CONTROLLED VENTILATION FOR CEREBRAL ANGIOGRAPHY

BY

S. H. DALLAS AND C. P. MOXON

SUMMARY

Various techniques of general anaesthesia were studied in sixty patients undergoing cerebral angiography to determine the separate influences of arterial carbon dioxide tension, controlled ventilation and trichloroethylene upon the quality of the films obtained. A low carbon dioxide tension and controlled ventilation both increased the probability of high quality films. The use of trichloroethylene did not appear to affect film quality. Anaesthesia for cerebral angiography is discussed and it is concluded that moderate hyperventilation under nitrous oxide and tubocurarine anaesthesia resulted in high quality films with the greatest diagnostic value.

Cerebral angiography is performed by the injection of radiopaque contrast medium into the internal carotid or vertebral arteries following direct puncture of the common carotid artery or catheterization of the vertebral artery via one of the femoral arteries. Direct puncture of the carotid arteries may be performed under local analgesia although general anaesthesia is always preferred for vertebral angiography (Davis and Statham, 1962).

In this Centre, general anaesthesia with the patients spontaneously breathing nitrous oxide, oxygen and trichloroethylene was the method preferred for all cerebral angiography in patients of all ages. Local analgesia was only used for the occasional emergency case.

A number of children were anaesthetized by the technique of curarization and controlled ventilation with nitrous oxide and oxygen recommended by Rees (1965) and in these the general standard of film quality was observed to be markedly better than that obtained when spontaneous ventilation was used. Adults were therefore anaesthetized with the same technique and an impression of improved film quality was again obtained. An investigation was therefore undertaken to confirm whether this impression was valid and to try to standardize a technique for obtaining optimum conditions for radiologically demonstrating intracranial pathology.

Sixty patients (35 male, 25 female—average age 41 years—including 4 children under 10 years) were included in the study; 38 had unilateral carotid angiograms, 19 had bilateral carotid angiograms and there were 5 vertebral angiograms.

METHOD

Premedication consisted of atropine 0.6 mg injected intramuscularly half an hour before induction of anaesthesia.

When breathing was to be spontaneous, anaesthesia was induced with thiopentone and followed by suxamethonium. The larynx was sprayed with 4 per cent lignocaine solution and the trachea was intubated with a plain nylon reinforced latex endotracheal tube. Anaesthesia was maintained with nitrous oxide, oxygen and trichloroethylene, supplemented with intravenous pethidine if tachypnoea or straining occurred.

When it was intended to control pulmonary ventilation, anaesthesia was induced with thiopentone and muscle relaxation was obtained by means of tubocurarine. The trachea was intubated with a cuffed nylon reinforced latex endotracheal tube after full relaxation had developed and ventilation was controlled using a pressure-limited, volume-cycled Manley ventilator (Manley, 1961) aiming at a minute volume of about 30 per cent greater than that derived from the Radford nomogram. Anaesthesia was maintained with nitrous oxide and oxygen in the proportions of 2:1 and incremental doses of tubocurarine were given as necessary.

judged clinically necessary. Curarization was reversed at the end of the procedure with atropine and neostigmine.

Sixteen patients (27 per cent), aged 23–76 years (average 46), breathed spontaneously and in 44 patients (73 per cent), age 2–67 years (average 40 years) ventilation was controlled.

After cannulation or catheterization of the artery concerned, the contrast medium was injected rapidly and a series of six lateral films was taken in sequence with a hand film changer. The contrast medium used for all cases in this investigation was Urografin (Schering). The films were taken over a period of about 6 seconds and in this time two arterial, one capillary and two or three venous films were usually obtained. With controlled ventilation the series was found to need 7–8 seconds, and two to four arterial, one capillary and one to three venous films were obtained. A second injection of contrast medium was given to enable a series of three anteroposterior films to be taken over the same time interval resulting in one film of each of the arterial, capillary and venous phases. Further injections of contrast medium were given for a series of oblique or special views to be taken as necessary. A film series therefore consists of three or six films taken during one injection of contrast medium. In each patient two or more film series are taken in the course of one cerebral angiogram.

In 31 patients the ventilation pattern was changed after completion of the original investigation. When a steady state had been reached further film series were taken for comparison under the new conditions. Five of the spontaneously breathing patients were hyperventilated by the technique of assisted manual ventilation using the semiclosed Magill circuit. At the moment of injection of the contrast medium the expiratory valve was released and the patient allowed to resume spontaneous respiration. This procedure enabled a number of films to be obtained of patients breathing spontaneously at a low arterial carbon dioxide tension. Two and a half or 5 per cent carbon dioxide was added to the fresh gas flow in 14 of the mechanically ventilated patients, and in a further 12 patients deliberate hyperventilation at a minute volume of up to 15 l./min was practised.

The allocation of patients to the spontaneous or controlled ventilation groups was randomized, irrespective of the suspected intracranial pathology. Hyperventilation was not, however, used in patients with raised intracranial pressure or in whom gross vasoconstriction secondary to a recent subarachnoid haemorrhage was suspected.

