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An Evaluation of Hypocarbia and Hypercarbia During Carotid Endarterectomy

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SUMMARY **One hundred consecutive patients were randomly given hypocarbic ($Paco_2 < 25$ torr) or hypercarbic ($Paco_2 > 60$ torr) general anesthesia during carotid endarterectomy to test the effect of the two regimens upon the incidence of postoperative neurological deficit. An indwelling shunt was not used. One patient died, two have permanent neurological deficits and two have temporary neurological deficits. Although hypocarbic patients had fewer neurological complications than hypercarbic patients, the difference was not statistically significant ($p < 0.13$). Hypercarbia significantly increased the incidence of intraoperative arrhythmia. Also, no relationship was found between the incidence of postoperative stroke and the internal carotid back pressure or the time of carotid occlusion.**

CAROTID ENDARTERECTOMY is a safe, time-tested, and effective method of treatment for selected patients with cerebrovascular insufficiency. However, the details of the operative management of these patients are still a subject of debate. One of these controversies is the use of hypercarbia or hypocarbia during carotid thromboendarterectomy to protect the brain and thus decrease the incidence of postoperative neurological deficits.

$Paco_2$ is a major factor in determining cerebrovascular resistance. With an increasing $Paco_2$ cerebrovascular resistance decreases and total cerebral blood flow (CBF) increases, while a decrease in $Paco_2$ increases resistance and lowers total CBF.[1, 2]

However, in an ischemic area of the brain, the vessels may show a lack of responsiveness to changes in $Paco_2$ or a "cerebral vasomotor paralysis." In this case, administration of CO_2 to a patient might lower the vascular resistance in the nonischemic areas, thus stealing blood from a local area of vasomotor paralysis. Conversely, hypocarbia will increase the vascular resistance of the brain in all areas except the area of vasomotor paralysis. The collateral pressure will be elevated and the blood flow in the ischemic area will be increased.[3]

Hypercarbia, therefore, has been used as an adjunct to general anesthesia for carotid endarterectomy because it enhances total CBF.[4] Hypocarbia has been used by its proponents because it enhances regional blood flow in areas of vasomotor paralysis.[5]

The following randomized study was designed to compare the effects of hypocarbia and hypercarbia given during general anesthesia upon the incidence of postoperative stroke for carotid endarterectomy.

Methods

One hundred consecutive patients scheduled for carotid endarterectomy were randomized into hypercarbic ($Paco_2 > 60$ torr) and hypocarbic ($Paco_2 < 25$ torr) groups. The following standardized anesthetic technique was used to eliminate many variables that affect CBF.

Anesthetic Technique

Following the administration of 0.6 mg atropine, Fentanyl was injected slowly intravenously until the patient had slurring of speech. Nitrous oxide (70%) and oxygen (30%) were then started. D-tubocurarine was used to avoid trunchal rigidity, to facilitate tracheal intubation, and to control respiration at 1½ Radford in each group. The lungs were ventilated mechanically with a Bennet volume ventilator and

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a nonrebreathing system. Arterial blood gases and pH were repeatedly measured and the intra-arterial blood pressure continuously monitored using a Statham transducer. Hypocarbia was established by maintaining minute ventilation at 1½ Radford[6] to produce a $Paco_2$ of less than 25 torr. Hypercarbia was obtained by measuring CO_2 at the right angle endotracheal adapter until a $Paco_2$ of greater than 60 torr was achieved. A mixture of N_2O and O_2 was adjusted to maintain a Pao_2 of 90 to 100 torr. Metaraminol bitartrate, 50 mg per 500 cc of D5W, was used to maintain blood pressure within 10% of the patient's highest recorded preoperative systolic blood pressure. At the end of the operation D-tubocurarine was reversed with atropine and prostigmin; the Fentanyl was reversed with increments of Naloxone.

Operative Technique

The carotid bifurcation was exposed, taking care not to manipulate the atheromatous areas. Heparin (5,000 units) was given intravenously and vascular clamps applied. The internal carotid back pressure and common carotid pressures were measured using a Statham transducer. Regardless of the pressure, an internal shunt was never used. The total clamp time was recorded.

