THE ACHIEVEMENT OF OPTIMAL BRAIN RELAXATION BY
HYPERVENTILATION TECHNICS OF ANESTHESIA

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The problem of the swollen or tight brain is one that has plagued the neurosurgeon since the inception of intracranial surgery. Numerous attempts have been made to offset this condition by hypertonic solutions injected into the blood stream or by a physical approach such as hypothermia. To these technics we wish to add another technic which, in our experience, has proved quite satisfactory. We have used the technic of hyperventilation anesthesia since February 1958 for over 325 patients who have had intracranial procedures for various types of lesions. These lesions have been located both supra- and infratentorially. The application of the technic varies in relationship to the location of the lesion for which the operation is performed.

TECHNICS OF HYPERVENTILATION ANESTHESIA

Preanesthesia medication consists of a belladonna drug only. Opiates are not used on patients with intracranial lesions. To avoid respiratory depression during anesthesia, barbiturates are not administered within 12 hours of the operative procedure. The induction is accomplished with a minimal hypnotic dose of thiopental followed by nitrous oxide, oxygen and ether. Etherization is continued until the pupils of the eyes begin to dilate. At this time, the glottis and carina are cocainized. The gas, oxygen and ether mixture is continued until the cocainization is completely effective. Approximately 2 cc. of succinylycholine are administered and a cuffed endotracheal tube is inserted. Moderate overventilation is used just before the succinylycholine is administered. The same gas-ether mixture is continued immediately after intubation. Just before the patient is positioned for the procedure, the ether is discontinued and a 4-liter flow of nitrous oxide and oxygen (half and half) with 1 per cent halothane is used for maintenance of anesthesia. A muscle relaxant is administered intermittently to prevent the patient’s resistance to changes in ventilatory compliance. Variations in the technic of anesthesia may include halothane and gas for both induction and maintenance of anesthesia; following ether induction, increments of thiopental and a muscle relaxant may be used for maintenance of anesthesia. At this time, the ventilator is introduced into the anesthesia breathing system and the control of respiration is initiated. When the operative procedure involves the posterior fossa, the patient’s respiratory efforts are assisted rather than controlled.

One of several types of ventilators is used, of which the Bird unit seems most satisfactory for either assisted or controlled respirations. The minute-volume respiration is based upon the “Radford Nomogram.” We feel that an increase of 25 to 50 per cent above the rated minute-volume for the patient should produce adequate hyperventilation. The rule of thumb is that when the average patient shows expansion of the chest at the apices, hyperventilation is in effect. When the Bennett or Stephenson type of ventilator is used, plus 15 and minus 5 mm. of mercury pressures are recommended and for each 3-foot length of tubing, 100 cc. are added to the calculated stroke volume to compensate for the ventilatory dead space. When the Bird unit is used, this compensation is unnecessary. The desired effects of hyperventilation anesthesia upon the brain tissue are attained after approximately 45 minutes.

RESULTS

When the effect of hyperventilation has been well established, an unusual depth of the pia-arachnoid space is observed (Fig. 1). The brain is quiet, relaxed and feels rather compliant. If the full effect of hyperventilation has not been achieved, the pia-arachnoid space will not be observed to be enlarged and the consistence of the brain will be friable, resembling that of an infantile brain.
fixed in formalin. Manipulation of the brain at this stage will damage the brain. The superficial cortical vessels appear normal to gross observation. There is no unusual sensitivity of the vessels upon manipulation as indicated by minimal vasospastic response. Approximately 50 to 75 cc. of cerebrospinal fluid can be aspirated from the parachiasmatic cisterns. Lumbar drainage rarely is necessary. Following removal of the cerebrospinal fluid, reduction in the volume of the brain tissue is apparent immediately (Fig. 2).

To prevent the unsupported dura mater from separating from the skull, it is important, at this point, to place tack-up sutures to hold it against the skull. With gentle retraction, the brain tissue is easily displaced to expose the lesion. Fig. 3 shows the visualization of an aneurysm of the anterior communicating artery as exposed through a small Dandy pituitary type of flap. Also visible are the anterior cerebral arteries, the optic nerves and the internal carotid artery with the retracting spatulas in place. Fig. 4 shows the
Fig. 3. The clip is on the stalk of an anterior communicating aneurysm. The right optic nerve, internal carotid artery and A1 and A2 segments of anterior cerebral artery are clearly seen.

same field after removal of the spatulas. With the exception that the brain tends to flow with gravity, the exposure essentially is the same. This is the degree of brain relaxation to be expected as a result of hyperventilation technic. Unexplained postoperative brain edema has been negligible. It has been impossible to accomplish four operative procedures because of a tight brain. Twice this was caused by faulty technic of anesthesia, and twice poor surgical judgment was responsible.

During the peak of hyperventilation anesthesia, intermittent determination of plasma CO₂ revealed a decrease of plasma CO₂ to approximately 30 mm. mercury tension. Continuous monitoring of the end expiratory CO₂ showed an average of 4 per cent. The sodium and potassium levels of both blood and spinal fluid have shown no significant deviation from normal. A slight decrease in blood bicarbonate has been noted.

DISCUSSION

It has been stated that hyperventilation
produces harmful effects, the most undesirable of which is cerebral hypoxia. Hypotension, peripheral vasoconstriction and an increase in fluid acids with the production of a metabolic acidosis, as well as changes in serum electrolytes and a probable loss of plasma water are said to result from hyperventilation. The data leading to these conclusions have been obtained chiefly from subjects who have been actively hyperventilating. To eliminate the factor of work metabolism, Robinson passively hyperventilated both conscious and anesthetized subjects and found minimal changes from normal of the sodium potassium, plasma water and standard bicarbonate, which he considered to be of little clinical significance. The amount of hyperventilation he used was increased approximately 100 per cent over the normal minute volume. Using hyperventilation of 25 to 50 per cent increase over the patient's estimated minute volume, we have achieved optimal reduction in brain mass. The changes of the electrolytes, CO₂, pH and pCO₂ that we have observed have been within normal threshold limits.

Although there is very little reference to this work in the American literature, British writers have published on their observations. Furness has reported favorably on the use of controlled respiration for neurosurgical procedures and emphasized the negative phase of controlled anesthesia respiration. Her report stresses the use of apneic ventilation as an aid in maintaining normal or decreased blood levels of carbon dioxide to minimize cerebral vascular congestion. She stated that the negative phase has "considerable effect on the tension of the brain," feeling that the reduction of intrathoracic venous pressure is reflected in a reduction of cerebral venous pressure. We agree with this concept of venous pressure relationships. However, we have observed that a slight elevation of the head in relation to the mediastinum will provide adequate cerebral venous drainage. To assure this drainage, there must be a zero-mean airway pressure at the end of each expiratory phase as well as an expiratory pause sufficient in length to permit adequate filling of the right atrium. Systemic blood pressure is not affected by the proper utilization of moderate hyperventilation regardless of position. Others have reported the use of controlled respiration in conjunction with hypothermia and/or the intravenous use of hypertonic solution such as sucrose and urea. In our experience it has been unnecessary to supplement our techniques of hyperventilation anesthesia to reduce brain mass. The lack of rebound phenomena has convinced us that adherence to physiological principles has significant advantages over methods that involve chemical dehydration.

Two factors seem to be responsible for the reduction of total brain mass. The first is a reduction in the cross sectional cerebral blood volume through the capillary bed as a result of decreased plasma CO₂. The second factor would seem to be a transfer of fluid from the glial cells to the "Virchow-Robin space," as evidenced by the increased depth of the fluid-filled pia-arachnoid space and the increased density of the brain tissue. The accuracy of this latter assumption is, at present, being investigated.

CONCLUSION

Hyperventilation anesthesia has proved to be a definite aid in reducing total brain mass. This reduction in brain mass has expedited the accomplishment of intracranial surgery with a consequent reduction of trauma caused by retraction and manipulation of the brain. No rebound phenomena have been observed such as are seen when hypertonic solutions are administered intravenously.

REFERENCES


DISCUSSION

Dr. H. J. Savin: We have employed mechanically controlled hyperventilation techniques of anesthesia in our neurosurgical patients for approximately 1 year. We use this method not only for craniotomies in the supine position, but also for posterior fossa and cervical spine procedures in the sitting position, and for protruded lumbar discs for which we use the prone position.

In our early experience with this method, we now know that we used too large a tidal volume with too broad a sweep of inspiratory pressure. The result was evident, particularly in our lumbar-disc patients, in which the extradural veins were seen to fill to excessive fullness and then collapse. This resulted in excessive bleeding during disc operations. The big advantage of the mechanical respirator is that all the factors; tidal volume, rate, phasing, inspiratory positive sweep and expiratory negative sweep can be modified individually. At the present time we use Fludrahan, which necessitates a minimum of muscle relaxants, a respiratory rate of 16, a phasing of 1 to 1.5 inspiratory-expiratory ratio, a sweep of 10 to 12 positive pressure to 8 to 10 negative pressure and an alveolar volume, in a man weighing 175 pounds, of about 500 cc. We have made the following observations: 1) we note a significant decrease in brain bulk in many cases, particularly if cerebral edema is not present; 2) consistent, and almost predictable, lowering of central venous pressure (by central venous pressure we mean the venous pressure as measured from a catheter passed up into the region of the lower superior vena cava or upper atrium); 3) we have noted no adverse clinical effects of decreased pCO2, or suboxgenation of cerebral tissue consequent upon lowered pCO2; and 4) a decrease in postoperative atelectasis and pneumonitis.