As there was an arterial cannula in situ throughout the procedure, arterial blood samples could be taken at any stage for blood-gas analysis without further arterial puncture. \( P_aO_2 \), pH and standard bicarbonate were measured using the Astrup interpolation technique (Siggaard-Andersen et al., 1960) on arterial blood samples thus obtained before the first injection of Urografin and after the last injection. Further samples were analyzed if there were any change of ventilation during the procedure. It was thus possible to ascertain the blood-gas state during each film series. Arterial blood samples were immediately placed in a refrigerator at 4°C and analyzed within 1 hour. Heart rate and brachial blood pressure (using an oscillotonometer) were also monitored throughout. The duration of each film series was recorded in order to assess the speed of the cerebral circulation.

The films obtained were later reviewed by one of us (C.P.M.) without prior knowledge of the technique of anaesthesia used or of the arterial carbon dioxide level at the time the films were taken. The films were assessed according to the sharpness of detail of large arteries, the presence and clarity of small arteries and veins and the definition of aneurysms and tumours, and placed in one of three categories, namely "poor", "adequate" or "good".

**RESULTS**

Two hundred and thirty-six film series were obtained from 60 patients. Comparison of the quality of the films with the patient's arterial carbon dioxide tension at the time the film series was taken confirmed the clinical impression of the beneficial influence of a low carbon dioxide tension (table I). Irrespective of the technique of anaesthesia, the lower the arterial carbon dioxide tension the greater the probability of high quality film series being obtained with increased sharpness of detail of large arteries, greater clarity of small arteries and veins, and improved definition of intracranial pathology.
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Separate consideration of the 59 film series obtained from 16 patients breathing spontaneously (table II) and the 143 film series obtained from 44 patients who were anaesthetized with nitrous oxide, oxygen and tubocurarine only (table III) confirmed the previous finding that within the limits of carbon dioxide tension observed, the lower the value the higher was the probability of high quality films being obtained.

### Table I
**Relationship between the quality of the film series obtained (236 series in 60 patients) and the arterial carbon dioxide level, for all techniques.**

<table>
<thead>
<tr>
<th>Number of film series in each category at PaCO₂</th>
<th>&gt;45 mm Hg</th>
<th>45–35 mm Hg</th>
<th>35–25 mm Hg</th>
<th>&lt;25 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>15</td>
<td>7</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Adequate</td>
<td>34</td>
<td>15</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>10</td>
<td>10</td>
<td>85</td>
<td>35</td>
</tr>
</tbody>
</table>

χ² = 97.7863; P < 0.0005

### Table II
**Relationship between the quality of the film series obtained (59 series in 16 patients) and the arterial carbon dioxide level in patients spontaneously breathing nitrous oxide, oxygen and trichloroethylene.**

<table>
<thead>
<tr>
<th>Number of film series in each category at PaCO₂</th>
<th>&gt;45 mm Hg</th>
<th>45–35 mm Hg</th>
<th>35–25 mm Hg</th>
<th>&lt;25 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>12</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Adequate</td>
<td>23</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>0</td>
</tr>
</tbody>
</table>

χ² = 36.594; P < 0.001

### Table III
**Relationship between the quality of the film series obtained (143 series in 44 patients) and the arterial carbon dioxide level in patients under nitrous oxide and tubocurarine anaesthesia with controlled ventilation.**

<table>
<thead>
<tr>
<th>Number of film series in each category at PaCO₂</th>
<th>&gt;45 mm Hg</th>
<th>45–35 mm Hg</th>
<th>35–25 mm Hg</th>
<th>&lt;25 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Adequate</td>
<td>2</td>
<td>3</td>
<td>23</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>0</td>
<td>3</td>
<td>73</td>
<td>35</td>
</tr>
</tbody>
</table>

χ² = 36.44; P < 0.0005

### Table IV
**Relationship between the quality of the film series obtained (34 series in 14 patients) and the arterial carbon dioxide level in patients under nitrous oxide and tubocurarine anaesthesia, hyperventilated with added carbon dioxide.**

<table>
<thead>
<tr>
<th>Number of film series in each category at PaCO₂</th>
<th>&gt;45 mm Hg</th>
<th>45–35 mm Hg</th>
<th>35–25 mm Hg</th>
<th>&lt;25 mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Adequate</td>
<td>10</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Good</td>
<td>9</td>
<td>3</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

χ² = 7.1596; P < 0.05

### Table V
**Relationship between the quality of the film series obtained and the technique of anaesthesia at high arterial carbon dioxide levels (over 45 mm Hg).**

<table>
<thead>
<tr>
<th>Method</th>
<th>PaCO₂ (mm Hg)</th>
<th>Poor</th>
<th>Adequate</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled ventilation with and without added carbon dioxide (24 series in 8 patients)</td>
<td>Mean PaCO₂ ± SE</td>
<td>54.7 ± 7.6</td>
<td>57.3 ± 8.6</td>
<td></td>
</tr>
<tr>
<td>Spontaneous ventilation with trichloroethylene (36 series in 10 patients)</td>
<td>Poor</td>
<td>3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Adequate</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>9</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

χ² = 12.304; P < 0.001

### