

Transient Changes in Cerebral Vascular Resistance During the Valsalva Maneuver in Man

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SUMMARY Measurements of cerebral spinal fluid pressure, arterial pressure, and internal carotid artery blood flow were obtained in a series of patients during a Valsalva maneuver. During straining (phase II), an 11% reduction in mean arterial pressure was associated with a 21% decrease in internal carotid flow from control values; and following release (phase IV), the 19% increase in mean arterial pressure produced a 22% increase in internal carotid artery flow. Perfusion pressure computed as the mean arterial pressure minus cerebral spinal fluid pressure and internal carotid artery blood flow were used to calculate an index of cerebral vascular resistance. The data indicate that a modest but significant decrease in vascular resistance occurred during phases II and III followed by return to control levels during phase IV. These changes in vascular resistance were not rapid enough or of sufficient magnitude to maintain constant cerebral perfusion during the Valsalva maneuver.

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THE PRECISION with which cerebral vascular blood flow can be maintained at a constant value during rapid changes in perfusion pressure has not been defined in man primarily due to the methodologic limitations encountered in measuring phasic cerebral blood flow. Quantitative measurements of phasic internal carotid artery flow have been obtained in man with an electromagnetic flowmeter and can be used as an index of cerebral flow.^{2,3} The Valsalva maneuver is associated with marked changes in arterial pressure and thus, can be used to study the effects of rapid changes in arterial pressure on cerebral blood flow.⁹ The purpose of this study was to measure the internal carotid artery blood flow and to compute for the first time the changes in cerebral vascular resistance which occur accompanying a brief Valsalva maneuver in a series of nine patients.

Methods

Nine male patients were studied who had been hospitalized on the Neurosurgical Section of the Veterans Administration Hospital, Durham, North Carolina. In each patient subtotal resection of a supratentorial malignant brain tumor had been carried out from 10 to 20 days previously. The data described in this report were obtained during exposure of the carotid vessels so that an antitumor agent (S-112, a chlorethylthioacetamide, 8 μ g/kg) could be infused directly into the internal carotid artery. This drug was given immediately after the completion of the studies described. The informed consent of each patient was obtained.* At the time of study, the patients were alert and showed no major neurological deficits. The cerebrospinal fluid (CSF) pressure was less than 250 mm H₂O.

*This investigation was carried out under the procedures currently applicable for human investigation.

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Before the surgical procedure the patients were premedicated with 50 mg of meperidine and 25 mg of promethazine. Local anesthesia was accomplished with injections of lidocaine. The common carotid artery and proximal portions of both the internal and external carotid arteries were exposed, and the small arterial branches in this area were ligated. The probe of a Satham Model K-2000 electromagnetic flowmeter (EMF) was placed around the common carotid artery proximal to the bifurcation. The probe size was selected so that the vessel was not constricted more than was necessary to obtain an adequate flow signal. Since the EMF probe was on the common carotid artery, flow in the internal artery could be measured by briefly occluding the external carotid artery with a nontraumatic arterial clamp. A short polyvinyl catheter was inserted into the superior thyroid artery and the tip advanced to the common carotid artery. This catheter was connected to a Satham P23Db strain gauge and used for recording arterial pressure. In six patients, a lumbar puncture was performed in the usual manner with an 18 gauge lumbar puncture needle at the fifth lumbar interspace. The needle was connected to a Satham P23Db strain gauge via a short plastic tube. The zero flow reference for both arterial pressure and cerebral spinal fluid (CSF) pressure was assumed to be at the level of the spinal axis.

Blood flows and pressures were recorded continuously during the control period and during a brief Valsalva maneuver. Due to the patient's clinical status, prolonged rigorous straining was not attempted. The Valsalva maneuver was performed by encouraging the patient to strain and maintain an intraoral pressure of 20 mmHg for approximately 15 seconds. The oral pressure was monitored with an air-pressure gauge. In each patient at least two Valsalva maneuvers were performed. The zero-flow reference was obtained by temporarily occluding the vessel distal to the probe. Prior to these studies, the EMF and probes were calibrated by passing known quantities of physiological saline through the probes in a given period of time. They were found to be linear \pm 2% through the range of flows encountered and the calibration factor remained within a SD \pm 5%. Arterial blood samples were obtained for mean PCO₂, using Instrumentation Laboratories Model 113 gas analyzer. Data were re-

corded on a Sanborn Model 850 direct-writing oscillograph.

