THE ROLE OF ARTIFICIAL HYPERVENTILATION IN THE CONTROL OF BRAIN TENSION DURING NEUROSURGICAL OPERATIONS*

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SUMMARY

The value of artificial hyperventilation during neuro-anaesthesia for the reduction of brain volume and tension has been investigated. Dural tension during operation was significantly lower in hyperventilated patients than in spontaneously breathing patients for every class of pre-operative intracranial condition. Hyperventilation was less effective than osmotic dehydrating agents. Osmotic dehydration and hyperventilation showed a synergistic action in patients with normal or slightly elevated pre-operative intracranial pressure. The regular use of hyperventilation consistently reduced the need for other treatments during operation. Intraventricular cerebrospinal fluid pressure could be reduced, inducing hypocapnia by hyperventilation. Variations in mean airway pressure between 0 and 12 mg Hg had little or no effect on cerebrospinal fluid pressure. With the type of respirator used no unwanted effects were observed even after long periods of hyperventilation.

Pulmonary hyperventilation was first suggested by Gray and Rees (1952) as an adjunct for the maintenance of anaesthesia. Lundberg (1960) and Lundberg, Kjällquist and Bien (1959) clearly demonstrated that hyperventilation can appreciably reduce the increased intracranial pressure in the neurosurgical patient. Hayes and Slocum (1962) stated recently that optimal brain relaxation could be achieved by the use of hyperventilation techniques of anaesthesia.

Since 1959 the authors have used controlled respiration and hyperventilation in anaesthesia for neurosurgery. The present study is intended to illustrate the possibilities of hyperventilation during neurosurgical operations.

Dural tension has been observed in spontaneously breathing patients and has been compared with dural tension observed in patients subjected to artificial hyperventilation and/or treated with osmotic dehydrating agents.

Two experimental schemes have been followed. In the first scheme clinical semi-quantitative data were collected in a large series of patients; the results were then statistically evaluated. In the second scheme quantitative data were obtained in a small series.

SCHEME I

MATERIAL AND METHODS

Four hundred and seventy-two patients were studied. All were subjected to intracranial surgical procedures.

Operations carried out in the sitting position and all posterior fossa explorations were excluded from this study for the following reasons. The prone and sitting position may per se change the intracranial pressure; in most cases of posterior fossa exploration the writers prefer to maintain spontaneous respiration in order to recognize as soon as possible disturbances due to surgical manipulation; both controlled respiration with a negative (subatmospheric) phase and hyperventilation may greatly increase the danger of air embolism during operations in the sitting position (Hunter, 1962).

Premedication consisted in most cases of intramuscular hydroxyzine hydrochloride (100–200 mg) with atropine (0.25 mg) and hyoscine (0.25 mg). Anaesthesia was induced with intravenous thiopentone (usually not more than 250 mg) and was followed by injection of suxamethonium.
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(50–150 mg), or tubocurarine (30 mg) and gallamine (40 mg). Long-acting relaxants were preferred in cases in which artificial pulmonary ventilation or hyperventilation was intended from the outset. Intubation was performed using latex cuffed tubes reinforced with steel or nylon wire. Anaesthesia was maintained using 60 per cent nitrous oxide in oxygen with ether or halothane.

The mean concentrations of these agents used for maintenance were 1.5–2 per cent ether (EMO Inhaler) and 0.25–0.75 per cent halothane (Fluotec vaporizer). At these low concentrations both agents had very little, if any, effect on vital functions; no difference could be detected between cases maintained with ether and those maintained with halothane as far as dural tension, brain volume and cerebrospinal fluid pressure were concerned. It was therefore deemed worthless to divide the groups according to the type of agent used for maintenance.

In the cases in which controlled ventilation was used the same inhalation agents were employed for maintenance. Small supplementary doses of muscle relaxants (tubocurarine 5 mg, gallamine 10–20 mg) were injected during the course of the operation, usually after opening of the skull. Engström ventilators were used. Minute volume was calculated from the Engström-Herzog nomogram (1959). Minute volumes of ventilation varied from the value predicted from the nomogram to twice this value. Beckman, Norlander and Widman (1959) and the writers (unpublished data) have demonstrated that, during maintenance of artificial ventilation with the “normal” minute volume calculated from the Engström-Herzog nomogram, a mild hypocapnia is present in all normometabolic patients with healthy lungs. All artificially ventilated patients were, therefore, considered as “hyperventilated”.

