



# Local cortical blood flow and oxygen consumption during isoflurane-induced hypotension

Results in patients undergoing intracranial aneurysm clipping

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■ Cerebral cortical blood flow (ICoBF) and metabolic rate for oxygen (ICoMRO<sub>2</sub>) were studied in eight patients undergoing intracranial aneurysm clipping. The patients were anesthetized with fentanyl 10 μg/kg and 70% nitrous oxide combined with 30% oxygen. Hypotension was induced with isoflurane. A thermal diffusion probe was used to measure ICoBF, and arterial and cerebral venous blood samples were obtained for measurement of arterio-cerebral venous O<sub>2</sub> content difference. Measurements were made prior to hypotension, during hypotension (to mean arterial pressure approximately 50 mmHg), and posthypotension. Mean ICoBF decreased from 69 ± 20 mL/100 g/min at normotension to 59 ± 13 mL/100 g/min during hypotension (*P* < .03, NS) and was 61 ± 18 mL/100 g/min upon return to normotension (all values mean ± 1 SD). The ICoMRO<sub>2</sub> averaged 3.9 ± 1.6 mL/100 g/min and 3.1 ± 1.5 mL/100 g/min, respectively (*P* < .03, NS) for normotension *v* hypotension. Values for cerebral venous PO<sub>2</sub> and O<sub>2</sub> saturation also did not differ significantly between study periods. These results indicate that isoflurane-induced hypotension during fentanyl-nitrous oxide anesthesia allows maintenance of a constant ICoBF and oxygen delivery.

□ INDEX TERMS: CEREBRAL ANEURYSM; ISOFLURANE □ CLEVE CLIN J MED 1989; 56:766-770

**D**URING surgical obliteration of an intracranial aneurysm, induced hypotension is frequently employed at critical times to decrease the risk of aneurysm rupture. Iso-

flurane has been used to induce hypotension in both animals and humans.<sup>1-3</sup> Its advantages include hemodynamic stability, minimal metabolism with no known toxic metabolites,<sup>4</sup> and rapid onset of and recovery from hypotension.

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Fentanyl-nitrous oxide-relaxant anesthesia is commonly employed during neurosurgical procedures, because fentanyl has no adverse effect on cerebral autoregulation<sup>5</sup> or CO<sub>2</sub> reactivity,<sup>5</sup> and it decreases the incidence of arrhythmias when epinephrine-containing local anesthetics are used.<sup>6</sup> We evaluated local cortical blood flow (ICoBF) and local cortical metabolic rate for oxygen (ICoMRO<sub>2</sub>) during isoflurane-induced hypoten-

TABLE 1  
CLINICAL INFORMATION

Patient no.	Age (yr)	Artery	Grade	Recent SAH?	Other history
1	56	Ant comm	I	No	
2	53	L ant cerebral	III	14 days preoperatively	
3	60	Basilar	I	No	Aneurysm rupture during clipping
4	62	R middle cerebral	I	No	
5	58	R internal carotid	II	No	
6	33	L post cerebral	0	No	
7	60	R internal carotid	0	No	
8	51	L middle cerebral	I	No	

SAH = subarachnoid hemorrhage; *ant* = anterior; *comm* = commissural; *L* = left; *R* = right.

sion in patients anesthetized with fentanyl and nitrous oxide who were undergoing clipping of an intracranial aneurysm.

#### METHODS

Eight adults (seven women, one man) undergoing intracranial aneurysm clipping gave written consent to a protocol approved by the Institutional Review Board of the Cleveland Clinic Foundation. Two patients were Hunt and Hess<sup>7</sup> Grade 0, four were Grade I, one patient was Grade II, and the other was Grade III (Table 1). One patient had sustained recent subarachnoid hemorrhage, 14 days before operation. Other patients either had not bled from their aneurysms or the hemorrhage had occurred months previously. Patients with cardiovascular, hepatic, renal, or pulmonary disease were not included in the study. Patients received diazepam, 10 mg orally one hour before transport to the operating room. Anesthesia was induced with thiopental 4–5 mg/kg and fentanyl 10 µg/kg. When a stable blood pressure was attained, lidocaine 100 mg and pancuronium 0.1 mg/kg were administered and endotracheal intubation was performed. Anesthesia was maintained with nitrous oxide 70%, oxygen 30%, and isoflurane approximately 0.4% end-tidal as measured by mass spectrometry. The patients were given mechanical ventilation to a PaCO<sub>2</sub> between 35 and 40 mmHg. Temperature was maintained within ±1°C of the temperature at the beginning of anesthesia by using heating blankets and a cascade humidifier, or low fresh gas flow rates. All operations were performed with patients in the supine position. Patients were monitored with ECG, radial arterial catheter, end-tidal CO<sub>2</sub>, mass spectrometer (Perkin-Elmer Advantage®), esophageal temperature, and a central venous catheter. Pressure transducers (Gould) were zeroed at

