral blood flow response ("steal phenomenon") was found to be predictive of an increased risk of stroke as well as an increased oxygen extraction fraction [16, 20, 25]. In our series, the SPECT study showed a disturbed response to ACZ in all cases. In addition, the intra-operative CO_2 CVR study revealed that 79% of all cases showed a negative CO_2 CVR value. The other 21% of cases also showed reduced CO_2 CVR values. Therefore, our 19 cases were at high risk of stroke according to both the pre-operative SPECT study and the intra-operative CO_2 CVR study. Anderson *et al.* have reported that STA-MCA bypass can result in an increase in CBF and an improvement in CO_2 CVR values in patients at high risk for recurrent stroke [1]. The 19 cases in our study showed signs of severe haemodynamic compromise according to the pre-operative SPECT studies and intra-operative LCBF and CO_2 CVR studies. Immediately after bypass, LCBF and CO_2 CVR significantly improved, and 4 cases resolved their inverse steal effect.

The results of our study confirm the usefulness of the STA-MCA bypass for improving CBF and CO_2 CVR values in cases showing severe haemodynamic compromise. Yokota *et al.*, however, have recently reported that cerebrovascular reactivity, as defined by the CBF response to ACZ, does not identify a subgroup at high risk for stroke [23]. Therefore, in our 19 cases, the effect of the bypass on clinical symptoms should be carefully evaluated in the future, as should the effects of the bypass on patients showing severe haemodynamic compromise before surgery.

Conclusion

In ischaemic CVDs before bypass, LCBF and CO_2 CVR values were severely low. Seventy-nine percent of our bypass cases showed the inverse steal phenomenon pre-operatively. After bypass, LCBF and CO_2 CVR values significantly improved. The STA-MCA bypass exerted a favourable effect on CO_2 CVR and LCBF values immediately after bypass in cases showing a severe pre-operative haemodynamic compromise. SPECT findings with ACZ challenge before and at 1 month after bypass correlated well to intra-operative LCBF and CO_2 CVR values.

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Comments

This is an interesting well-written article concerning the effect of cerebral revascularization by way of a conventional extra-intracranial bypass (branch of superficial temporal artery to posterior temporal or temporal occipital branch of middle cerebral artery) in 19 patients with an occlusion or severe stenosis of the ipsilateral internal carotid artery or middle cerebral artery.

The most innovative part of the study is the peroperative registration of local CBF and local changes in CO2 cerebro-vascular reactivity (CO2-CVR) by way of a thermal diffusion technique. The site of the peroperative recordings was the precentral gyrus.

Pre-operatively the CBF and the acetazolamide reactivity was registrered by way of SPECT-scanning.

All 19 patients showed a disturbed response to acetazolamide and, as I suppose, that was one of the selection criteria for the revascularization operation.

Interestingly enough the CO2-CVR value was -1.50% mm/Hg when recorded during the operation before the bypass was created. The CO2-CVR in the negative is an expression of the so-called 'steal phenomenon'; 15 patients showed this steal phenomenon and 4 patients had a CO2-CVR in the positive, but a very low value. In the 15 patients with the steal phenomenon, immediately after the bypass in 4 cases this steal phenomenon was resolved. In the remaining 11 cases the CO2-CVR increased significantly, however, remained in the negative indicating still a discrete steal effect.

The authors discuss extensively in the section "Results" and again in the "Discussion" the relationship between pre- and postoperative SPECT-results and the peroperative CBF registrations by way of the local thermal diffusion technique.

It is not unlikely that the patients showing a much more normal CO2-CVR and local CBF post-bypass are protected against a haemodynamically caused stroke; however, as the authors state in the discussion the only way to prove this is a clinical randomized trial.

A weak point of the local thermal diffusion technique is that it picks up the local CBF in a very small portion of the brain close to the bypass anastomosis site. This might explain some of the discrepancies between peroperative (post-bypass) and postoperation CBF and CO_2-CVR findings.

C. Tulleken

In this report, S. Kawaguchi *et al.* present data of 19 patients with haemodynamic cerebral ischaemia who underwent extra-intracranial bypass surgery. In addition to pre- and postoperative studies for the evaluation of cerebral haemodynamics, this is one of the few reports which also includes intra-operative CBF studies directly before and after bypass surgery. The authors were able to show an immediate improvement of both resting flow and reactivity of flow during hyerventilation after completion of the bypass. This is an important study providing more support for the use of bypass surgery in selected cases presenting with signs or symptoms of cerebral ischaemia.

P. Schmiedek

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THE LANCET

Effects of bypass on ocular ischaemic syndrome caused by reversed flow in the ophthalmic artery

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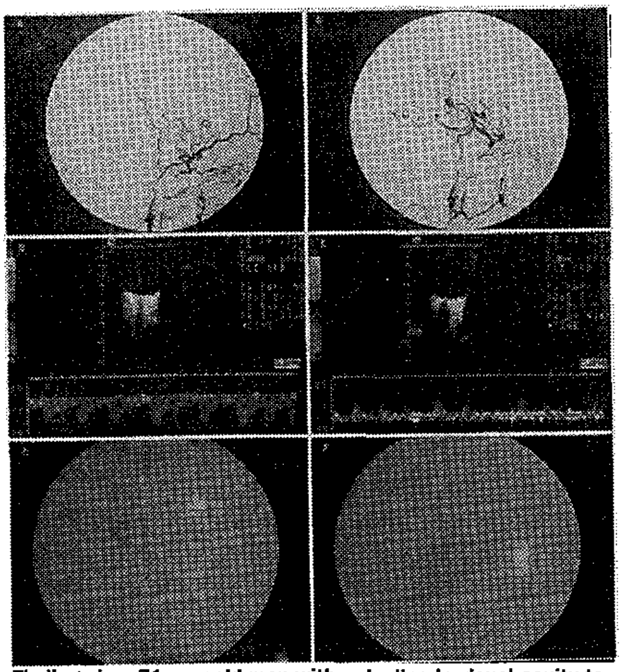
Effects of bypass on ocular ischaemic syndrome caused by reversed flow in the ophthalmic artery

Shoichiro Kawaguchi, Toshisuke Sakaki, Tetsuya Morimoto, Shuzo Okuno, Norikiyo Nishikawa

Superficial temporal to middle cerebral artery bypass was useful for ocular ischaemic syndrome caused by reversed flow in the ophthalmic artery as shown by opthalmic-artery colour doppler flow imaging.