Three different types of treatment were used: artificial hyperventilation, osmotic dehydration, and the combination of both. These were distributed at random in the “treated” group. A sample of spontaneously breathing patients used in a similar previous study was used as a “control” group. Relevant differences in the patient population or in the surgical and anaesthetic techniques between “control” and “treated” groups were ruled out.

The dural tension was evaluated by the surgeons who did not know which type of treatment the patient had received.

The dural tension was classified according to five degrees:

degree 1 indicated a hypotensive dura mater, which was wrinkled and depressed in relation to the bone edges;
degree 2 indicated a normotensive dura, which was slightly convex but pulsating and easily depressible;
degrees 3 and 4 indicated a slightly tense or tense dura which, however, could be opened without difficulty or injury to the underlying cerebral tissue;
degree 5 indicated a hypertensive dura, for the safe opening of which special measures were required to prevent laceration or herniation of the underlying cerebral cortex.

Operations were performed by four different surgical teams. Subjective differences in the evaluation of dural tension were noticed, especially in the classification of intermediate degrees 2 or 3 and 3 or 4 (normotensive or slightly tense dura; slightly tense or tense dura).

The variable “surgical team”, however, was distributed evenly in all groups of control and treated cases. This observer error, therefore, could be neglected as a source of bias in the samples studied.

For statistical evaluation a “mean degree of dural tension” was calculated, using as arbitrary units the same absolute numbers indicating the degree of dural tension. Means were compared by Student’s “t” test and the analysis of variance.

RESULTS

Artificial hyperventilation was carried out in 184 patients. In 81 of these osmotic dehydration methods were used in addition.

Spontaneous breathing was permitted in 288 patients; in 99 of these osmotic dehydration was used.

For the evaluation of results the patients studied were grouped into three classes according to their pre-operative intracranial conditions: class I included patients without space-occupying lesions; class II included patients with space-occupying lesions and normal or moderately
Mean degree of dural tension found at craniotomy in 189 spontaneously breathing patients. No osmotic dehydration treatment had been given.

The actual numbers and statistical results are shown in table I.

Effect of pulmonary hyperventilation on dural tension.

SP = spontaneously breathing patients; HV = hyperventilated patients.

For actual numbers and statistics see table II. Classes of pre-operative intracranial condition as in fig. 1.
increased intracranial pressure; and class III included patients with severely raised intracranial pressure and/or in coma.

It has been previously demonstrated that, when no treatment is given, the degree of dural tension at craniotomy is directly correlated with the presence and severity of the pre-operative intracranial hypertension (Bozza, Maspes and Rossanda, 1961). In figure 1 and table I this type of correlation is fairly evident; untreated cases only are represented, that is to say spontaneously breathing patients not subjected to any treatment designed to reduce the dural tension.

Table I

<table>
<thead>
<tr>
<th>Degree of dural tension</th>
<th>Classes of pre-operative intracranial condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I  4   II  3   III 1</td>
</tr>
<tr>
<td>2</td>
<td>I 31   II 26   III 2</td>
</tr>
<tr>
<td>3</td>
<td>I 17   II 27   III 5</td>
</tr>
<tr>
<td>4</td>
<td>I 8    II 25   III 10</td>
</tr>
<tr>
<td>5</td>
<td>I 0    II 11   III 19</td>
</tr>
</tbody>
</table>

Total no. of cases 60 92 37
Mean degree of dural tension 2.48 3.16 4.19

The differences among the three means are highly significant (P<0.001).

In the statistical analysis of the data of this table and of tables II and III, owing to the evident asymmetry of the distributions and to the heteroscedasticity, it has been necessary to use the distribution-free test given by Kruskall and Wallis (1952).

