

## Original Article

# Monitoring of brain oxygenation in surgery of ruptured middle cerebral artery aneurysms

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## Abstract

**Background:** The occurrence of brain ischemic lesions, due to temporary arterial occlusion or incorrect placement of the definitive clip, is a major complication of aneurysm surgery. Temporary clipping is a current technique during surgery and there is no reliable method of predicting the possibility of ischemia due to extended regional circulatory interruption. Even with careful inspection, misplacement of the definitive clip can be difficult to detect. Brain tissue oxygen concentration (PtiO<sub>2</sub>) was monitored during surgery of middle cerebral artery (MCA) aneurysm presenting with subarachnoid hemorrhage (SAH), for detection of changes in brain oxygenation due to reduced blood flow, as a predictor of ischemic events, during temporary clipping and after definitive clipping.

**Methods:** PtiO<sub>2</sub> was monitored during surgery of 13 patients harboring MCA aneurysms presenting with SAH, using a polarographic microcatheter (Licox, GMS, Kiel, Germany) placed in the territory of MCA.

**Results:** A decrease in PtiO<sub>2</sub> values was verified in every period of temporary clipping. Brain infarction occurred in 2 patients; in both cases, there was a decrease in PtiO<sub>2</sub> greater than 80% from basal value, a minimum value of less than 2 mmHg persisting for 2 or more minutes during temporary clipping, and an incomplete recovery of PtiO<sub>2</sub> after definitive clipping. In 2 patients, incomplete recovery of values after definitive clipping led to verification of inappropriate placement and repositioning of the clip.

**Conclusion:** The results suggest that intraoperative monitoring of PtiO<sub>2</sub> may be a useful method of detection of changes in brain tissue oxygenation during MCA aneurysm surgery. Postoperative infarction in the territory of MCA developed in cases with an abrupt decrease of PtiO<sub>2</sub> and a very low and persistent minimum value, during temporary clipping, and an incomplete recovery after definitive clipping. Verification of clip position should be considered when there is an incomplete recovery or a persistent fall in PtiO<sub>2</sub> after definitive clipping.

**Key Words:** Aneurysm, middle cerebral artery, monitoring, PtiO<sub>2</sub>, ruptured, surgery

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## INTRODUCTION

Regional circulatory interruption by application of temporary clips on the parental artery is a current technique in aneurysm surgery, used for safer dissection of the aneurysm and for control of intraoperative aneurysm rupture. The main problem of temporary clipping is the occurrence of brain ischemia, with postoperative cerebral infarction, due to extended time of temporary arterial occlusion.<sup>[1,5,7,9-11,14,15,17]</sup> The safe temporary occlusion time is not known, and great variations have been described.<sup>[6,7,9,10,13,15,17]</sup> Incorrect placement of the definitive clip with incidental total or partial arterial occlusion is another possible cause for ischemia.

We prospectively monitored the partial pressure of tissue oxygen (PtiO<sub>2</sub>), representing the concentration of oxygen in the brain tissue, during surgery of 13 patients with MCA aneurysms presenting with SAH, to detect ischemic episodes during temporary clipping and after placement of the definitive clip.

## MATERIALS AND METHODS

Thirteen patients submitted to MCA ruptured aneurysm surgery, with use of temporary clips, were included. The study was approved by the Ethics Committee, and an informed consent was obtained for inclusion.

Six male and 7 female patients were studied, and the mean age was 48.7 years (median 52 years). All patients were operated in the first 24 h after the onset of SAH. Clinically, they were evaluated with Hunt and Hess scale, and computed tomography (CT) scans were evaluated with Fisher scale. Vasospasm was determined by transcranial Doppler (TCD), executed every day in the first week after surgery. Outcome was graded using the Glasgow Outcome Score (GOS), 3 months after surgery.

All patients were anesthetized with total intravenous anesthesia and neuroprotective agents were not used. The arterial blood pressure, PO<sub>2</sub>, and PCO<sub>2</sub> were maintained as stable as possible during surgery, accordingly with our current procedure (mean arterial pressure between 67 and 90 mmHg, PaCO<sub>2</sub> between 34.6 and 40 mmHg).

PtiO<sub>2</sub> and brain temperature were monitored, from dural opening to dural closure, using an oxygen probe (Licox, GMS, Kiel, Germany) and a temperature catheter, placed in a standardized way in the middle temporal gyrus, on the side of the aneurysm, 2 cm away from the sylvian fissure, and inserted 25 mm into the cerebral tissue, distanced 5 mm one from the other. The depth of the catheter was marked and checked continuously during surgery. Using adequate software, PtiO<sub>2</sub> values (in mmHg) were continuously measured and registered. Brain temperature was stable in all cases, between 34.9°C and 35.7°C, without variations that could lead to changes in PtiO<sub>2</sub> values.

The PtiO<sub>2</sub> value registered immediately prior to the first application of a temporary clip was considered as the basal value. The relationship between the basal values and the clinical status and CT findings on admission was studied, as was the time elapsed between the introduction of the probe and the registration of the basal values.

Temporary clips were applied to MCA proximal to the aneurysm to facilitate aneurysm dissection, without cases of intraoperative aneurysm rupture. The amplitude of decrease (percentage from the basal value) of PtiO<sub>2</sub> values during temporary clipping and the lowest value in each patient were documented. The recovery of PtiO<sub>2</sub> values after definitive clipping was evaluated; final and basal values were compared and the time elapsed until the final value was registered.

## RESULTS

The results are summarized in Table 1.

Basal values of PtiO<sub>2</sub> ranged from 1.3 to 21.0 mmHg (mean 8.1 mmHg, median 7.3 mmHg). Basal values below 10 mmHg were found in 9 cases. The time elapsed from the placement of the PtiO<sub>2</sub> and temperature catheters to the registration of basal values ranged from 11 to 98 min, depending on the time necessary to identify and dissect the aneurysm complex. Attempts at establishing a correlation between basal values and clinical status (HandH scale) and CT findings (Fisher scale) were made, applying Spearman's statistical method, but no significance was obtained ( $P > 0.05$  in both cases).

The number of periods of temporary regional circulatory interruption was variable from case to case, with a minimum of 1 and a maximum of 6 periods. The approximate duration of circulatory interruption ranged from 1 to 5 min.

There was a significant decrease in PtiO<sub>2</sub> values (between 21% and 100%, compared to basal values) in every application of temporary clips. The minimum value during each period of temporary circulatory interruption varied from 0 to 12.1 mmHg. In 7 of the 13 cases included, PtiO<sub>2</sub> values of less than 2 mmHg were found during temporary clipping. The lowest PtiO<sub>2</sub> value persisted for 2 or more minutes in 8 cases, lasting no longer than 1 min in the remaining 5 cases. The persistence of the lowest PtiO<sub>2</sub> value was related to the duration of temporary regional circulatory interruption (1–10 min).

In all cases, the definitive clip was applied under regional circulatory interruption using a temporary clip. In 9 cases, there was a recovery of PtiO<sub>2</sub> values after definitive clipping, in a percentage of 60% or more compared with basal values. The time elapsed until recovery, in these 9 patients, ranged from 1 to 8 min.

Table 1: Results of the Study (Per Case Number)

Sex/ age	Hess scale	Hunt and Fisher scale	Basal value (mmHg)	Time to basal value (min)	Periods of circulatory interruption	Time of circulatory interruption (min)	Decrease of PtiO <sub>2</sub> (%)	Lower value during surgery (mmHg)	Duration of lower value (min)	Recovery after definitive clipping final value (% from basal)	Time to recovery (min)	Infarction on CT scan	Vasospasm on TCD	GOS
M/66	III	4	9.5	52	4	2-4	32-68	2.8	1	9.7 (102%)	5	—	—	2
M/56	I	2	15.0	42	1	4	78	2.2	1	8.9 (60%)	8	—	—	5
F/56	III	4	10.6	98	4	1-4	24-83	1.9	2	3.2 (30%)	6	Infarction MCA	—	3
F/53	II	3	21.0	11	2	1-1	38-39	12.1	1	28.2 (134%)	2	—	—	5
F/22	II	3	2.7	43	1	2	29	1.9	1	5.6 (207%)	1	—	Vasospasm	5
M/52	IV	3	7.3	68	6	2-4	66-100	0	10	0 (0%)*	10	Infarction MCA	—	3
M/51	I	2	5.5	33	2	2-2	89-92	0.6	1	10.6 (145%)	29	—	—	5
F/64	I	2	1.8	77	1	2	63	0.4	2	2.9 (53%)**	7	—	—	5
F/40	I	3	2.8	19	2	2-2	29-32	1.7	2	7.3 (133%)	4	—	Vasospasm	5
M/40	IV	4	1.3	47	2	1-1	31-50	0.5	16	1.5 (83%)	2	—	—	5
										2.0 (71%)	2	—	—	5
										0.5 (38%)	16	Infarctions multiple	Vasospasm	3
F/40	I	2	13.2	12	4	2-5	77-82	3.0	3	15.8 (120%)	5	—	—	5
F/40	I	2	6.2	78	5	1-2	21-76	2.6	2	5.8 (94%)	8	—	Vasospasm	5
M/53	II	3	8.9	62	6	2-4	43-78	2.5	3	15.4 (173%)	7	—	—	5

PtiO<sub>2</sub>, brain tissue oxygen concentration; TCD, transcranial Doppler; GOS, Glasgow Outcome Score; \*In case 6, a 10-min period went on without any recovery after definitive clipping; when the clip was revised, a PtiO<sub>2</sub> level of 10.6 mmHg was achieved after 29 min; \*\* In case 7, 7 min after definitive clipping recovery was limited to 53%; when the clip was revised, a PtiO<sub>2</sub> level of 7.3 mmHg was achieved after 4 min

This recovery could not be verified in 4 cases:

- In case 3, the final PtiO<sub>2</sub> value was 30% of the basal value, the recovering time being of 6 min. Clip position was verified and seemed appropriate;
- In case 6 [Figure 1], the PtiO<sub>2</sub> value of 0 mmHg persisted for 10 min after the placement of the definitive clip, leading to verification of an incidental occlusion of an MCA trifurcation branch. The position of the clip was changed, with recovery to a value superior to the basal (145% compared with the basal, after 29 min);
- In case 7, PtiO<sub>2</sub> value was 53% of the basal value, after 7 min of recovery. A partial occlusion of an MCA branch was detected after re-inspection of the clip. After changing the position, there was a recovery to a value superior to the basal (133% comparing with the basal, after 4 min);
- In case 10, there was a very low basal PtiO<sub>2</sub> value (1.3 mmHg). After definitive clipping and withdrawal of the last temporary clip, PtiO<sub>2</sub> value was persistently low (0.5 mmHg, 38% of the basal value), without recovery during 16 min. Clip position seemed correct after verification.

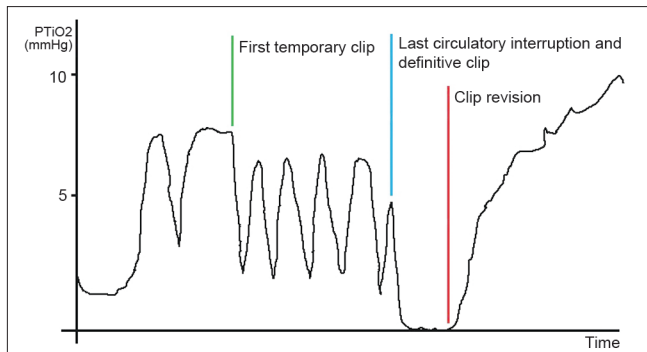
All patients were admitted in the Neurocritical Care Unit after surgery. CT scan was obtained in the first 6–8 h after surgery; a new CT scan, with Angio CT, was performed in the first 7 days after surgery, depending on the clinical status of the patient. Angio CT showed exclusion of the aneurysm in all cases. Infarction in the territory of MCA on the side of the aneurysm, not visible before surgery, was detected in CT scan, 24 h after surgery, in patients 3 and 6.

During the first week after surgery, values compatible with vasospasm were detected in TCD in 4 patients, 3 of them without any clinical symptoms or deficits, but another patient (case 10) developed multiple ischemic lesions due to generalized vasospasm.

The clinical outcome was verified 3 months after surgery. Except for 4 patients, the GOS was 5. One patient had a GOS of 2 (patient with chronic hydrocephalus and multiple shunt infections) and 3 patients had a GOS of 3 (2 patients with infarction in the MCA territory in the aneurysm side, and one with multiple ischemic lesions and hydrocephalus).

## DISCUSSION

Mortality and morbidity directly related to surgical treatment of ruptured MCA aneurysms are usually associated with intraoperative aneurysm rupture and with ischemia due to prolonged regional circulatory interruption or inadequate placement of the definitive clip leading to vascular occlusion.<sup>[1,5,7,10,11,14,15,17]</sup> Temporary clips are often used to control intraoperative aneurysm



**Figure 1: Schematic diagram of monitoring in case 6**

rupture and to facilitate aneurysm dissection. The main problem is that the regional circulatory interruption may cause ischemic lesions, leading to postoperative brain infarction and increased morbidity and mortality.<sup>[1,6-10,12,15,17]</sup> The rate of ischemic complications could theoretically be reduced by using an intraoperative method of monitoring brain oxygenation during temporary clipping and after definitive clipping.

In this work, PtiO<sub>2</sub> was monitored during surgery. PtiO<sub>2</sub> and temperature probes were placed in a standardized way, avoiding positional variation. PtiO<sub>2</sub> reflects the oxygen concentration in a small area of the brain tissue (a sensitive surface of 7.1 mm<sup>2</sup> around the probe), directly dependent on the cerebral blood flow in stable conditions of brain temperature.<sup>[2-4,8,9,12,16]</sup> Hence, regional circulatory interruption or incidental occlusion of temporal branches of MCA<sup>[2-4,8,9,12,16]</sup> should lead to a decrease in PtiO<sub>2</sub> values. Variations in brain oxygenation during surgery were analyzed to identify the indicators of high risk for postoperative ischemic lesions.

### Basal values

As in previous works,<sup>[8]</sup> there was a wide range of variation in basal values (1.3–21.0 mmHg), and a reason for this variation was not found. Basal values were lower than previously described, in SAH<sup>[1,6,8,9]</sup> and traumatic brain injury.<sup>[2,4,12,16]</sup> The reasons for this are unknown, but lower values were reported in patients submitted to early surgery,<sup>[8]</sup> and in our series, differently from previous studies,<sup>[1,6,8,9]</sup> all patients underwent surgery in the first 24 h after SAH. Even admitting that complete stabilization of PtiO<sub>2</sub> values might be undergoing, very low values were obtained in cases with a long period of time until the application of the first temporary clip. An association between these values and the clinical status or the CT findings was not found.

### PtiO<sub>2</sub> values during temporary clipping

In our experience, intraoperative monitoring of PtiO<sub>2</sub> was a very sensitive (100%) method of detecting a decrease in brain oxygenation (21%–100%, comparing with the basal value) when blood flow is reduced due to circulatory interruption during MCA aneurysms surgery. This very

high sensitivity may be related to the fact that, unlike previous works,<sup>[6,8,9]</sup> only MCA aneurysms were included, with poor collateral blood flow available after arterial occlusion.

The amplitude of decrease was superior to 60% whenever the circulatory interruption lasted for 4 min or more; however, decreases superior to 60% were registered in shorter periods of temporary clipping.

In cases with low basal values, low minimum values during temporary clipping should be expected; however, even in these cases, the amplitude of decrease was always superior to 20%.

The minimum PtiO<sub>2</sub> value registered during temporary clipping was below 2 mmHg in 7 patients, and between 2 and 3 mmHg in other 4 cases. These values are considered an indicator of high risk for brain ischemia in cases of traumatic brain injury.<sup>[2,4,12,16]</sup> These minimum values, considered individually, were not associated with development of brain infarction. However, in the 2 cases developing brain infarction in the territory of MCA, there was simultaneously an amplitude of decrease of PtiO<sub>2</sub> values greater than 80% and a minimum value of less than 2 mmHg lasting for 2 or more minutes. Although further studies are needed, this simultaneous occurrence of an abrupt decrease in PtiO<sub>2</sub> values and a very low minimum value persisting for 2 or more minutes, may be indicative of high risk of ischemia during temporary clipping.

### Recovery after definitive clipping

In cases 3, 6, 7, and 10 there was an incomplete recovery (less than 60%, compared to basal values), no recovery or a persistent fall in PtiO<sub>2</sub> values after definitive clipping. In 2 of these patients (cases 6 and 7), partial or total occlusion of MCA branches was detected after verification of the position of the clip, leading to clip replacement and complete recovery of PtiO<sub>2</sub> values. In case 7, the postoperative course was uneventful. Postoperative brain infarction developed in case 3 (the position of the clip seemed appropriate and was not changed) and case 6 (clip position was changed after detection of occlusion of one branch of MCA trifurcation, but, previously to clip replacement, a PtiO<sub>2</sub> value of 0 mmHg persisted for 10 min). In case 10, there was severe vasospasm and multiple ischemic lesions, probably not related to an incorrect clip position.

According to our data, and although the placement of the PtiO<sub>2</sub> probe in the temporal lobe may not allow detection of occlusion in all branches of MCA, verification of clip position is advisable if there is an incomplete recovery or persistent decrease in PtiO<sub>2</sub> values after definitive clipping.

### Infarction on the territory of MCA

Postoperative infarction in the territory of MCA developed in 2 patients. In these patients there were no criteria of

vasospasm on TCD, and these ischemic lesions may be related to surgery. In both cases, there was a coincidence of (a) decrease in  $PtiO_2$  of more than 80% compared to basal value; (b) minimum  $PtiO_2$  value below 2 mmHg lasting for 2 or more minutes; and (c) incomplete recovery or persistent decrease in  $PtiO_2$  values after definitive clipping. Even considering the small number of cases, the simultaneous occurrence of these findings may be indicative of an increased risk for ischemia.

## CONCLUSION

Intraoperative monitoring of  $PtiO_2$  is a very sensitive method of detecting the decrease of oxygen available for cell utilization during ruptured MCA aneurysm surgery.

This monitoring can be helpful to detect situations of high risk of ischemia, during temporary clipping or due to inadequate position of the definitive clip. When using temporary clips, the occurrence of an abrupt decrease in  $PtiO_2$  values, together with a very low minimum value persisting for 2 or more minutes may indicate a high risk for ischemic lesions. After definitive clipping, careful inspection of the position of the clip is recommended when there is an incomplete recovery or fall in  $PtiO_2$  values.

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