In patients with severe stenosis or occlusion of the internal carotid artery, the ophthalmic artery shows reversed flow.[1-3] The visual outcome of the resultant ocular ischaemic syndrome is generally poor.[4,5] We undertook superficial temporal to middle cerebral artery (STA-MCA) bypass in patients with this disorder.

We did colour doppler flow imaging (CDFI) in the ophthalmic arteries of 32 patients, with ocular ischaemic syndrome shown by reversed ophthalmic-artery flow, who underwent STA-MCA bypass. The visual symptoms included amaurosis fugax in one patient, decline of visual acuity in 24 patients, and both these symptoms in seven patients. The ischaemic changes of the optic fundi included tiny iris rubeosis in 27 patients, neovascularisation on the disc in 19, peripheral haemorrhage in 13, and cotton-wool patches in ten. The intraocular pressure was within the normal range (less than 25 mm Hg) in all patients. The systolic retinal artery pressure was low (less than 54 mm Hg), and the mean was 42·9 mm Hg (SD 8·9). The arm-to-retina circulation time was longer than normal (more than 16 s) as shown by fluorescein angiography; the mean was 29·4 s (16·0). Standard STA-MCA bypass was done as soon as possible after the patient had been diagnosed with ocular ischaemic syndrome due to occlusive internal carotid artery disease. After bypass surgery, ophthalmological manoeuvres such as panretinal photocoagulation were done in selected patients. All patients were followed up after surgery (mean 3·2 years).



Findings in a 71-year-old man with a decline in visual acuity to 0·1 in the right eye

Carotid angiography showed occlusion of the right internal carotid artery (A). CDF of right ophthalmic artery showed reversed flow (peak systolic flow velocity −0·46 m/s, B). The right optic fundi showed ischaemic changes (C). 2 weeks after surgery, potency of the bypass was confirmed on right carotid angiography (D). 3 months after bypass, CDFI showed antegrade flow (peak systolic flow velocity 0·08 m/s, E). The right optic fundi were almost normal (F). Right visual acuity had improved to 0·4.

The ophthalmic-artery CDFI studies used computed sonography 128XP/10 (Acuson Co Ltd, Mountain View, CA, USA) with a 7·0 MHz probe, and provided information on flow direction and peak systolic flow velocity in the ophthalmic artery. These studies were done before the bypass, and at 1 month and 3 months afterwards. Ophthalmological examinations were done before and after bypass, including during the follow-up period. The physiological data were compared by means of a two-tailed Student's t test and χ^2 test. The control group consisted of nine patients with ocular ischaemic syndrome who had not undergone STA-MCA bypass. CDFI showed reversed flow in all nine controls. The mean peak systolic flow velocity was −0·27 m/s (0·09). During the 2 year follow-up period, the patients' visual symptoms gradually deteriorated. One patient became blind on the affected side.

Before bypass, the flow direction of the ophthalmic artery was reversed in all 32 treated patients. The mean peak systemic flow velocity was −0·26 m/s (0·16). 1 month after bypass, the ophthalmic artery in 13 patients (41%) showed antegrade flow on CDFI, and this improvement in flow direction was significant (p=0·0001). The average peak systolic flow velocity significantly (p=0·002) improved to 0 m/s (0·20). 3 months after bypass, 18 patients (56%) showed antegrade ophthalmic-artery flow direction. Three patients showed normal ophthalmic-artery CDFI findings. 14 patients still showed a reversed flow pattern, though the flow velocity was lower in each. The mean peak systolic flow velocity was 0·15 m/s (0·10), significantly higher than that 1 month after bypass (p=0·041; figure).

During the follow-up period, no patient had amaurosis fugax. In the final stage of the follow-up period, improvement of visual acuity was seen in 15 patients (47%), and the visual acuity of the remaining 17 patients showed no further deterioration. 19 patients showed normal fundoscopic findings. The mean (SD) systolic retinal-artery pressure significantly increased to 53·0 mm Hg (11·3; p=0·002). The mean arm-to-retina circulation time significantly decreased to 17·5 s (3·6; p=0·001).

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東　北　大　学

血行再建術後脳出血発症例の検討

日下康子[1]、吉本高志[2]、白根礼造[1]、冨永悌二[1]

A．研究目的

モヤモヤ病に対する頭蓋内外血行再建術の脳出血予防効果についてはいまだ明らかでない。血行再建術後の脳出血発症例は経験的に知られているが、その発生率、病態報告は少ない。当科で経験した症例について検討した。

B．研究方法

対象は1989年から2003年11月までに当科で血行再建術を施行した本症患者87例である。男女比は31：56（1：1.8)、手術時年齢は10ヶ月～57歳（19.3±15.7)、術後経過観察機関は1～180ヶ月（平均59.3）である。手術方法については図1に示した。

