The Effects of Increased Intracranial Pressure Upon the Oxygenation of Blood in Dogs

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Respiratory disturbances have been observed in association with a variety of intracranial abnormalities. These disturbances include upper airway obstruction, ventilatory abnormalities, aspiration pneumonia, and the development of pulmonary edema. In Vietnam we have observed arterial hypoxemia in patients who have localized head injuries in the apparent absence of any of these disturbances. The present studies have been designed to clarify the mechanism by which arterial hypoxemia may develop in animals with experimentally increased intracranial pressure.

Materials and Methods

The principles of laboratory animal care as promulgated by the National Society for Medical Research were observed in these experiments. Mongrel dogs weighing 10 to 22 kg were used throughout the study. All animals were anesthetized with intravenous pentobarbital 30 mg/kg, and endotracheal tubes were passed to assure a patent airway. A polyethylene catheter was placed in the abdominal aorta to monitor blood pressure and to obtain arterial blood samples. Arterial blood pressure was monitored via pressure transducers connected to appropriate preamplifiers and an amplified recording system (Sanborn 150 Recorder, Sanborn Co., Waltham, Mass.). The heart rate was taken from an electrocardiographic recording. Respirations were controlled by a Harvard Constant Volume Ventilator at a minute volume sufficient to maintain control of arterial pCO₂ within a range of 35 to 45 mm Hg to minimize the effect of hyperventilation on subsequent lactate determinations. Arterial blood was drawn anaerobically into heparinized disposable plastic syringes for pH and blood gas determinations which were performed immediately on an IL Blood Gas/Ph Analyzer (Instrumentation Laboratories, Watertown, Mass.). Room air was used in the early experiments. In later experiments 100% O₂ was supplied to the ventilator.

Once the dog was hemodynamically stable with respect to blood pressure and pulse rate, and the blood gas tensions were observed to be repeatedly normal, an epidural balloon was placed through a burr hole over the parietal lobe. A second set of control readings was made to insure that the intracranial manipulations had no effect on the blood pressure, pulse or arterial blood gases. The intracranial balloon was then inflated sufficiently to produce diastolic hypertension equal to 100 mm Hg. Readings of the blood gases were repeatedly performed until adjustment of the brain had been sufficient for the diastolic blood pressure to return toward normal. The balloon was then further inflated to produce a diastolic blood pressure of 150 mm Hg, and further serial blood gas determinations were performed. Each animal was hyperventilated for five to six respiratory cycles every 10 minutes to minimize the possibility of atelectasis during the experimental period.

The effect of intracranial hypertension on the production of relative arterial hypoxemia was initially analyzed in 12 paired experimental studies in the intact animal while breathing both room air and 100% oxygen. Then the effects of cervical cordotomy, adrenalectomy, cervical truncal vagotomy, atropine, and alpha and beta adrenergic blockade were each assessed in eight paired experiments. In those experiments in which the arterial hypertensive response was blocked, balloon volumes were equal to those used in control untreated dogs. All

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procedures were performed after the craniotomy and insertion of the balloons. Cervical cordotomy was performed bluntly through the posterior laminar elements between the axis and atlas. Cervical vagotomy was performed through bilateral neck incisions at the level of the larynx. Atropine was administered intravenously in a dose of 1.2 mg/kg, phenoxybenzamine in a dosage of 2 mg/kg, and propanolol in a dose of 0.8 mg/kg. Animals pretreated with phenoxybenzamine were subjected to intracranial pressure elevation 1 hour after infusion to allow maximal alpha receptor blockade. Complete bilateral adrenalectomy was performed via a mid-line abdominal incision. After each of the above procedures, further control readings were taken, and complete stability of all parameters was assured prior to the institution of intracranial hypertension.

All animals were sacrificed with intravenous pentobarbital at the end of the experiments. Autopsies were then performed to rule out the development of pulmonary edema in these dogs.

**Results**

The results are summarized in Fig. 1 and Table 1 in which each mean is calculated from at least eight determinations. No dogs were found to have developed pulmonary edema in these experiments. Figure 1 illustrates the effect of increased intracranial pressure on the arterial oxygen tension. In intact animals the initial elevation to a level necessary to raise the diastolic blood pressure to 100 mm Hg affects arterial oxygen tension only on room air. However, further elevations to a diastolic pressure of 150 mm Hg reduce the arterial oxygen tension more than 30% of control values. These effects occur both in animals breathing room air and in those breathing 100% oxygen. The results imply that a significant degree of venous admixture occurs in the arterial blood after intracranial pressure elevation.

Cordotomy was performed in eight animals prior to the elevation of intracranial pressure. Cordotomy completely prevented the systemic hypertensive effect of increased intracranial pressure. Cordotomy per se has no effect on arterial oxygen tension (Fig. 1). There was no alteration of arterial pO₂ in these dogs despite equal volumes of intracranial displacement and equivalent elevation in intracranial pressure. Identical results were obtained following alpha adrenergic blockade with phenoxybenzamine. In this latter group, it was necessary to delay initial increase of intracranial pressure for an hour after phenoxybenzamine administration in order to allow the alpha blockade to take effect. Although the blocking agent had a slight effect in itself on raising arterial oxygen tension, no further change was elicited with intracranial hypertension. Adrenalectomy failed to prevent the hypoxemic response as did beta adrenergic blockade with propanolol and vagotomy and atropine. Arterial pCO₂ did not vary significantly in any of the animals.

**Discussion**

We have previously shown that inflation of a balloon within the intracranial cavity has profound effects upon the pulmonary circulation. As pressure is increased, a sequence of events is triggered, consisting of systemic vasoconstriction, transient bradycardia, a positive myocardial inotropic re-

![Fig. 1. Arterial oxygen tensions after increased intracranial pressure with various pretreatment methods, mm Hg. Values expressed represent the mean of all determinations.](image-url)