the level of the right atrium and all waveforms were recorded continuously using a Hewlett-Packard E for M monitor.

After the dura was opened, prior to dissection of the aneurysm, a flow probe (Flowtronics Thermal Diffusion Cerebral Blood Flow Monitor, Flowtronics, Inc., Phoenix, AZ 85019) was placed on the surface of the middle frontal gyrus. The lCoBF was measured using a thermal diffusion technique as previously described.<sup>8–11</sup> The probe was gently held in place with cottonoids or by placement just under the dura. Following a 10-minute stabilization period, lCoBF measurements were made under baseline (normotensive) conditions. The lCoBF measurements did not vary by more than 5% over a 5-minute period, and the average value was recorded. Simultaneous heparinized blood samples were obtained from the arterial catheter and from a cerebral cortical vein adjacent to the flow probe. Analysis of PO<sub>2</sub>, PCO<sub>2</sub>, and pH was performed with an IL BGM 1312 Blood Gas Analyzer, and oxyhemoglobin saturation with an IL Co-Oximometer 282. Blood gas data were not corrected for temperature. Following completion of baseline measurements, we decreased mean arterial pressure (MAP) to 40–50 mmHg by increasing the end-tidal isoflurane concentration. After 15 minutes at a stable blood pressure, all measurements were repeated. Blood pressure was then returned to baseline value by decreasing the concentration of isoflurane; after a 15-minute stabilization period, the measurements were repeated. No surgical stimulation occurred during the study period. Subsequently, the aneurysm was clipped under hypotensive conditions induced with isoflurane. Patients were monitored postoperatively in the neurosurgical intensive care unit.

Arterial and venous oxygen contents were calculated as:

**TABLE 2**  
CHANGES IN LOCAL CORTICAL BLOOD FLOW AND METABOLISM BEFORE, DURING AND AFTER ISOFLURANE-INDUCED HYPOTENSION (MEAN ± SD)

	Prehypotension	Hypotension	Posthypotension
MAP (mmHg)	83 ± 9	48 ± 5†	79 ± 5
Arterial PCO <sub>2</sub> (mmHg)	40 ± 4	40 ± 4	37 ± 4§
ICoBF (mL/100g/min)	69 ± 20	59 ± 13	61 ± 18
ICoMRO <sub>2</sub> (mL/100g/min) × 0.01	3.9 ± 1.6	3.1 ± 1.5	3.4 ± 1.5
AV O <sub>2</sub> difference* (mL/100mL)	5.7 ± 1.9	5.2 ± 1.7	5.7 ± 2.2
Cerebral venous PO <sub>2</sub> (mmHg)	38 ± 9	37 ± 7	36 ± 8
Cerebral venous oxygen saturation (%)	63 ± 10	64 ± 11	61 ± 12
Isoflurane concentration (% end-tidal)	0.5 ± 0.2	1.56 ± .63‡	0.35 ± .24

\* Arterial-cerebral venous O<sub>2</sub> content difference.  
 † p < .001 compared to values pre- and posthypotension.  
 ‡ p < .002 compared to values pre- and posthypotension.  
 § p < .003 compared to value at hypotension.  
 All other differences not significant.