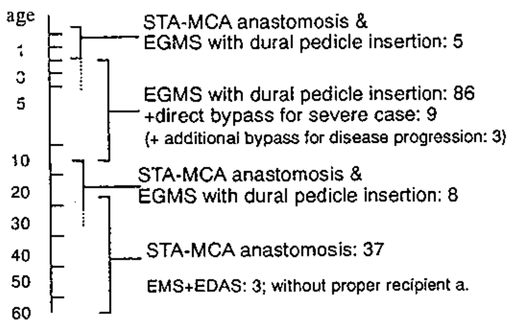

図1　手術方法内訳
N= No. of hemisphere

C．研究結果

経過観察中に脳出血を発症した症例は5例、5.7%あった。そのうちの2例は、CT、MRIにより明らかに非手術（血行再建手術）側が出血源と推測される脳室内出血だった。したがって、頭蓋内外血行再建手術を施行した大脳半球からの術後脳出血発症は、85手術症例中3例、3.53%だった。各症例の詳細は表1、および図2，3に示した。一方、初回発作型と再脳卒中発作型の詳細は、表2に示した。

表1　虚血発症型・両側血行再建術後の脳出血発症例

症例	性別/年齢	初発症状	出血までの期間	出血形式	転帰 mRS
1	M 20	脳梗塞	2 y	IVH	1/1
2	F 26	TIA	7 y	IVH	0/0
3	M 6	TIA	8 y	IVH	0/0

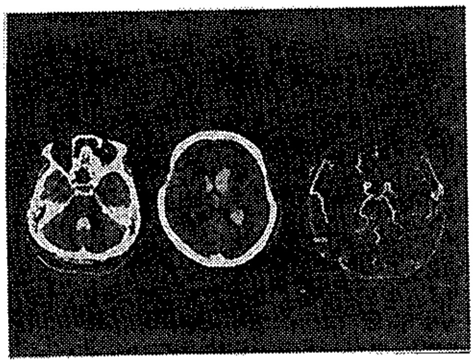

図2a　症例2：26歳時TIA発症、33歳時脳室内出血発症

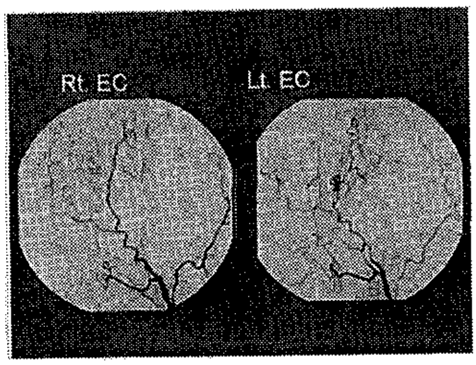

図2b　症例2：血行再建術後外頸動脈撮影

D．考　察

脳卒中再発時の発作型は5例とも脳出血で、これは本研究班で行ったモデル3県悉皆調査における再脳卒中発作においても脳出血が多かったことと同様であった[1]。血行再建術後87例中の脳出血発生率3

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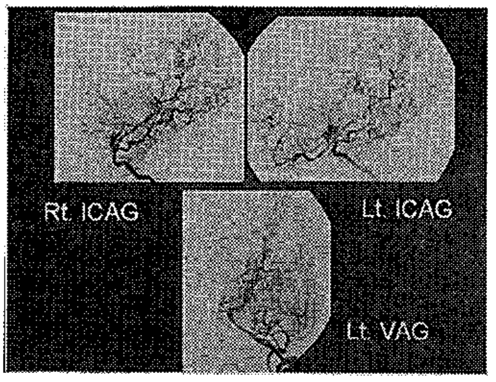

図2c　症例２：内頸動脈・椎骨動脈撮影

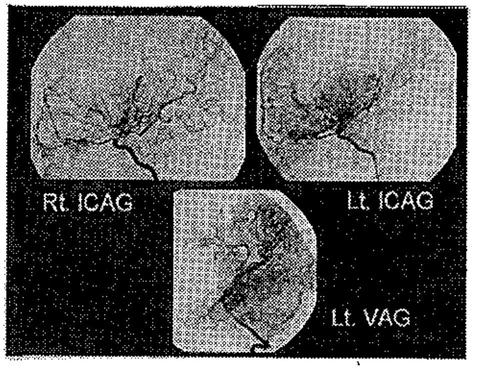

図3c　症例３：内頸動脈・椎骨動脈撮影

例、3.53%は、モデル３県悉皆調査のモヤモヤ病患者287例中の再脳卒中発作：脳出血発生率28例、37.8%よりも低い数値であり、血行再建術の出血予防効果と期待したいが、経過観察期間が4.9年と短いため、結論には至らない。また、初回発作型による再脳卒中発作の発生頻度も、当施設で虚血発症型4.9%、出血型16.7%、３県悉皆調査では虚血方9.0%、出血型37.8%と、いずれの結果でも脳出血発症型の再発率の方が高い傾向にあった。

再脳卒中発作が脳出血である原因を、図２、３に示したごとく、脳血管撮影による仮性動脈瘤の有無、側副血行路の発達程度、脳循環予備能の程度など、各症例で画像上の検討を試みたが、明らかな原因は特定できなかった。血行再建術後の症例では各々バイパスの効果は画像上認められていた。ただし、症例2のように、吻合されたSTAが開存しており、側副血行路が形成されていても、モヤモヤ血管、後大脳動脈からのretrograde fillingの残存が認められている症例もあった。しかし、このような側副血行路からの血流量が不十分な原因を同定するのは困難であった。外来通院経過観察時の記録上も、高血圧など、脳出血のリスクとなるような問題点は認められなかった。当施設での限られた症例数では、血行再建術の効果と、脳出血発症との関連を解明するにはいたらなかった[2)]。