Both CSF and arterial pressures and the flow data were computed directly from the oscillographic recordings. Mean data were obtained by electrical integration. In comparing the simultaneous pressure and flow measurements, corrections were made for the time delay introduced by the electrical circuit employed to record the mean data. The Valsalva maneuver was divided by convention into four phases.⁹ Measurements were made as follows: during the control state; at the initial maximal increase in arterial pressure (phase I); at the lowest value of flow during straining (phase II); at the lowest value of arterial pressure immediately following release (phase III); at the maximum value of arterial pressure during the arterial pressure overshoot (phase IV); and at the time the arterial pressure returned to control values. Data were evaluated using standard statistical techniques and are presented as a mean \pm standard deviation.

Results

During the control state the mean arterial PCO_2 was $39.47 \text{ mmHg} \pm 4.84$. Arterial blood samples were not obtained either during or following the Valsalva maneuver. Figure 1 illustrates a typical recording of the mean internal carotid artery flow, mean arterial pressure, and CSF pressure during a Valsalva maneuver in one of the patients. In Figure 2, the mean and \pm standard deviation for the internal carotid artery flow and for the mean arterial pressure computed from the nine patients is illustrated. In addition, the mean and standard deviation for the CSF pressure from six of these nine patients is given. During the control state the mean arterial pressure was 97 mmHg , internal carotid artery flow $162 \text{ cm}^3/\text{min}$, and CSF pressure 16.5 mmHg . During the phase I, the arterial pressure increased by a mean value of 17 mmHg , and was associated with a mean increase in CSF pressure of 7 mmHg . This rise in CSF pressure appeared to lag the increase in mean arterial pressure by two to three seconds. An increase in mean internal carotid artery flow of $23 \text{ cm}^3/\text{min}$ occurred concomitantly with the rise in arterial pressure during phase I. During the phase II, the mean arterial pressure fell to an average value of 86 mmHg , and the CSF pressure increased further to a mean value of 27 mmHg . This was associated with a marked decrease in mean internal carotid flow to $128 \text{ cm}^3/\text{min}$, a decrease of 21% from the control flow. During phase III, the arterial pressure fell significantly ($p = 0.02$) further to a mean value of 80 mmHg . The average CSF pressure decreased rapidly and was not significantly different from control values. The average internal carotid artery flow rose significantly ($p = 0.04$) to $136 \text{ cm}^3/\text{min}$. During phase IV, mean arterial pressure increased markedly to 115 mmHg , and CSF pressure was 20 mmHg which was slightly but significantly higher than during the control state. Internal carotid artery flow increased to $198 \text{ cm}^3/\text{min}$, a 22% increase from the control flow. At the time that the mean arterial pressure returned to the control values, both CSF

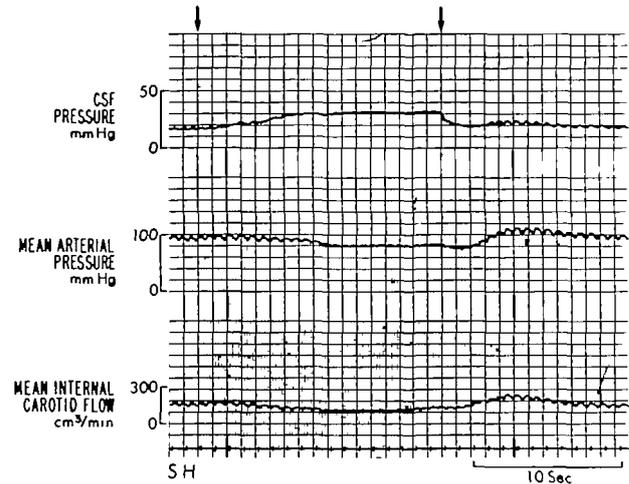


FIGURE 1. CSF pressure, mean arterial pressure, and mean internal carotid blood flow recorded during a Valsalva maneuver. The arrows indicate the beginning and end of the straining period.

pressure and internal carotid artery flow were not statistically different from those which occurred during the initial phase.

Discussion

Although there is a wealth of information concerning the multiple factors which control cerebral blood flow and metabolism, a paucity of data exists which define the changes in cerebral flow during rapid transient changes in arterial pressure. Most techniques used to quantitate cerebral flow measure mean flow and require at least several minutes for equilibration and therefore are not suitable to study transient alterations in cerebral flow. Phasic changes in flow in an artery can be quantitated with an electromagnetic flow-

