Effect of Isovolemic Hemodilution on Cerebral Blood Flow Following Experimental Head Injury*

CARL O. MEAD, M.D., ROBERT A. MOODY, M.D., SERI RUAMSUKE, M.D., AND SEAN MULLAN, M.D.

Division of Neurological Surgery, The University of Chicago Pritzker School of Medicine, Chicago, Illinois

The pathophysiology of head injury results from a complex set of interrelated and interdependent factors such as concussion, changes in intracranial pressure and cerebral blood flow, cerebral edema, and cerebrospinal production and absorption. This report is primarily concerned with alterations in cerebral blood flow during acute compression of the brain and in the hours thereafter. While other studies have been carried out on blood flow during various types of head injury and increased intracranial pressure, few have investigated the beneficial effects of increasing blood flow during poor flow conditions. This investigation utilizes our model of extradural compression previously described.10 The model furnishes a relatively controlled means of altering brain compression, brain distortion, and intracranial pressure. It also lends itself to greater reliability in studies of mortality and morbidity in a series of animals.

This study was carried out in three parts:
1. Changes in cerebral blood flow and arteriovenous oxygen difference induced by extradural compression.
2. Alterations in cerebral blood flow with isovolemic hemodilution.
3. Effects of hemodilution and hemodilution plus hyperbaric oxygenation on mortality and morbidity following cerebral injury.

Material and Methods

Blood Flow Studies. Twenty-six mongrel dogs were used, varying in weight from 26 to 35 lbs. Under sodium pentobarbital anesthesia (10 mg/lb), extradural balloons were placed over the frontal cortices bilaterally, the right utilized for compression and the left for recording intracranial pressure. Silver electrodes were placed over the parietal cortices for bipolar recording of the EEG. A femoral arterial catheter was inserted to the descending aorta for obtaining blood gas samples and for recording systemic blood pressure. A pneumatactic device measured respiratory rates, and a Beckman Dynograph recorder with Statham strain gauges was used for recording data. A PE 90 polyethylene catheter was inserted 1 cm into the anterior superior sagittal sinus for obtaining venous blood samples.

A right neck dissection was carried out as described by Rosomoff and Holaday44 in which the external carotid vessels were tied off from the common carotid artery, thus isolating the flow to the internal carotid artery. The right vertebral artery was isolated as it branched from the right subclavian artery. Previous India ink injection studies we performed indicate that approximately 95% of the blood flow in these vessels is limited to the intracranial circulation. More precise measurements of cerebral flow could have been obtained by using primate animals which have fewer anastomotic channels with the external carotid system than the dog. The dog was used, however, since more animals could be used for a survival study with the available funds, and relative changes in flow were of greater importance than absolute flow values. Square-wave Carolina electromagnetic flow probes were used to measure flow in the vertebral and common carotid vessels. Probes were calibrated on isolated perfused vessels using whole blood at varying hematocrits. As recording was only performed on the vessels of the right side, the sum of flow in the right vertebral and carotid arteries was doubled to approximate total cerebral blood flow. Arterial and venous blood samples were analyzed for PO2.

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PCO₂, and pH with a Beckman physiological gas analyzer (Model 160).

Expansion of the right extradural balloon was carried out with 0.1 to 0.2 cc increments of water over a 1½- to 2-hr period, to the point of a self-sustained rise in intracranial pressure and blood pressure and a bilaterally flat EEG for 3 min. Periodic sagittal sinus and arterial blood samples were drawn for blood gas analysis. After decompression of the expanding balloon, dogs were monitored for approximately 8 hrs.

Eight dogs were studied under condition of spontaneous respiration. A No. 30 endotracheal tube was employed to maintain an airway. In eight other dogs, controlled respirations were used. A Bird respirator, which used room air, maintained a PaO₂ of approximately 80 mm Hg and a PaCO₂ of 30 mm Hg.

A third group of 10 animals was prepared and compressed as above and then subjected to isovolemic hemodilution within 10 minutes of deflation of the extradural balloon. Hemodilution was carried out over a 10-min period using a 5 mm diameter polyethylene catheter inserted to the inferior vena cava via the femoral vein. It was performed by rapid withdrawal of 50 cc of venous blood and replacement of 50 cc of 6% dextran in normal saline (Gentran-MW 75,000)* until the hematocrit was reduced from a mean value of 47 to 20. This required 450 to 500 cc exchanged in all animals. Hemoglobin concentration was reduced to between 7 and 8 gm%. Flow measurements and arterial and venous blood gases were monitored over the next 4 hrs. Flow probes were previously calibrated with whole blood at a hematocrit of 45 and with whole blood diluted with Gentran to a hematocrit of 20.

Survival Studies. Fifty dogs were included in this series. All were subjected to extradural compression as described above to the point of spontaneously rising intracranial pressure and a flat EEG bilaterally for 3 min (Cal 50 µV = 5 to 10 mm). These animals were allowed spontaneous respiration during the compression period. Following deflation of the extradural balloon, 20 animals were utilized as controls, 20 were subjected to isovolemic hemodilution as described above, and 10 after hemodilution were placed in a hyperbaric oxygen chamber pressurized to 2 atmospheres with 100% O₂. The latter group were left in the chamber for 4 hrs and received no further oxygen therapy after this time.

Results

Blood Flow Studies. Figure 1 demonstrates graphically the changes in the eight dogs studied under spontaneous respiration. The rate of rise in intracranial pressure is primarily dependent on the rate of expansion of the extradural balloon. However, it should be noted that nearing the point of maximal compression, smaller increments of fluid, added at less frequent intervals, were used to raise the pressure. The steeper slope near this point reflects the increasing loss of compensatory accommodation to the expanding intracranial mass.

Blood pressure and pulse showed the typical "Cushing response" to increased intracranial pressure; that is, a rising blood pressure and slowing pulse as the intracranial pressure is elevated. After deflation of the compression balloon, only a slow spontaneous rise in intracranial pressure was noted in these animals, never to exceed 20 mm Hg.

Cerebral blood flow (CBF) started to decrease after a pressure of approximately 40 mm Hg (520 mm H₂O) had been reached and continued to decline until deflation of the expanding balloon. With deflation there was a surge of flow followed by a subsequent decline in flow over the next 8 hrs, which was not associated with a decrease in blood pressure or increase in the intracranial pressure (ICP). It should be noted that as the point of maximal compression was approached, periodic waves were noted in the ICP and blood pressure. Figure 2 shows the synchronization of these waves with respiration and the concomitant rise in blood flow with the rise in blood pressure. Figure 1 plots the flow at the basal levels, rather than at peaks of these "vasopressor" waves, so that as maximal compression was approached the peaks of these waves accounted for some recovery of flow according to their frequency.

Cerebral arteriovenous (A-V) O₂ difference, calculated from the PaO₂ and sagittal...