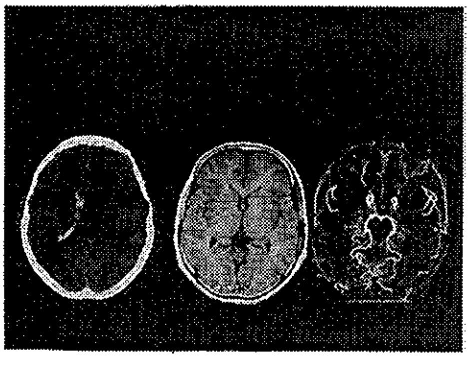
図3a　症例３：６歳男児TIA発症、14歳時脳室内出血発症

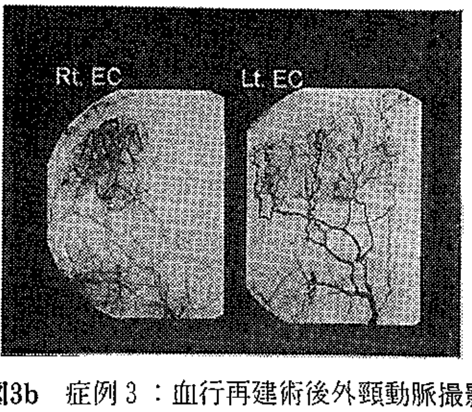

図3b　症例３：血行再建術後外頸動脈撮影

E. 結　論

脳虚血に対して有効な頭蓋内外血行再建術後症例の再脳卒中発作発生頻度は、３県悉皆調査よりも低かった。再発作はいずれも脳出血で、脳梗塞はなかった。血行再建手術の効果は得られているが、脳出血の予測、原因特定は困難だった。血行再建術による脳梗塞予防効果は認められたが、脳出血発症の原因解明研究がさらに必要と考えられる。

F. 健康危険情報

なし

G. 研究発表

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H．知的財産権の出願・登録状況

なし

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ABSTRACT

Analysis of cerebral hemorrhage of moyamoya disease after bypass surgery.

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The preventive effect of bypass surgery against cerebral bleeding is prospective one, however it is a fact that a few patients experience hemorrhage after revascularization. We examined 87 cases in our department operated between 1989 and November, 2003. The man and woman ratio is 1:00 1.8. Their ages at initial bypass are from 10 months to 57 years old (19.3±15.7), and the follow-up period is 1-180 months (mean 59.3). Five cases (5.7%) developed cerebral haemorrhage after initial stroke attacks. The two cases of them showed the intraventricular haemorrhage. Their CT and MRI images sugeested the responsible side of bleeding should be the non-operated hemisphere. Therefore, we may say that 3 cases (3.53%) presented cerebral bleeding after bypass surgery. This rate is lower than that of the complete research of three model prefectures which this study group reported in 2002. All re-attack was cerebral hemorrhage. The effect of bypass surgery was recognized on clinical course, MRI, MRA, cerebral angiogram and SPECT. The prediction and the cause specification of bleeding were difficult by retrograde analysis of each examination. We couldn't find pseudo-aneurysm either, which is considered one of cause of bleeding. The effect of cerebral infarction prevention by bypass surgery was recognized, but we need a further cause elucidate study of the cerebral haemorrhage of moyamoya disease.

総説

中大脳動脈瘤の解剖と手術

冨永悌二

Surgical Management of Middle Cerebral Artery Aneurysms

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Middle cerebral artery aneurysms arise mostly at the bifurcation of the horizontal part (M1) of the middle cerebral artery. In many cases, proper dissection of the sylvian fissure allows observation of the whole aneurismal structure, so that neck clipping is not so difficult. However, care should be taken to avoid postoperative morbidity in particular cases including a short M1, broad neck, and atherosclerosis of the neck/body. Surgical techniques for those cases are described in detail.

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Key words : aneurysm, middle cerebral artery, surgery
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はじめに

中大脳動脈瘤の手術は，脳動脈瘤の手術のなかで比較的難易度が低い．術野が浅く，動脈瘤の解剖を把握しやすく，proximal control が容易だからである．しかし中大脳動脈瘤のなかには巨大動脈瘤でなくとも，処置に難渋する症例もある．未破裂脳動脈瘤の治療が広く行われるようになった現在，術後 morbidity の出現は，未破裂脳動脈瘤治療の外科治療全体の趨勢にも影響を与えかねない．中大脳動脈瘤であるからといって安易に取り組み，術後の morbidity をきたすことは避けねばならない[2]．本稿では，中大脳動脈瘤を処置する際の基本と，処置の際に特に注意を要する中大脳動脈瘤について報告する．巨大中大脳動脈瘤の治療に関してはこれまで多くの報告があり，本稿では割愛する．

アプローチ・開頭

中大脳動脈瘤のアプローチには，subfrontal approach, proximal sylvian approach, distal sylvian approach がある[1)3)~5)7)]．subfrontal approach と proximal sylvian approach は実質同じ strategy であり，頸動脈から M1 を露出して MC bifurcation に至るもので，動脈瘤の proximal control が可能であるが，distal sylvian approach に比較して前頭葉の圧排は強くなる．distal sylvian approach は，sylvian fissure を遠位から分けて M2 を確保，近位にこれをたどりながら動脈瘤に至るものである．破裂脳動脈瘤の際には，通常 neck よりも dome が先に見えるため，より習熟が必要である．また欧米の文献では，transcortical superior temporal gyrus approach も報告されている．本邦では中大脳動脈瘤に対してこの approach が用いられることはあまりない．たとえ側頭葉内に血腫を伴う破裂中大脳

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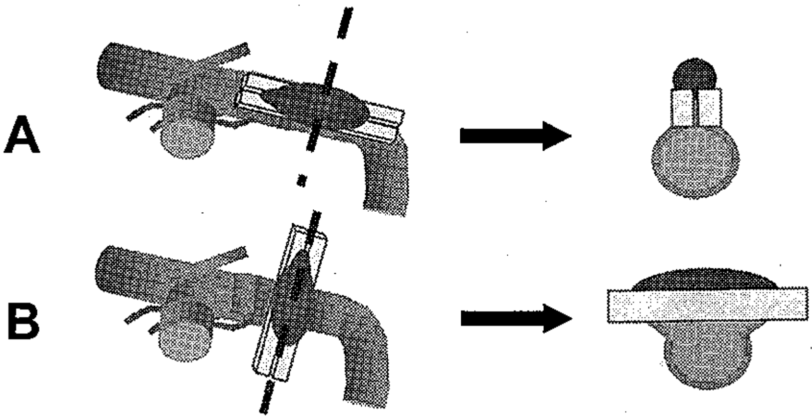


Fig. 1 Schematic drawings showing neck clipping of middle cerebral artery aneurysms
Neck clipping parallel to the bifurcation (A) is appropriate, and that perpendicular to the bifurcation may cause a "dog ear" type of residual neck (B).