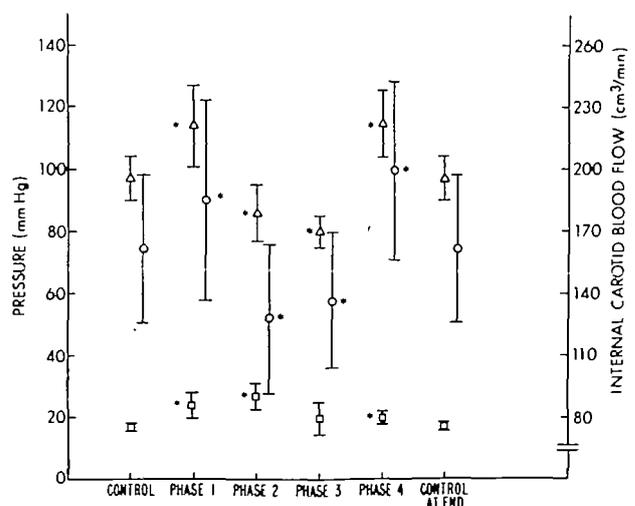


FIGURE 2. The mean and standard deviation for mean arterial pressure (triangles), mean internal carotid artery flow (circles) and CSF pressure (squares) are illustrated during the four phases of the Valsalva maneuver and during the control at the beginning and end of the maneuver. An asterisk denotes a significant ($p < 0.05$) difference from control values.

meter. Measurement of internal carotid artery blood flow with this technique should provide at least a reasonable index of cerebral flow and these data will reflect transient variations in cerebral perfusion.^{2,3}

The Valsalva maneuver should not be associated with obligatory changes in cerebral metabolism and thus, if the autoregulatory mechanisms which control cerebral flow were ideal, cerebral perfusion should remain constant during this maneuver. However, this is not likely, since a prolonged Valsalva maneuver can be associated with dizziness or frank unconsciousness, presumably due to reductions in cerebral flow. In the nine patients studied in this report, the changes in internal carotid artery flow were directionally similar to those which occurred in mean arterial pressure. During phase II, the reduction in mean arterial pressure was associated with a 21% decrease in internal carotid artery flow and during phase IV, the increase in mean arterial pressure was associated by a 22% increase in flow above control values. Recently, Samnegard, Tyden and Thulin studied internal carotid artery flow in five patients with autonomic dysfunction during straining and noted a mean decrease in internal carotid artery flow of 39%.⁸ Thus, the mechanisms which control cerebral blood flow are not rapid enough to maintain a constant cerebral perfusion under the conditions present during the Valsalva maneuver.

In order to demonstrate that any change in the cerebral resistance occurs during the Valsalva maneuver, it is necessary to compute cerebral vascular resistance from the pressure-flow data. However, before this calculation is made the perfusion pressure must be obtained. In classical physiology, the perfusion pressure would be the pressure drop across the cerebral circulation and would be computed as the mean arterial pressure (driving pressure) minus internal jugular venous pressure (back pressure). However, since the cerebral circulation may be roughly approximated by the pressure-flow relationships known to exist in a Starling resistor, it is probably more correct to use the CSF pressure as the back pressure.^{1,2,5} In the Starling resistor or vascular waterfall model the resistance (r) would be computed from the following:

$$r = P_p/Q \quad (1)$$

where P_p , the perfusion pressure, is computed as the mean arterial minus CSF pressure and Q is the internal carotid artery blood flow. This resistance will be correct so long as the CSF pressure is greater than the internal jugular venous pressure. However, if internal jugular venous pressure rises above CSF pressure then it will become the back pressure and the perfusion pressure will be computed as mean arterial pressure minus internal jugular venous pressure. The increase in mean arterial pressure during phase I is similar to the increase in intrathoracic pressure during straining and should be similar to the increase in internal jugular venous pressure.⁹ In our six patients in whom CSF pressure was measured the increase in mean arterial pressure during phase I did not exceed the CSF pres-

sure: thus, it seems reasonable to use the CSF pressure as the back pressure. In these six patients the cerebral vascular resistance was calculated from equation 1 and is expressed in Figure 3 as the percent change from the control. As can be seen there is a significant reduction in cerebral vascular resistance to 90% of control during phase II which falls further to 85% of control during phase III of the Valsalva maneuver. Cerebral vasoconstriction occurs during phase IV so that resistance returns approximately to control levels.

The mechanism for the decrease in cerebral vascular resistance cannot be determined from these data. The possibilities include local autoregulation due either to a myogenic or metabolic response and possibly to changes in PCO_2 which occur during breath holding. Myer et al measured arterial PCO_2 during a Valsalva maneuver and noted an average 2 mmHg decrease after 20 seconds of straining.⁶ Arterial PCO_2 was not measured in our patients during straining but if it did decrease this would be expected to result in vasoconstriction and not the observed vasodilatation. During Phase III when vasodilatation was maximal the flow was reduced by 16% from control values. However, if vasodilatation had not occurred flow would have fallen by 26%. A myogenic response initiated by the changes in perfusion pressure is an attractive explanation for the vasodilatation and has been shown to be operative in the cerebral circulation.¹⁰ The time required for the myogenic mechanism to be activated in the cerebral

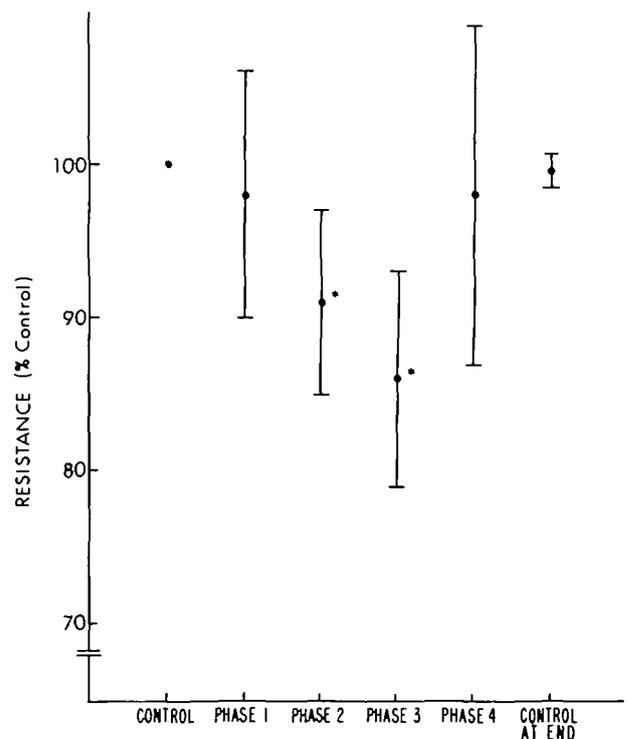


FIGURE 3. The percent change in cerebral vascular resistance from control values was calculated from equation 1. The asterisk denotes a significant ($p < 0.05$) difference from control value. Note that resistance decreases significantly during phase II, and decreases further during phase III. During phase IV the resistance returned to control levels.

vasculature generally has been found to be longer than that obtained in our patients.¹⁰ Whatever the mechanism, it would appear that it becomes effective within five to eight seconds but is not of sufficient magnitude to return the flow back to control levels during phases II and III. During phase IV, cerebral vascular resistance returns within five seconds to control values.

In the patients studied by Samnegard, Tyden and Thulin, cerebral resistance was not computed, so whether the decrease in mean arterial pressure and internal carotid flow was associated with cerebral vasodilatation during phases II and III is unknown.⁸ During phase IV in their patients, no pressure overshoot occurred but flow was higher than during control, indicating the presence of cerebral vasodilatation. Miyazaki used an ultrasonic Doppler method to estimate cerebral vascular resistance and found that the resistance was increased during the Valsalva maneuver.⁷ Since CSF pressure was not measured and no data are given to validate the measurement of flow, it is unclear how the cerebral vascular resistance was quantitated.⁷

Obviously studies of the regulatory mechanisms which control cerebral blood flow are ideally obtained in subjects with normal cerebral structures. In each of our patients a subtotal resection or biopsy of a glioblastoma had been performed ten days to two weeks before the studies were carried out. The operative procedure was not extensive, and the bone flap was replaced. In each case the patient was alert, cooperative and had no major neurological deficit at the time of the study as evidenced by their ability to perform the Valsalva maneuver. **The fact that the intracranial pressure increased rapidly and varied in the expected manner during the Valsalva maneuver would indicate that the dynamic changes in cerebral perfusion are similar to that which would be found in normal subjects.** The only difference between the change in intracerebral pressure during the Valsalva maneuver with that reported previously was that the maximum increase in cerebral pressure lagged the maximum increase in mean arterial pressure by two to three seconds during phase I (see fig. 1). In the studies reported by Hamilton et al,⁴ the increase was concomitant. This difference may well be related to the slightly increased capacitance of the cerebral structures as a result of the operative procedure. Nevertheless, it is our contention that the important aspects of this study i.e., the transient changes in cerebral vasomotion which occurred as a result of the fall in mean arterial pressure, occurred at a

time which the intracerebral pressure was essentially constant and hence should not be affected by the abnormal intracranial pathology. Certainly the majority of the intracerebral arterioles perfused by the internal carotid artery were unaffected by the operative procedure. Thus we feel that the data obtained in these patients is representative of the transient changes in cerebral hemodynamics which occur during the Valsalva maneuver.

The data obtained in these patients clearly demonstrate a rather marked change in cerebral flow associated with the Valsalva maneuver and indicate that although the vasoregulatory mechanisms which control cerebral perfusion are operative, they are not rapid enough to maintain constant cerebral flow during these conditions.

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