The use of controlled ventilation with positive pressure alone has been advocated for neurosurgical patients by some, notably Gallon, who described improved operating conditions. Others hold that as the normal negative inspiratory phase of the thoracic pump is abolished, venous return is impeded and venous pressure in the head becomes elevated. We counteract this abolished thoracic pump action by a 5 degree head-up position and the addition of a negative-pressure phase.

My colleagues in anesthesia, Dr. Howard Terry, Dr. Edward Daw and Dr. John Michenfelder, have demonstrated a rise in central venous pressure and increase in cerebrospinal fluid pressure under circumstances of rapid intermittent positive pressure in patients rendered unable to breathe on their own, and also have demonstrated these increases under conditions of unassisted ventilation in surgical anesthetized patients. The pressure in the central venous area may go up from the 10 to 12 cm. normal to 25 or 30 cm., and the cerebrospinal fluid pressure may rise as high as 90 cm. By properly controlling respirations and adding a negative expiratory phase, these increased pressure states can be rectified to normal or lower. We feel that these changes of venous pressure, and the consequent changes of venous pressure on cerebrospinal fluid pressure are a function of mean airway pressure. Mean airway pressure depends upon phasing, sweep between positive and negative, tidal volume and rate. Increase in mean airway pressure results in increased central venous area pressure to as much as twice normal, while, conversely, central venous pressure can be reduced to as little as half normal by decreasing mean airway pressure.

Whether or not there is a shift of fluid from the brain tissue to the subarachnoid space under well controlled hyperventilation anesthesia, we are not prepared to say. Irrespective of whether or not this shift occurs, there are two factors brought about by this technique which we think are important in lessening brain bulk: 1) a decrease in the patient's pCO2, resulting in vasodilatation of the vessels of the brain, and 2) increased venous drainage from the brain into the central venous area, because of lowered venous pressure in this region. It has been demonstrated that CO2 accumulates in unassisted respiration anesthesia techniques at levels of surgical anesthesia. It has been well established that increased pCO2 leads to vasodilatation of cerebral vessels which means increased brain bulk and increased cerebrospinal pressure.

As concerns the use of this method of anesthesia in posterior fossa surgery, some believe that the patient should breathe on his own so that warning signals of changes in vital signs caused by manipulations near the brain-stem centers are not obliterated. We have taken the line that when such changes as fall in blood pressure and slowing or cessation of respiration occur with the patient breathing on his own, suboxgenation of brain tissue may result with deleterious effects such as edema and coma postoperatively. We currently believe that it is better to maintain by mechanically controlled respirations the proper amount of oxygen and the consistent preferred level of pCO2 throughout the operation, rather than risk these periods of apnea, fall in blood pressure, etc. We do not use a negative expiratory phase when the patient is in the sitting position because of the possible danger of air embolism. Gravity flow in the sitting position achieves the same effect on cerebral venous return as a negative phase does in the prone or supine position. We have used controlled respirations in our last 65 posterior fossa procedures without any regrets on this score.

Dr. Robert G. Fisher: I appreciate this opportunity to congratulate Colonel Hayes and Colonel Slocum on a new advance in the treatment of increased intracranial pressure, still one of our major neurosurgical problems. This method represents a more physiologic means to check pressure at the time of surgery than
by the administration of a cell poison—urea. We have used urea routinely in a large number of cases with few complications (we have started to use this other technique); but always worry about the obvious loading of the body by waste nitrogen. Serious complications from urea have been reported by many centers and we as well as others are convinced that rebound phenomenon does occur with use of urea.

Our recent clinical investigative work seems pertinent and complimentary to this paper.

[Slide] This illustrates work reported at the meeting of the Harvey Cushing Society 2 years ago with more extensive elaboration. There is a normal state of acidosis in the cerebrospinal fluid as contrasted to the arterial blood. The pH is lower and the pCO₂ is higher. In this case, a 24-year-old male attempted suicide by shooting himself in the left frontal region. He was aphasic, had a right hemiparesis and was tube-fed at the time of these studies 7, 18 and 21 days after injury, with a transient ataxemia, despite no urea therapy.

The control studies show that the cerebrospinal fluid is more acid than the serum. The cerebrospinal fluid pCO₂ is considerably higher than that of the serum.