Table II

<table>
<thead>
<tr>
<th>Degree of dural tension</th>
<th>Classes of pre-operative intracranial condition</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I  SP  HV   II  SP  HV   III  SP  HV</td>
</tr>
<tr>
<td>1</td>
<td>4    4     3    6     1    3</td>
</tr>
<tr>
<td>2</td>
<td>31   13    26   33    2    8</td>
</tr>
<tr>
<td>3</td>
<td>17   4     27   11    5    3</td>
</tr>
<tr>
<td>4</td>
<td>8    1     25   8     10   4</td>
</tr>
<tr>
<td>5</td>
<td>0    0     11   3     19   2</td>
</tr>
</tbody>
</table>

Total no. of cases 60 22 92 61 37 20
Mean degree of dural tension 2.48 2.09 3.16 2.49 4.19 2.70

Difference between means not significant (0.10>P>0.05) highly significant (P<0.001) highly significant (P<0.001)

HV = pulmonary hyperventilation. SP = spontaneous respiration.

Figure 2 shows the effects of artificial pulmonary hyperventilation; the mean degree of dural tension is lower for hyperventilated patients in each class of pre-operative condition. The differences between the mean degree of dural tension become larger with increase in intracranial pressure and reach a high level of statistical significance in classes II and III (table II). This observation seems to imply that hyperventilation may be more useful when the intracranial hypertension is more severe.

Osmotic dehydrating agents, such as hypertonic urea, sucrose or sorbitol, appear to be more effective than hyperventilation alone in reducing brain volume and tension (fig. 3 and table III). The difference, however, between the mean degree of dural tension in hyperventilated patients and in spontaneously breathing patients receiving osmotic dehydrating agents does not reach the level of statistical significance in any of the three classes (table III).

In classes I and II of pre-operative condition the simultaneous use of osmotic dehydrating agents and of hyperventilation caused a further lowering of the mean degree of dural tension (fig. 4 and table III). The difference between the mean degree of dural tension in the group of patients treated with osmotic dehydrating agents only and the mean tension in the group of patients in which both dehydrating agents and pulmonary hyperventilation were used (columns OSM/SP and OSM/HV) is significant at the P=0.05 level in class I and is highly significant in class II; in class III the same difference is...
ARTIFICIAL HYPERVENTILATION IN THE CONTROL OF BRAIN TENSION

CLASSES OF PREOPERATIVE INTRACRANIAL CONDITION

MEAN DEGREE OF DURAL TENSION

Comparison between effectiveness of hyperventilation and osmotic dehydrating agents (hypertonic urea, sucrose or sorbitol) on reducing dural tension.

OSM/SP=spontaneously breathing patients treated with osmotic dehydrating agents. For actual numbers and statistics see table III. Classes of pre-operative intracranial condition as in fig. 1.

TABLE III

Distribution of dural tensions of cases represented in figures 3 and 4.

Comparison between effects on dural tension of hyperventilation alone (HV) in 113 patients, with osmotic dehydration agents (OSM SP) in 99 patients, and with hyperventilation combined with osmotic dehydration therapy (OSM HV) in 81 patients.

<table>
<thead>
<tr>
<th>Degree of dural tension</th>
<th>HV</th>
<th>OSM SP</th>
<th>OSM HV</th>
<th>HV</th>
<th>OSM SP</th>
<th>OSM HV</th>
<th>HV</th>
<th>OSM SP</th>
<th>OSM HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>10</td>
<td>16</td>
<td>6</td>
<td>17</td>
<td>25</td>
<td>3</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>13</td>
<td>10</td>
<td>1</td>
<td>33</td>
<td>21</td>
<td>13</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>11</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Total no. of cases</td>
<td>22</td>
<td>23</td>
<td>19</td>
<td>61</td>
<td>55</td>
<td>41</td>
<td>20</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Mean degree of dural tension</td>
<td>2.09</td>
<td>1.74</td>
<td>1.31</td>
<td>2.49</td>
<td>2.13</td>
<td>1.49</td>
<td>2.70</td>
<td>2.28</td>
<td>2.38</td>
</tr>
</tbody>
</table>

Difference between means

- not significant (0.20>P>0.10)
- not significant (0.10>P>0.05)
- not significant (0.30>P>0.20)

significant (P=0.05)
highly significant (0.01>P>0.001)
not significant (0.10>P>0.05)

slightly over the P=0.05 level of statistical significance (see table III). It is emphasized that class III only includes patients with very high preoperative intracranial pressure.

No convincing correlation could be shown between the different absolute levels of hyperventilation and the degree of dural tension, although the data in table IV suggest that, within the range of minute volumes of 9-16 l./min the higher ventilation rates were associated with the lower degrees of dural tension (fig. 5). It must be pointed out that only a small number of patients had been treated with the higher ventilation volumes and moreover that only absolute
CLASSES OF PREOPERATIVE INTRACRANIAL CONDITION

Combined effect of osmotic dehydrating agents and hyperventilation (OSM/HV). For actual numbers and statistics see table III. Classes of pre-operative intracranial condition is in fig. 1.

TABLE IV
Distribution of dural tensions of cases represented in figure 5.

<table>
<thead>
<tr>
<th>Degree of dural tension</th>
<th>Spontaneous respiration</th>
<th>Artificial ventilation minute volume (l./min)</th>
<th>Mean degree of dural tension</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;10</td>
<td>11-12</td>
<td>&gt;13</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>3</td>
<td>27</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>25</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>11</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Total no. of cases</td>
<td>92</td>
<td>39</td>
<td>25</td>
</tr>
<tr>
<td>Mean degree of dural tension</td>
<td>3.16</td>
<td>2.67</td>
<td>2.28</td>
</tr>
</tbody>
</table>

Analysis of variance for the four means: P<0.001.
Analysis of variance for the three means of HV: 0.20>P>0.10.
Difference between means for spontaneous respiration and "less than 10 l./min"; 0.02>P>0.01.
Difference between means for "less than 10 l./min" and "more than 10 l./min"; 0.10>P>0.05.

The different volumes of ventilation were given at random to the cases studied. All classes of pre-operative intracranial condition are represented. Forty-four patients were of pre-operative class II, 15 of class I, and 14 of class III. Numbers representing dural tensions of cases of classes I and III have been corrected in order to obtain a homogeneous group; as in the control cases the numbers representing the averages of dural tension for the three classes differ from each other roughly by 1, one point was added to all cases of class I and one point was subtracted from those of class III.

MEAN DEGREE OF DURAL TENSION

Effect on dural tension of different minute volumes of artificial ventilation in 165 patients, 92 of whom breathed spontaneously. For actual numbers, distribution of cases in the three classes of pre-operative condition and statistics, see table IV.
ventilation values were considered: this might explain the uncertainty of statistical results. The effect of different levels of minute volume relative to the body weight of the patients is now under investigation. It is interesting to note, however, that even the low degree of hyperventilation of the cases represented in the second column (minute volume of 10 l./min or less) is associated with a significant reduction of dural tension. Hyperventilation was useful in a number of cases even when it was begun after the dura mater was already exposed.

In over 60 per cent of spontaneously breathing patients other treatments were necessary to improve surgical conditions while they were required in about 40 per cent of hyperventilated patients.

SCHEME II

MATERIAL AND METHODS

In six patients the intraventricular and/or spinal pressures were measured directly during anaesthesia and operation by means of a strain gauge pressure transducer and recorded on a direct-writing Sanborn Polyrecorder. The mean airway pressure was measured by a manometer on the Engström respirator and was recorded on the same apparatus. The expired carbon dioxide concentration was simultaneously measured by means of an infra-red analyzer (Godart "Capnograf") and recorded by means of a direct-writing recorder (Godart "Omniscriptor"). Unfortunately the Sanborn recorder and the carbon dioxide recorder could not be adjusted to run at exactly the same speed.

The anaesthetic and respiratory managements were the same as for the first scheme. In this group one posterior fossa operation was included.

In a previous investigation (Bozza Marrubini and Invernici, 1962, unpublished data) it had been demonstrated that, during artificial ventilation with the Engström respirator in anaesthetized patients with normal lungs, the arterial-alveolar difference in carbon dioxide tension was negligible.

In these patients, however, the accuracy of the capnometric data was checked at least once during the experiment by estimation of the carbon dioxide tension in arterial blood directly and/or with the rebreathing method of Campbell and Howell (1960) and Sykes (1960).