**TABLE 3**  
LOCAL CORTICAL BLOOD FLOW, METABOLIC RATE, AND CEREBRAL VENOUS PO<sub>2</sub> WITH CHANGES IN MEAN ARTERIAL PRESSURE

Patient no.	Prehypotension					Hypotension					Posthypotension				
	MAP (mmHg)	Isoflurane (% end-tidal)	CBF (mL/100g/min)	CMR O <sub>2</sub> (mL/100g/min)	CVPO <sub>2</sub> * (mmHg)	MAP (mmHg)	Isoflurane (% end-tidal)	CBF (mL/100g/min)	CMR O <sub>2</sub> (mL/100g/min)	CVPO <sub>2</sub> * (mmHg)	MAP (mmHg)	Isoflurane (% end-tidal)	CBF (mL/100g/min)	CMR O <sub>2</sub> (mL/100g/min)	CVPO <sub>2</sub> * (mmHg)
1	92	0.17	78	4.3	40	37	1.53	55	3.1	37	80	0	76	4.3	35
2	97	0.22	70	2.8	41	48	0.94	70	2.7	42	82	0.29	60	2.9	36
3	75	0.40	48	3.5	26	45	1.10	48	2.7	31	71	0.40	50	2.9	31
4	72	0.72	74	2.0	53	48	1.75	59	1.5	48	73	0.74	73	2.6	45
5	82	0.60	88	6.3	37	50	1.20	76	4.9	33	84	0.40	84	6.0	30
6	73	0.55	41	2.0	40	55	2.85	45	1.7	44	79	0.53	44	1.4	49
7	80	0.83	53	4.5	27	48	1.93	43	2.4	37	81	0.17	38	3.6	25
8	90	0.53	97	5.5	38	50	1.14	74	5.9	26	N/A	N/A	N/A	N/A	N/A

\*Cerebral venous PO<sub>2</sub>.

$$[(\% \text{ arterial or venous oxygen saturation}/100) \times \text{hemoglobin concentration (g/100 mL)} \times 1.34 \text{ mL/g}] + 0.003 \text{ mL}/100 \text{ mL}/\text{mmHg} \times \text{PO}_2 \text{ (mmHg)}$$

posthypotension), the value for statistical significance was set at  $P < .05/3$ , or  $P < .016$ .

**RESULTS**

No complications were attributable to the anesthetic technique, controlled hypotension, or the flow probe. Neurological outcome was excellent in seven patients. One patient sustained residual neurological deficits following intraoperative aneurysm rupture, which occurred after the study period during an attempt to clip the aneurysm. Complete data for normotension, hypotension, and return to normotension were obtained in all patients except one, where time constraints did not allow data collection after return to normotensive status. The results are presented in *Tables 2 and 3*.

(The units of oxygen content are thus mL/100 mL.) Arteriovenous oxygen content difference (AV O<sub>2</sub> difference) was calculated as arterial oxygen content minus venous oxygen content. The ICoMRO<sub>2</sub> was calculated as the product of ICoBF and AV O<sub>2</sub> difference multiplied by 0.01. Means of the different variables at hypotensive and normotensive conditions were compared using a paired t-test. To adjust for multiple comparisons, a Bonferroni correction was made. Since three comparisons were made (normotension to hypotension, hypotension to posthypotension, and normotension to

Hypotension was induced over an average of eight minutes. The mean ( $\pm 1$  SD) end-tidal isoflurane concentration was  $0.50 \pm 0.23\%$  during normotension,  $1.56 \pm 0.63\%$  during hypotension, and  $0.35 \pm 0.24\%$  upon return to normotension. Mean lCoBF decreased from  $69 \pm 20$  mL/100 g/min at normotension to  $59 \pm 13$  mL/100 g/min during hypotension, but this change did not achieve statistical significance ( $P < .03$ ). Upon return to normotension, lCoBF increased to  $61 \pm 18$  mL/100 g/min. Mean lCoMRO<sub>2</sub> also decreased from  $3.9 \pm 1.6$  mL/100 g/min at normotension to  $3.1 \pm 1.5$  mL/100 g/min during hypotension, but this difference was not statistically significant ( $P < .03$ ). There was an increase in mean lCoMRO<sub>2</sub> upon return to normotension ( $3.4 \pm 1.5$  mL/100 g/min), but the difference from the mean value at hypotension was not significant ( $P < .03$ ). The MAP decreased from  $83 \pm 9$  mmHg during normotension, to  $48 \pm 5$  mmHg during hypotension, and was returned to  $79 \pm 5$  mmHg. There were no statistically significant differences among the values for AV O<sub>2</sub> difference, cerebral venous oxygen tension, or cerebral venous oxygen saturation during prehypotension, hypotension, and posthypotension. Mean arterial PCO<sub>2</sub> was  $40 \pm 4$  mmHg at normotension and  $37 \pm 4$  mmHg upon later return to normotension, and that difference was statistically significant ( $P < .003$ ), although probably not of a degree to be clinically significant.