In this particular man the serum pH was very much the same but notice his cerebrospinal fluid pH, 7.122. Several days later the pH was still uncorrected and his pCO₂ was considerably higher, also the serum CO₂ at this particular time was higher. The pH of the serum by this time had dropped a bit. This man eventually recovered. His cerebrospinal fluid pressure was relatively normal within a month's time.

[Slide] This is a case of pseudotumor cerebri. We feel this is fairly well substantiated. This man had papilledema, increased cerebrospinal fluid pressure at 310 mm. of water. This study was done preoperatively with a pH of 7.295 and increased tension in spinal fluid.

Studies made 2, 6 and 11 days postoperatively showed correction of pH and pCO₂. The cerebrospinal fluid pressure dropped after a bilateral subtemporal decompression. The subsequent cerebrospinal fluid pressure was 120 mm. All symptoms and his papilledema have disappeared.

Colonel Hayes has shown that partial respiratory alkalosis aids the surgeon in reducing cerebrospinal fluid pressure. Our work indicates an increased acid medium for the brain occurs after traumatic or surgical insult. One wonders if there is an interrelationship between the two.

I would like to ask Dr. Hayes these questions: 1. Does tetany occur? 2. As a result of hyperventilation, are there more seizures postoperatively? 3. Is this increased arachnoid fluid the same as Courville's so-called "wet brain"?

Dr. Joseph H. Siris: I have had a limited but up to now highly gratifying experience with this technique and I would like to call attention to another area of usefulness that I think is promising and may appeal to all of us. My attention was called to this by a paper appearing in the Acta Psychiatrica et Neurologica Scandinavica (supplement 139, 1939) by a group of Swedish investigators, Lundberg, Kjillquist, and Bied. These gentlemen did not have the extensive experience that Doctors Hayes and Slocum reported upon. I believe their report covered 18 patients.

What was interesting was that some of these patients were treated by this technique outside of the operating room; that is, their symptoms ascribable to increased intracranial pressure were found to abate on hyperventilation.

I would like to ask Colonel Hayes if he has had an opportunity to utilize this particular technique in such conditions outside of the operating room?

Dr. John E. Adams: It is difficult to argue with success. However, we have been interested in this from another standpoint, namely, to measure the oxygen tension of the cerebral cortex directly during hyperventilation under the same circumstances. I will just merely give you these figures and let you think about them.

One finds in the average anesthetized patient, as well as in the awake patient, that the cortical oxygen tension is around 15 to 20 mm. of mercury when the arterial pO₂ and pCO₂ are kept at normal levels. When one produces forced hyperventilation, the oxygen tension of the cortex (as measured by the Liston microelectrode) actually drops down to as low as 1 to 2 mm. of mercury. From a biochemical standpoint this is a level of tissue pO₂ that is inadequate theoretically to support the cytochrome oxidase system in the Krebs cycle. Therefore, I would merely raise the question as to the length of time that it might be safe to utilize this from the standpoint of the oxygen metabolism of the cortex.

Col. George J. Hayes: Before answering the questions, I would like to correct any misapprehension anyone may have. We are not offering these techniques as panaceas for the problem of brain swelling. We are, in essence, trying to make available to you what has been useful to us. We do not feel that we know very much about it. We do not feel that we know the basic reasons why the results observed are attained.

In answer to the questions; at this level of hyperventilation, tetany does not occur. Tetany occurs in people who actively hyperventilate and impose work metabolism and the products of metabolism on top of the hyperventilation; therefore, tetany occurs. Robinson was unable to produce tetany with 100 per cent passive hyperventilation.

We have not seen more seizures using these technics.

I would suspect, but cannot prove, that this is part and parcel of the wet-brain problem, of the shift of fluid from the glial cells to the subarachnoid space. We have now started a basic study and hope, at a later report, to give an answer to the question of whether or not this is true.

In answer to Dr. Siris' question, a number of things mitigated against our use of this technic in the way you remarked upon: (1) availability of respirators, and (2) the availability of competent people to manage them. You cannot take a respirator and slip it into the airway system and say, "Now, all my troubles are over." You must have a competent anesthesiologist who understands his ventilatory physiology well, and who knows your aims, as well as the patient's needs. Thus, these limitations have not let us use these techniques to any extent in such circumstances, although I suspect that what has been reported is accurate.

In answer to Dr. Adams' question, we have not seen any patient that we felt suffered from cerebral anoxia. There is a grave question, apparently, in the minds of the biochemists as to the reliability of the electrode used for measuring oxygen tension. From the clinical side, I would say in operations extending up to 5 hours, we have not had any trouble.