RESULTS

The more relevant observations made in the six cases are shown in table V and may be summarized as follows:

(a) The cerebrospinal fluid pressure and the expired carbon dioxide tension were closely related in most cases; this was well shown in a spontaneously breathing patient operated on for a posterior fossa meningioma. Each time the expired carbon dioxide tension was artificially elevated a peak of pressure could be observed in the cerebrospinal fluid record (case B.D.; table V, fig. 6). In figure 7 the actual record of the second peak is reproduced.
### Table V

*Details of cases discussed in Scheme II.*

<table>
<thead>
<tr>
<th>Case</th>
<th>Site of CSF pressure measurement</th>
<th>Position of patient on operating table</th>
<th>Starting level of CFS pressure (mm Hg)</th>
<th>Type of change induced</th>
<th>End-tidal CO₂ change (mm Hg)</th>
<th>Maximal CSF pressure change (absolute level and difference in mm Hg)</th>
<th>Time interval between (4) and (6) (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.L. Anterior cerebral artery aneurysm</td>
<td>Spinal subarachnoid space</td>
<td>Supine</td>
<td>12</td>
<td>Respiratory minute volume from 10 to 20 l/min. Mean airway pressure from 2.5 to 8 cm H₂O</td>
<td>From 40 to 21</td>
<td>8 (-4 or -35%)</td>
<td>10</td>
</tr>
<tr>
<td>(Fig. 10)</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>30% urea 12 g. in 15 min</td>
<td></td>
<td>From 21 to 28</td>
<td>11 (+2 or +21%)</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>30% urea 12 g. in 3 min</td>
<td></td>
<td>From 25 to 33</td>
<td>16 (+8 or +100%)</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Bone trephining and sawing, Resp. min. vol. from 10 to 20 l/min. Mean airway pressure from 2.5 to 6 cm H₂O</td>
<td></td>
<td></td>
<td></td>
<td>From 30 to 15</td>
<td>19 (+12 or +170%)</td>
<td>19</td>
</tr>
<tr>
<td>B.D. Sigmoid sinus meningioma (Figs. 6 and 7)</td>
<td>Right ventricle</td>
<td>Sitting</td>
<td>-16</td>
<td>Rebreathing 1 min 30 sec in 2 l. bag filled with O₂</td>
<td>From 35 to 40</td>
<td>-12 (+4 or +25%)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-12</td>
<td>Back to non-rebreathing anæsthesia system</td>
<td>From 40 to 35</td>
<td>-15 (-3 or -25%)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-13</td>
<td>Rebreathing 20 sec in 2 l. bag filled with 5% CO₂ in O₂</td>
<td>From 35 to 44</td>
<td>-8 (+5 or +38%)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-8</td>
<td>Back to non-rebreathing anæsthesia system</td>
<td>From 44 to 37</td>
<td>-14 (-6 or -75%)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-11</td>
<td>Rebreathing 1 min 30 sec in 2 l. bag filled with O₂</td>
<td>From 22 to 42</td>
<td>-3 (+8 or +73%)</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-3</td>
<td>Back to non-rebreathing anæsthesia system</td>
<td>From 42 to 24</td>
<td>-11 (-8 or -270%)</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-9</td>
<td>Rebreathing 20 sec in a 1 l. bag filled with 5% CO₂ in O₂</td>
<td>From 23 to 38</td>
<td>-5 (+4 or +44%)</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-5</td>
<td>Back to non-rebreathing anæsthesia system</td>
<td>From 38</td>
<td>-9 (-4 or -44%)</td>
<td>1</td>
</tr>
<tr>
<td>Condition</td>
<td>Position</td>
<td>Position</td>
<td>Change</td>
<td>Change</td>
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<td>-----------------------------------------------</td>
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<td>------------------------------------------------------------------------</td>
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<tr>
<td>Z.A. Anterior cerebral artery aneurysm</td>
<td>Spinal</td>
<td>Supine</td>
<td>From spontaneous breathing to artificial hyperventilation, 20 l/min (mean airway pressure 6 cm H2O)</td>
<td>From 40 to 19 (-1 or -6%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>From 20 l. resp. minute volume to 10 l. Mean airway pressure from 6 to 2 cm H2O</td>
<td>From 17 to 28 (no change)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fig. 11)</td>
<td></td>
<td></td>
<td>Resp. minute volume from 10 to 20 l. Mean airway pressure from 2 to 5 cm H2O</td>
<td>From 30 to 20 (-2 or -13%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fig. 12)</td>
<td></td>
<td></td>
<td>Mean airway pressure from 2 to 5.5 cm H2O; no change in ventilation</td>
<td>No change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fig. 12)</td>
<td></td>
<td></td>
<td>Mean airway pressure from 5.5 to 0.5 cm H2O; no change in ventilation</td>
<td>No change</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P.E. Left temporal metastasis (Fig. 8)</td>
<td>Right</td>
<td>Supine</td>
<td>From spontaneous to artificial hyperventilation 10 (14 minutes) and 20 (5 minutes) l. of minute volume. Mean airway pressure between 1 and 4 cm H2O respectively</td>
<td>From 41 to 21 (-16 or -50%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Resp. minute volume from 20 to 10 l. Mean airway pressure from 4 to 0.3 cm H2O</td>
<td>From 20 to 30 (+2 or +12.5%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bone trephining and sawing. Resp. minute vol. from 10 to 20 l. Mean airway pressure from 0.3 to 4 cm H2O</td>
<td>From 30 to 15 Peaks to 33 and 36. Mean 29 (+11 or +61%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M.A. Cerebral angioma (Fig. 9)</td>
<td>Lateral</td>
<td>Supine tilted head up</td>
<td>From spontaneous to artificial hyperventilation 10 (14 minutes) and 20 (5 minutes) l. of minute volume. Mean airway pressure between 1 and 4 cm H2O respectively</td>
<td>From 21 to 28.5 (+5.5 or +69%)</td>
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<td>30% urea 80 g in 18 minutes; artificial respiration, constant minute volume 14 l.</td>
<td>From 21 to 28.5 (+5.5 or +69%)</td>
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<td>End of urea infusion.</td>
<td>From 28.5 to 22 (-8.5 or -63%)</td>
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<td>T.A. Hydrocephalus</td>
<td>Lateral ventricle and spinal subarachnoid space</td>
<td>Supine (ventricle)</td>
<td>From spontaneous respiration to artificial ventilation 8 l./min volume</td>
<td>From 50 to 30 (-4 or -21%) (ventricle)*</td>
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*Closely parallel changes observed at spinal level.*
(b) Hyperventilation induced an appreciable fall of the cerebrospinal fluid pressure in about 50 per cent of the trials. The fall was greater when the starting level of cerebrospinal fluid pressure was high (fig. 8) and varied from a few mm Hg to a maximum of 16 mm Hg. The effect of hyperventilation was more evident when the theca was closed; the induction of general anaesthesia, laryngoscopy and tracheal intubation as well as the surgical manoeuvres on the bone flap (especially the use of trephine and Gigli saw) induced sustained elevations of the intracranial pressure which could sometimes be partially corrected by hyperventilation (cases B.L. and P.E.). The rapid infusion of hypertonic urea, during which a puzzling elevation of the expired carbon dioxide tension was observed, was followed by a broad elevation of the cerebrospinal fluid pressure tracing (cases M.A. and B.L.; figs. 9 and 10).

(c) No consistent relationship could be found between the mean airway pressure and the cerebrospinal fluid pressure. With the Engström ventilator the mean airway pressure remained usually within a very low range even despite very high minute volumes of ventilation. The hypotensive effect of hyperventilation on cerebrospinal fluid pressure seemed to exceed the possible hypertensive effect of slight elevations of the airway pressure (cases P.E., Z.A., B.L.; figs. 8 and 11). Even when ventilation and the expired carbon dioxide level were maintained constant and the airway pressure was modified, withdrawing the Venturi effect during expiration or substituting with a moderate positive pressure, no clear relation between airway pressure and cerebro-
Female, P.E. Left temporal metastasis. Supine position. The induction of anaesthesia, the tracheal intubation and the first surgical manoeuvres are followed by very wide fluctuations in intraventricular cerebrospinal fluid pressure. At the beginning of artificial ventilation cerebrospinal fluid pressure is six times higher than the pre-anaesthetic level. Hyperventilation is followed by a dramatic fall in pressure. Note that the wide variations in airway pressure have no apparent effect on cerebrospinal fluid pressure while bone trephining and sawing are followed by a great increase of pressure.

spinal fluid pressure could be seen (case Z.A.; fig. 12).

**DISCUSSION**

The effects of hyperventilation have been widely studied to ascertain the potential dangers as well as the advantages during general anaesthesia. Cerebral hypoxia, metabolic acidosis and electrolyte imbalance have been regarded as potentially harmful results of hypocapnia by many authors (Allen and Morris, 1962; Clutton-Brock, 1957; Papadopoulos and Keats, 1959; Brown et al., 1949).

On the other hand, Robinson and Gray (1961) and Ingvar (1963) demonstrated that there is little evidence for the hypothesis that hyperventilation can produce cerebral hypoxia through uncontrolled constriction of cerebral vessels, while Brown and colleagues (1959), Cutter and King (1961), Robinson (1961) and Markello, Cutter and King (1963) observed that biochemical and metabolic changes were of little clinical significance and spontaneously reversible.

An increase in cerebrovascular resistance and a reduction of cerebral blood flow are, however, well-known effects of hypocapnia (Sokoloff, 1960). During general anaesthesia with hyperventilation these changes can be of sufficient magnitude to influence the exchange of anaesthetics between the blood and the nervous tissue (Guy et al., 1959) and to reduce intracranial hypertension (Lundberg, Kjällquist and Bien, 1959; Lundberg, 1960).

As far as concerns anaesthesia for neurosurgery the latter observation is of the greatest value.
Female, M.A. Cerebral angioma. Supine position. Ventilation was controlled from the beginning of anaesthesia. Hyperventilation is followed by a fall in expired carbon dioxide tension. Intraventricular pressure, already low, does not change. During the infusion of 80 g of 30 per cent urea in about 20 minutes an increase in expired carbon dioxide tension and cerebrospinal fluid pressure is observed. Note that during this period ventilation, as well as arterial pressure, was absolutely constant.

**Fig. 9**

Male B.L. Anterior cerebral artery aneurysm. Moderate hypothermia. Upper record: intraventricular cerebrospinal fluid pressure. Lower record: expired carbon dioxide in vol. per cent. 12 g of 30 per cent urea was infused in less than 5 minutes (between 9.01 and 9.05). During this time a parallel rise in intraventricular pressure and expired carbon dioxide tension is observed.
ARTIFICIAL HYPERVENTILATION IN THE CONTROL OF BRAIN TENSION

FIG. 11

Upper record: airway pressure. Middle record: intraventricular cerebrospinal fluid pressure.
Lower record: expired carbon dioxide in vol. per cent.
At the arrow the minute volume delivered by the Engström ventilator is doubled. Cerebrospinal fluid pressure falls in parallel with the expired carbon dioxide tension in spite of the sharp increase in airway pressure.
Fig. 12
Same case as fig. 11.
The airway pressure is increased from 2 to 6 mm Hg (first arrow) and then reduced to about zero (second arrow) by modifying the pressure on the Engström ventilator during the expiratory phase. Ventilation is kept constant. Also in this case cerebrospinal fluid pressure is unaffected by airway pressure.
the cerebrospinal fluid pressure of normal dogs, probably because the decrease in intracranial blood volume due to hypocapnia was compensated by a proportional increase in cerebrospinal fluid volume. On the other hand, the effect of hyperventilation was striking in the subjects with space-occupying lesions and increased intracranial pressure (classes II and III), so that the indications for the other means usually employed to reduce brain tension, such as the osmotic dehydrating agents or cerebrospinal fluid drainage, were greatly reduced. This difference in effect in class I compared with classes II and III may be explained in two ways. Lundberg, Kjällquist and Bien (1959) state that, as a rule, changes in cerebrospinal fluid pressure which follow cerebral blood flow variations are of greater amplitude at high than at low intracranial pressures; they think that the compensatory changes that damp changes in cerebrospinal fluid pressure, when the intracranial pressure is normal or low, may be blocked or severely impaired when the intracranial pressure is high.

Compensatory changes usually occur to counteract a shift from normality, and some sort of compensation may be expected to occur when the intracranial pressure is artificially reduced below the original "normal" value; but no compensatory change should occur when a pathological condition, such as intracranial hypertension is corrected. It must be pointed out here that all the animals of Rosomoff (1963) and Ueyama and Loehning (1963) had normal initial levels of intracranial pressure. Another explanation for the greater effect of hyperventilation in the subjects with higher intracranial pressure may be found in the fact that such patients may develop a respiratory depression under general anaesthesia more frequently than those with a normal intracranial condition. Hyperventilation should be useful, therefore, as postulated by Rosomoff (1963), only in the presence of hypocapnia. Similar conclusions have been reached by Schmidt (1963) who has measured in man the changes in cerebrospinal fluid pressure induced by premedication, by general anaesthesia and by neurosurgery.