#### DISCUSSION

Isoflurane produced rapid decreases in arterial pressure, a phenomenon that has also been documented by others.<sup>3,12</sup> The desired level of hypotension was easily maintained by adjusting the inspired concentration, and the hypotension was rapidly reversed by decreasing the isoflurane concentration.

The technique used to measure lCoBF has been described previously.<sup>11</sup> The cortical surface is in contact with the probe and the temperature gradient of the probe can be detected to a depth of 4 mm, the thickness of the probe. The lCoBF values therefore are assumed to reflect gray matter flow. Our baseline blood flow measurement ( $69 \pm 20$  mL/100 g/min) agrees with previously reported regional determinations of lCoBF, and is similar to the reports of Eintrei et al<sup>13</sup> of isoflurane-nitrous oxide-fentanyl anesthesia using a regional Xe-133 cerebral blood flow (CBF) measurement technique in humans. The thermal diffusion probe provides a continuous recording of lCoBF and it can accurately measure flow at ischemic levels. It has been safely used in humans without complication.

We obtained blood samples from a cerebral cortical vein to measure differences in cerebral arterial-venous oxygen content. This vessel was, in all cases, situated close to the blood flow probe, and therefore our AVO<sub>2</sub> difference and lCoMRO<sub>2</sub> values are considered regional determinations. Consequently, our results may differ somewhat from those using global measurements. Eintrei et al<sup>13</sup> also utilized a regional measurement of CBF, with similar baseline lCoBF values, and showed no change in CBF with 1.5% end-tidal isoflurane. Murphy et al<sup>14</sup> and Newman et al<sup>12</sup> report similar findings. However, the findings differ with regard to the effects of isoflurane on CMRO<sub>2</sub>. Our study indicates a decrease in lCoMRO<sub>2</sub> that did not reach significance. Newman et al<sup>12</sup> showed that isoflurane-induced hypotension (2.3  $\pm$  1.0% inspired for at least one hour) with a MAP of  $51 \pm 7$  mmHg produced a 25% decrease in CMRO<sub>2</sub>. These results agreed with those of Newberg et al<sup>1</sup> in dogs and Van Aken et al<sup>2</sup> in baboons. In contrast, and similar to our data, Hickey et al<sup>15</sup> found no change in CBF or global CMRO<sub>2</sub> in dogs with up to 30 min of isoflurane-induced hypotension.

Several reasons may account for differences in our CMRO<sub>2</sub> findings. Although the lCoBF probe was located close to the vessel used to sample venous blood, it is possible that the blood samples were contaminated with blood from areas with differing metabolic rates. This could also in part explain our inability to demonstrate a difference in values for lCoMRO<sub>2</sub> between hypotensive and nonhypotensive periods. Therefore the possibility of a type II statistical error cannot be entirely excluded. In addition, end-tidal isoflurane concentrations of  $1.5 \pm 0.6\%$  were lower than those reported to cause decreases in global CMRO<sub>2</sub> in humans and dogs. Furthermore, like Hickey et al,<sup>15</sup> we produced hypotension for a much briefer time (15 minutes) than that reported by either Newberg et al<sup>1</sup> or Newman et al,<sup>12</sup> where hypotension was sustained for at least one hour.

One of our patients (Patient 2, Table 1) was operated on two weeks following a subarachnoid hemorrhage, and showed no change in lCoBF during hypotension and a decrease in lCoBF upon return to normotension. There was no change in lCoMRO<sub>2</sub>. These changes suggest disturbed autoregulation following recent subarachnoid hemorrhage, a finding that has been reported previously in animals and humans.<sup>16,17</sup> Therefore, our results may also have been influenced by this possibly abnormal autoregulatory behavior in this particular patient.

In conclusion, we induced hypotension rapidly with isoflurane during fentanyl-nitrous oxide anesthesia for a relatively brief period. During that time, lCoBF,

ICoMRO<sub>2</sub>, and cerebral venous oxygen tension did not change appreciably. We therefore were unable to demonstrate differences in ICoBF, ICoMRO<sub>2</sub>, and cerebral venous oxygen tension between hypotensive and non-

hypotensive periods. These data are consistent with the concept that isoflurane-induced hypotension is safe during cerebral aneurysm clipping.

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