動脈瘤であっても，脳内血腫を吸引して減圧後，sylvian fissure を剥離して動脈瘤近傍の解剖を把握する必要がある．いずれの approach にしろ，sylvian fissure を近位から遠位まで十分剥離できることが動脈瘤外科の基本であり，一つの approach に固執せずに，症例ごとに必要な surgical view を想定し，最適な approach を選択すべきである．

本稿では，distal sylvian approach について述べる．

全身麻酔下に仰臥位にて頭部を約 30 度回旋して固定する．通常の前頭側頭開頭を行い，蝶形骨縁を十分削除して硬膜を切開翻転，シルビウス裂を剥離する．シルビウス裂を剥離する際には，いったんシルビウス裂深部に到達し，クモ膜 2 層に挟まれた Sylvian vein を裏側から同定し，クモ膜を鋭的に切離して静脈を剥離する．前頭葉と vein の切離に固執せず，vein の走行によっては側頭葉と vein を切離して，あるいは vein から完全にクモ膜を切離し，vein の伸展を利用して十分な視野を得る．頭部を過度に回旋すると，遠位からのシルビウス裂の剥離はかえって困難となるため，裂のなす面に常に垂直に顕微鏡の視軸が入るように心がける．

Neck clipping

通常 M1 bifurcation は 180 度近く開いているため，neck clipping は bifurcation にできるだけ平行に行うことが原則である．他部位の動脈瘤同様，neck clipping は動脈瘤への血流遮断であると同時に親血管の形成でもあるため，bifurcation 形成のためには，平行な clipping が合理的である．垂直方向では neck が小さくないかぎり "dog ear" 型に neck の残存を生じやすい（**Fig. 1**）．巨大動脈瘤を除いた中大脳動脈瘤は，neck 全周を視認できる動脈瘤であり，必ず neck 全周を完全剥離してから clipping を行う．

neck clipping を行う際に，clipping が安全に行い得ないと判断した時には，躊躇せず M1 に temporary clip を置くべきである．この際に M1 からの穿通枝を含んで temporary clip をかけてはならず，穿通枝を含まないようにスペースを作る．この時に穿通枝に対する操作にて mechanical spasm をきたした場合は，気づき次第塩酸パパベリンを塗布して spasm を解除する（**Fig. 2**）．

未破裂脳動脈瘤と破裂脳動脈瘤の処置の相違

破裂の有無によって，動脈瘤の処置には以下のような相違がある．

①破裂脳動脈瘤を処置する際には，まず親動脈の確保が必要であるが，未破裂脳動脈瘤においては必ずしもその限りではなく，直接動脈瘤に approach することも可能である．②破裂脳動脈瘤ではクモ膜下血腫を洗浄・吸引のため，通常脳底槽から distal sylvian fissure まで広範に剥離する必要があるが，未破裂脳動脈瘤での剥離範囲は，必要最小限にとどめることができる．③未破裂中大脳動脈瘤では，しばしば neck/body に静脈が癒着しており，これを可及的に剥離，温存しなければならない．

動脈瘤 clipping の際には誰でも best clipping を心がける．しかし状況によって best clipping の内容は異なる．破裂脳動脈瘤では，"complete clipping" が best clipping とほぼ相同であり，未破裂脳動脈瘤では必ずしも "com-

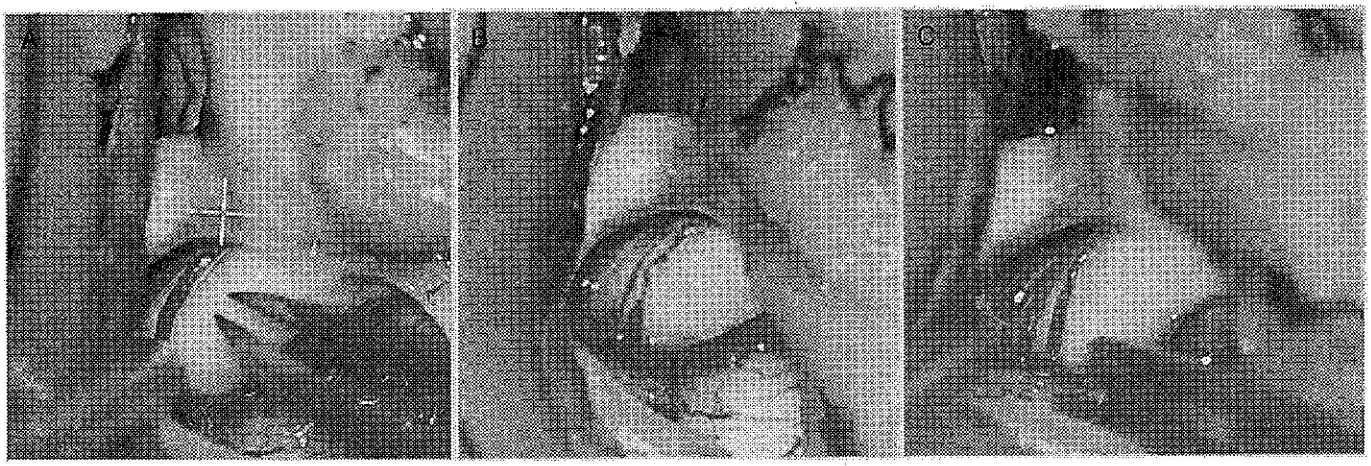


Fig. 2 Serial operative views showing mechanical spasm of the perforating arteries from the M1 and its reversal by application of papaverine hydrochloride solution
A：before surgical manipulation　B：mechanical spasm by surgical manipulation
C：reversal of mechanical spasm with application of papaverine hydrochloride solution

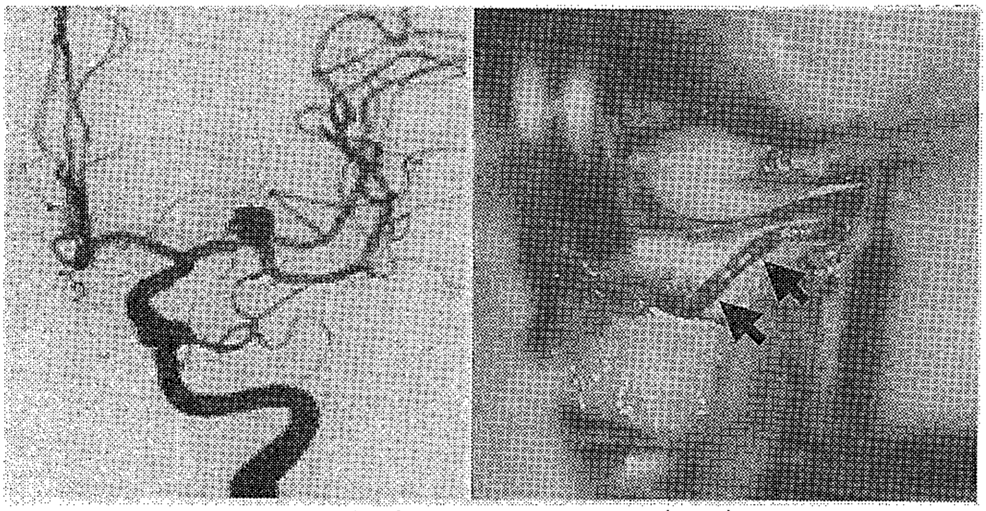


Fig. 3 Carotid angiogram (left) and operative view (right) showing a middle cerebral artery aneurysm with a short M1
Note the perforating artery from the M1 adherent to the body of the aneurysm (arrows).

plete clipping" ではなく，症例ごとの "optimal clipping" が best である．未破裂脳動脈瘤において完璧な clipping に固執するあまり，M1 の遮断時間を延長したり，M2 の血流不全を招いたりすることは避けなければならない．症例によっては"あまい"clipping や body clipping が optimal であり，muscle wrapping や何も処置しないことが optimal である場合もある．

注意すべき動脈瘤

1 Short M1 (early bifurcation)

short M1 は長さ 15 mm 以下との定義もあるが[3]，bifurcation が limen insula より近位に存在する症例である．Short M1 の clipping が特に注意を必要とする理由は，次の3点にある．①通常の distal sylvian approach では limen insula が視野をさえぎり，動脈瘤の neck に到達することが困難である．このため subfrontal あるいは proximal sylvian の view が必要であり，sylvian fissure を特に広範に剝離しなければならない．M1 が上方や後方に向かっている場合には，neck の全周を露出，視認するのは困難である．②短い M1 に穿通枝が密に存在しており[6]，動脈瘤の neck あるいは body に外側線条体動脈が癒着している場合がある（Fig. 3）．動脈瘤が大きい場合には，特に穿通枝の癒着が見えにくく，必ず動脈瘤の dome を

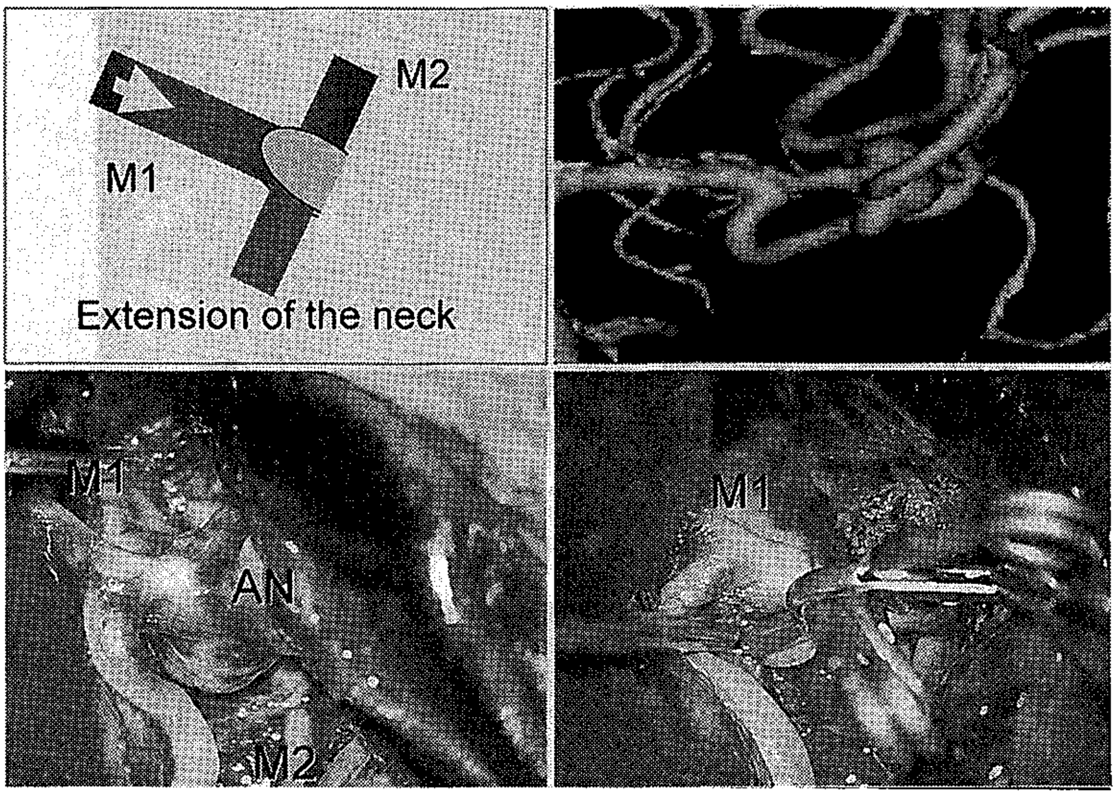


Fig. 4 Schematic drawing (**upper left**) showing the orifice of a broad neck middle cerebral artery aneurysm. Carotid angiogram (**upper right**) and operative views (**lower right and left**) showing a ruptured middle cerebral artery aneurysm with a broad neck extending from the end of the M1 to the M1 bifurcation. Cross-clipping technique is useful (**lower right**) for this type of aneurysm.

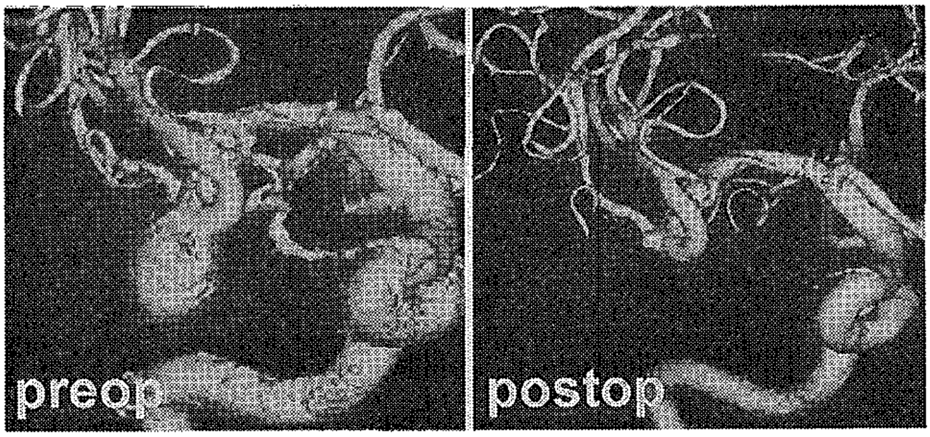
翻転して穿通枝の癒着がないかどうか確認しなければならない．③M1 に穿通枝が密なため，temporary clip をかける際には，慎重に穿通枝を避ける必要がある．

② Broad neck

動脈瘤塞栓術を行う際には neck と body の比が問題となり，broad neck は塞栓の可否に関与する．しかし neck clipping の場合は，相対的に neck が broad であるかどうかより，neck の大きさの絶対値が問題となる．broad neck の動脈瘤を clipping する際には，動脈瘤の orifice を正常血管壁の欠損と考えるとわかりやすい．orifice のなす局面が血管周に対して 180 度を超えていると，clipping になんらかの工夫が必要である．その長径が bifurcation の長軸方向であれば，やはり bifurcation を形成するように clipping する．1 本の straight clip で M2 に kinking が起こる場合には，curved clip や複数本の clip を用いて kinking を避けなければならない．neck の長径が bifurcation と直行して M1 終末部に及ぶ場合には複数本の clip を必要とする場合が多く，筆者は straight blade を ring clip の ring 内に収める形での clipping を行っている（Fig. 4）．M2 が 180 度を超えて大きく開大している場合も，必然的に neck は 180 度以上の局面にある．M1 が比較的長い症例に多く，動脈瘤と M1/M2 は，あたかもくらげのような形状を呈する（Fig. 5）．この際も単一の clip では M2 の血流不全をきたしやすく bifurcation を形成する必要があり，cross-clipping が有用である．

③ Neck/body の sclerosis

neck に全周性の sclerosis がある場合は，sclerosis を避けて body 側で clipping する[3]．しかし全周性に sclerosis がある症例は稀で，neck の一部が硬化している場合が多い．この場合，硬化部分を含んで clipping すると M2 の kinking をきたしやすく，硬化部分を clipping に含まないようにする．また neck の硬化は必ずしもサイズの大きい動脈瘤ばかりではないが，やはり large/giant 動脈瘤に多く，neck も large となる．large 動脈瘤の動脈硬化のある neck 近傍を clipping する際には，通常複数本の clip を必要とする．断面が類円形の neck を clip blade で平面とした場合，動脈硬化あるいは肥厚のある neck 部分は厚く，それ以外の部分は薄くなる．このため 1 本の clip ではこの薄い部分が締まらず incomplete clipping となるため，neck を regional に clipping する考えが必要である．締ま



Preoperative Postoperative

Fig. 5 Carotid angiograms showing a middle cerebral artery aneurysm with a broad neck