Postoperative Management

The blood pressure was not allowed to fall below the lowest recorded preoperative blood pressure minus 10% for the first 24 hours. Metaraminol bitartrate was used to support the pressure at this level. The blood pressure was not allowed to rise above the highest recorded preoperative blood pressure plus 10% for the first 24 hours. Chlorpromazine was given intravenously to keep the blood pressure below this level. Diazepam (5 mg) was used for sedation. Postoperatively the neurological status of the patients was evaluated daily.

Results

One hundred patients were randomized preoperatively into two groups of 50 patients each. However, only 42 patients achieved a $Paco_2$ of less than 25 torr (hypocarbia), and only 42 patients achieved a $Paco_2$ of greater than 60 torr (hypercarbia), leaving 16 patients in a "normocarbic" ($Paco_2$ of 25 to 60 torr) group.

One patient died, two patients had permanent neurological deficits and two patients had temporary neurological deficits (table 1).

Postoperative Neurological Deficit

No patients in the hypocarbic group awoke with a neurological deficit but two patients had neurological deficits within 24 hours. Both of these patients had angiographically proved internal carotid occlusions. One of the patients died a neurological death, and one survived with no neurological deficit.

Three patients in the hypercarbic group awoke with a postoperative neurological deficit. None of these patients had postoperative arteriograms but all had a normal directional flow of the supraorbital artery by Doppler examination, indicating that the internal carotid artery was not occluded. Two of these patients were neurologically incapacitated but one fully recovered from an upper extremity paresis.

One patient (W.C.) had a "starved retina" and bilateral carotid stenoses. Following arch aortography he complained of subjective numbness of the left arm but he was neurologically intact on physical examination. The next day a carotid thromboendarterectomy was performed uneventfully. His stump pressure was 45/40. He awoke with a paresis of his left arm. A Doppler examination was within normal limits.

Another patient (G.B.) had an emergency right carotid endarterectomy for transient ischemic attacks which were uncontrollable by anticoagulation. Three months later he returned with left hemispheric transient ischemic attacks. An arch aortogram revealed an ulcerative lesion of the left carotid bifurcation and a widely patent right internal carotid artery. He awoke after a left carotid endarterectomy with a left hemispheric stroke. His stump pressure was 45/40. Both endarterectomies were performed using hypercarbic anesthesia. A postoperative Doppler examination of the supraorbital artery was within normal limits.

One patient (L.R.) had a right carotid endarterectomy performed for right hemispheric transient ischemic attacks and unilateral carotid stenosis. Her stump pressure was 95/80. She awoke with a mild left arm paresis but had full recovery within one week. The postoperative Doppler examination of the supraorbital artery was normal.

There was no statistical difference in the incidence of postoperative neurological deficits between the hypercarbic (three of 42 patients) and hypocarbic (two of 42 patients) groups. Even if the patients with known occlusions of the internal carotid artery were excluded, the difference between the groups ($p < 0.13$) was not statistically significant.

Clamp Time

The average clamp time for the hypocarbic patients was 27.7 minutes, the normocarbic patients 28.4 minutes, and the hypercarbic patients 28.1 minutes, with a range of 14 to 48 minutes. Table 2 shows that the patients with the postoperative deficits had clamp times of 18, 21, 21, 30, and 30 minutes.

TABLE 1 *Carotid Endarterectomy: Postoperative Neurological Deficit*

Hypocarbia	Normocarbia	Hypercarbia
2* of 42 pts.	0 of 16 pts.	3 of 42 pts.

*Both patients had proved ICA occlusions.
The differences noted are not statistically significant even if the proved carotid occlusions are excluded ($p < 0.13$).

TABLE 2 *Carotid Occlusion Times During Carotid Endarterectomy*

Pts.	Clamp time (minutes)
3	<15
13*	15-20
24*†	21-25
32††	26-30
14	31-35
9	36-40
5	>40
100	

*Postoperative stroke, occluded ICA; †postoperative stroke.
The range of times of carotid occlusion are listed on the right and the distribution of the patients on the left.

Internal Carotid Back Pressure

Table 3 shows that the average internal carotid back pressure (stump pressure) was highest in the hypocarbic patients (79.4 torr) and lowest in the hypercarbic patients (57.2 torr).

Cardiac Arrhythmias

Nineteen (45%) hypercarbic patients had cardiac arrhythmias (fig. 1). Only five (12%) hypocarbic patients had arrhythmias. Four (25%) patients in the normocarbic group had premature ventricular contractions (PVC). Three of these four normocarbic patients had a $Paco_2$ between 50 and 60 torr, and one had a $Paco_2$ of 31 torr. These differences were statistically significant ($p < 0.004$). In addition, post-hypercapnia hypotension was a frequent problem.

Three patients with intraoperative cardiac arrhythmias had a postoperative stroke. One patient had a proved internal carotid occlusion that was not obviously related to her temporary nodal rhythm. Two other patients were hypercarbic and had PVCs which were not treated. None had a problem maintaining their blood pressure.

Discussion

Carotid endarterectomy is a relatively safe procedure for the treatment of cerebrovascular insufficiency. Our results (1% mortality, 2% permanent neurological deficit, and 2% temporary neurological deficit) are comparable with other published reports.[7-11]

Two of our patients had a stroke as the result of an obvious technical error, i.e., postoperatively the operated carotid artery was occluded with thrombus. One of these patients died; the other is alive without a neurological deficit. A third patient had a postoperative stroke despite an internal carotid back pressure of 95/80, suggesting intraoperative embolization. Therefore, at least three of five patients with neurological deficits probably had a technical misadventure during the operation that was responsible for the deficit. We believe that technical error is the single most important factor in the development of a stroke following carotid endarterectomy.

One patient (W.C.) had subjective symptoms following arteriography. Nonetheless the next day a carotid endarterectomy was performed which resulted in a stroke. It is tempting to suggest that the timing of the operation was improper, that is, the patient had a small stroke at the time of his x-ray study causing his subjective numbness and that cerebral ischemia at the time of his carotid endarterectomy accentuated this neurological deficit.

Postoperative stroke is difficult to relate to a low internal carotid back pressure, although four of the five patients with postoperative strokes had stump pressures less than 50. Two of these patients had technical errors (occluded internal carotid arteries). A third patient (W.C.) had a carotid endarterectomy in the face of an acute neurological syndrome following angiography. A fourth patient (G.B.) had a successful contralateral carotid endarterectomy performed three months before a carotid endarterectomy which resulted in a stroke. The same anesthesia (hypercarbia) and internal carotid back pressure (45/44) were obtained on each occasion, making it difficult to implicate either of these factors.

TABLE 3 *Internal Carotid Back Pressure (Stump Pressure)*

Hypocarbia	Normocarbia	Hypercarbia
79.4 torr	65.8 torr	57.2 torr

The average internal carotid back pressure varied inversely with the $Paco_2$.

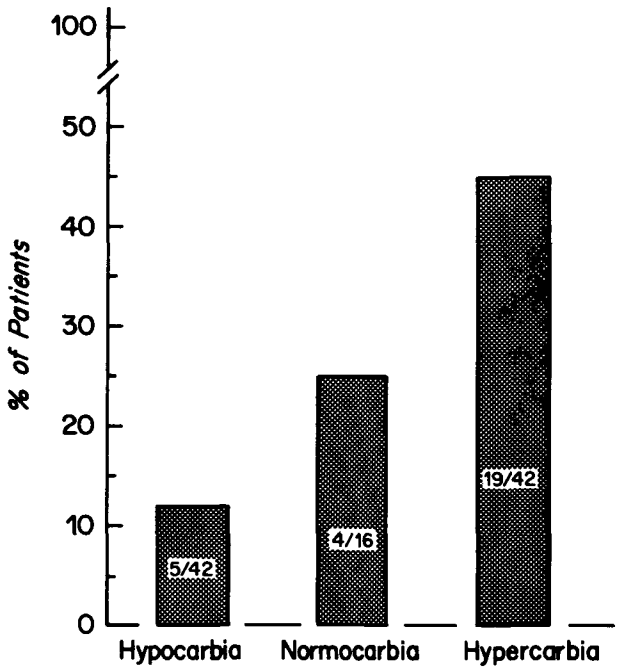

FIGURE 1. *Intraoperative cardiac arrhythmias. Cardiac arrhythmias were more frequently encountered during hypercarbia ($p < 0.004$). Post-hypercapnia hypotension also was frequently encountered.*

The clamp time in this series is somewhat prolonged (average 28 minutes). However, a postoperative stroke did not occur in the 28 patients with clamp times greater than 30 minutes, implying that excessive clamp time is not directly related to an unsatisfactory result.

Finally, there was no statistical superiority of either hypocarbia or hypercarbia in the prevention of stroke. If the patients with known postoperative internal carotid occlusions are excluded, hypocarbic anesthesia appears to offer more protection against postoperative stroke, but this is not statistically significant ($p < 0.13$). In addition, cardiac arrhythmias were more troublesome in the hypercarbic patients, making this a more undesirable anesthetic technique.

On the basis of the findings of this study, our current practice is to perform carotid endarterectomy maintaining the arterial Pco_2 in the normal range.

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Patterns of Changes of Blood Flow and Relationships to Infarction in Experimental Cerebral Ischemia

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SUMMARY **Regional cerebral blood flow (CBF) was measured in both middle ectosylvian gyri of ten cats by recording the clearance of molecular hydrogen (H_2) with implanted polarized electrodes 125 μ in diameter, before and up to seven days after occlusion of the left middle cerebral artery (MCA) with a device implanted in the intact cranium. Five patterns of changes of CBF were recorded with the left-sided electrodes. In eight cats MCA occlusion caused immediate decreases of CBF; in the other two cats CBF values were lowest two days after occlusion, presumably because of ischemic edema. Both persistent severe ischemia and early spontaneous postischemic hyperemia were associated with severe neurological deficits, marked swelling of the left cerebral hemispheres, and large infarcts. Late postischemic hyperemia was associated with less severe deficits, less swelling, and smaller infarcts, but the least severe deficits and smallest infarcts were noted in association with persistent moderate ischemia. No consistent patterns were recorded with the right-sided electrodes in this study. Hyperemia which develops spontaneously or is induced shortly after the onset of cerebral ischemia potentially may be harmful because of secondary increases of cerebral edema.**

AT DIFFERENT TIMES after the onset of focal cerebral ischemia regional cerebral blood flow (CBF) in and around the core of ischemic tissue may be decreased, increased, or relatively normal.[1-3] The changes of CBF that occur are related to the location of the region under study and the time after the onset of ischemia and may influence or be influenced by cerebral edema and swelling, the severity and extent of the resulting infarct, or systemic factors such as blood pressure, pulse rate, and respiration. Because of a paucity of studies of cerebral ischemia that have included serial measurements of regional CBF, the relationships among changes of CBF, edema and infarction are not known. These relationships may be important for the preservation or restoration of neuronal function and for the minimization of neurological deficits. For example, postischemic increases of CBF (reactive hyperemia or "luxury perfusion")[1, 4, 5] theoretically could be associated with a worsening of neurological deficits because of the development of focal cerebral edema resulting from an increase of the transendothelial distribution of water caused by an increase of intraluminal vascular pressure; or with a resolution of neurological deficits because of increases of the amounts of oxygen and glucose available to neurons and the clearance of acid metabolites. To help determine the relationships among blood flow, edema and infarction, measurements of regional CBF were made in cats before and up to seven days after occlusion of one middle cerebral artery (MCA), and were related to the extent and severity of the resulting neurological deficits, brain swelling, and infarcts.

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Methods

Implantation of Devices for MCA Occlusion and CBF Measurements

Ten unselected adult cats were anesthetized with phencyclidine hydrochloride, 1 mg per kilogram injected intramuscularly, and sodium pentobarbital, 20 mg per kilogram injected intraperitoneally. The head of each cat was immobilized in a headholder, and the left MCA was exposed transorbitally.[6] The MCA was freed from its arachnoidal investiture and a silicone-treated 6-0 silk suture was looped carefully around it at its origin. The suture was manipulated into a single knot and its ends were passed outside the incision through a solid-ended tube-and-stylet which was apposed flush to the MCA and fixed to the wall of the orbit with epoxy cement. The optic foramen was sealed around the tube-and-stylet with Silastic sheeting, oxidized cellulose, and contact adhesive, and the orbit was filled with epoxy cement. The protruding ends of the stylet-and-tube and the suture were covered with a protective cap.

Teflon-coated 90% platinum-10% iridium wires, 125 μ in diameter and 3 to 4 cm long, were prepared with conical tips