Hyperventilation was only slightly less effective than osmotic dehydrating agents and could be associated with advantage with this treatment when an actual retraction of the nervous tissue was needed.

It must be pointed out that this study gives clear evidence that even a very mild degree of respiratory alkalosis was sufficient to obtain a significant reduction of dural tension and brain volume; on the other hand, very high minute volumes did not appreciably improve the effect. This means that a useful effect on dural tension is obtained with mild hyperventilation so that the potential harmful effects of prolonged and extreme hypocapnia can be avoided.

In the postoperative phase no evidence of cerebral hypoxia or metabolic alteration imputable with certainty to hyperventilation could be detected. No harmful effects on circulation and acid-base regulation were observed even when very high minute-volumes were delivered or after many hours of hyperventilation. During operation arterial pressure was well maintained and no sign of impaired venous return to the heart was observed. Cerebrospinal fluid pressure appeared to be much more closely correlated with the level of ventilation and carbon dioxide tension than with the mean airway pressure. This observation agrees with the clinical experience of Hunter (1960) and Schmidt (1963) and would cast some doubt on the importance of the negative phase during artificial ventilation in neurosurgery, which has been strongly emphasized by many authors for controlled ventilation in neuro-anesthesia (Furness, 1957; Gallo, 1959; Deligné and David, 1960; Martin et al., 1960; Wertheimer et al., 1960; Stern and Bethune, 1961).

It is, however, believed that the absence of unwanted effects on arterial, venous and cerebrospinal fluid pressure must be attributed at least in part to the excellent performance of the mechanical ventilator used, which could deliver very high minute-volume without inducing great and sustained rises in mean intrathoracic pressure.

It is difficult to explain the rise observed in expired carbon dioxide concentration by the authors and by Ueyama and Loehning (1963), despite constant ventilation during urea infusion. An absolute increase in plasma volume (Alexander,
Eaton and Freedman, 1961) and severe electrolyte shifts (Bering and Avman, 1960) have been observed after rapid urea infusion in the experimental animal, but up to date no data are available which indicate a relationship between these or other effects of urea infusion and the observed increase in expired carbon dioxide concentration. Further discussion on this point would, therefore, be merely speculative and outside the scope of this work.

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REFERENCES


ARTIFICIAL HYPERVENTILATION IN THE CONTROL OF BRAIN TENSION


LE ROLE DE L'HYPERVENTILATION ARTIFICIELLE POUR LE CONTROLE DE LA TENSION CEREBRALE PENDANT LES INTERVENTIONS NEURO-CHIRURGICALES

SOMMAIRE

Etude de la valeur de l'hyperventilation artificielle pendant la neuro-anesthésie pour la réduction du volume et de la tension cérébrale. Pendant l'opération la tension durale était nettement plus basse chez les malades hyperventilés que chez les malades respirant spontanément pour n'importe quel groupe de conditions intra-crâniennes pré-opératoires. L'hyperventilation était moins efficace que les agents de déshydratation osmotique. La déshydratation osmotique et l'hyperventilation agissaient synergiquement chez les malades dont la pression intra-crânienne était normale ou peu élevée avant l'opération. L'emploi systématique de l'hyperventilation a diminué nettement les indications des traitements complémentaires intra-opératoires. La pression intra-ventriculaire du liquide céphalo-rachidien a pu être réduite par induction d'une hypocapnie au moyen de l'hyperventilation. La pression existant dans les voies respiratoires principales variant entre 0 et 12 mm Hg n'avait que peu ou pas d'effet sur la pression intraventriculaire. Avec le type d'appareil respiratoire que nous avons utilisé nous n'avons pas observé d'effets indésirables même pas après hyperventilation prolongée.

DIE ROLLE DER KUNSTLICHEN HYPERVENTILATION BEI DER KONTROLLE DES HIRNDRUCKES WAHREND NEUROCHIRURGISCHER EINGRIFFE

ZUSAMMENFASSUNG