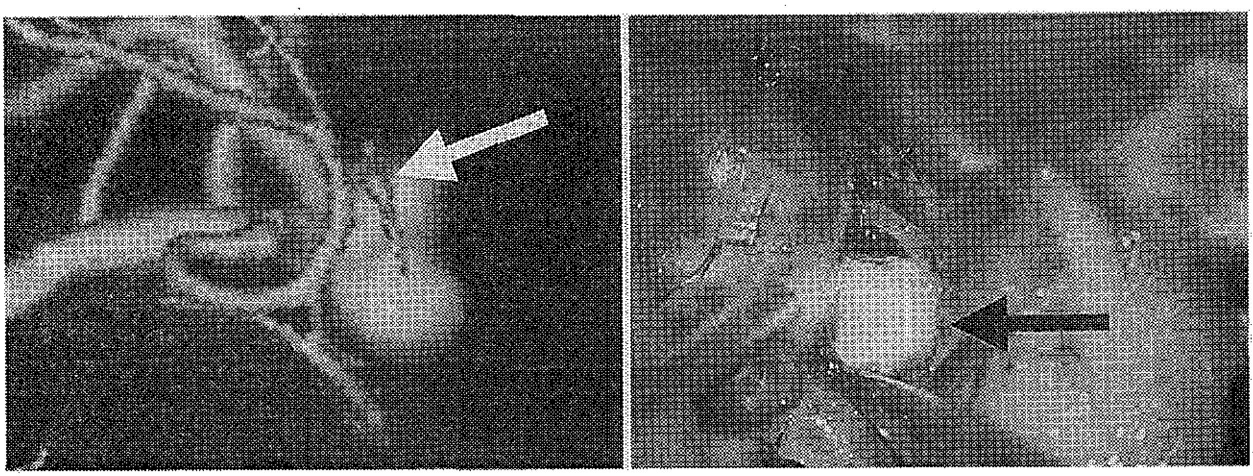


Fig. 6 Carotid angiogram (left) and operative view (right) showing a "verruca"-like extrusion of the aneurismal body (black arrow)

Note the carotid angiogram does not disclose that extrusion (white arrow).

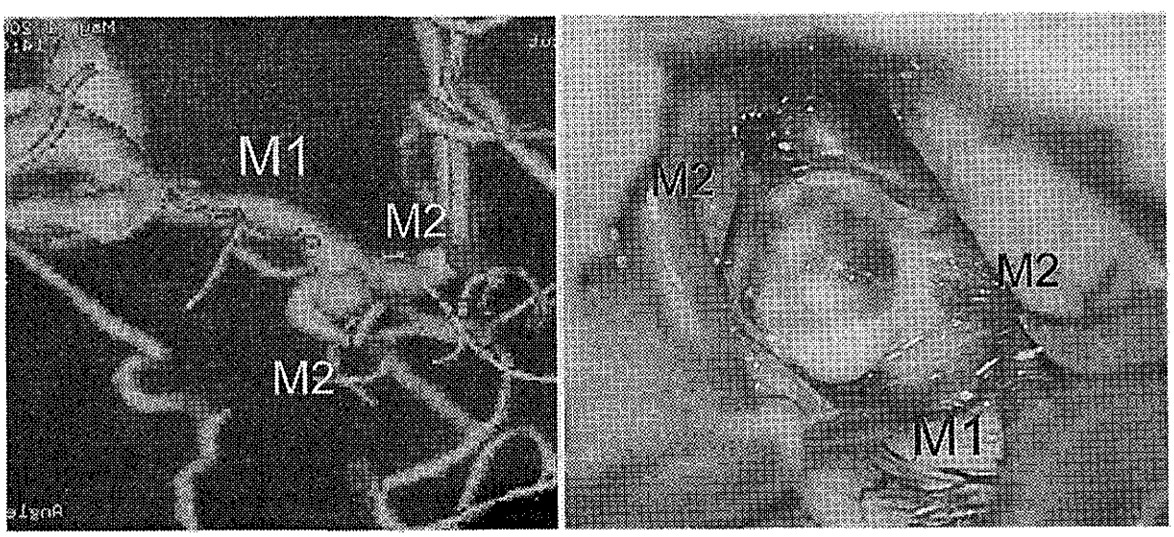


Fig. 7 Carotid angiogram (left) and operative view (right) showing an M2-aneurysm

らない薄い部分は ring clip を用いて，壁の厚い部分を ring 内に収め，薄い部分を blade で clipping するとよい．当然 neck の厚みを勘案して body 側に blade をおかないと，M2 の血流は維持できない．

動脈瘤 body の硬化に関しては neck clipping に際して通常問題となることはないが，稀に body の壁から血管写では造影されない疣状の突出が見られる場合がある（**Fig. 6**）．これが neck 近傍にあると，neck clipping の邪魔になるため工夫が必要である．

④ Proximal M2 aneurysm

一見 M1 bifurcation に動脈瘤が存在するように見えながら，M2 起始部に neck が存在し，neck が bifurcation を含まない症例がある（**Fig. 7**）．動脈瘤の処置は通常の bifurcation における動脈瘤と変わらないが，この部の動脈瘤の発生を考えるうえで興味ある動脈瘤である．

おわりに

中大脳動脈瘤は動脈瘤の全貌が容易に観察できることから，tight な clipping になりがちである．しかしあくまで正常血管の形成であることを念頭に，容易に見えるからこそ慎重に neck clipping を行う必要がある．

本稿の一部は，第 23 回日本脳神経外科コングレス（2003，大阪）プレナリーセッショで発表した．

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要　旨

中大脳動脈瘤の解剖と手術

冨永　悌二

中大脳動脈瘤の neck clipping における基本的手技と，特に注意を要する動脈瘤の処置について述べた．中大脳動脈瘤は，neck の全周を観察して bifurcation とできるだけ平行に血管を形成するように neck clipping を行うのが原則である．short M1 の場合は，十分なシルビウス裂の剥離と穿通枝の動脈瘤への癒着に留意すべきである．broad neck あるいは動脈硬化を伴う場合も，clipping の際に十分な注意を要する．

中大脳動脈瘤は動脈瘤の全貌が容易に観察できることから，tight な clipping になりがちである．しかしあくまで neck clipping が正常血管の形成であることを念頭に，慎重に neck clipping を行う必要がある．

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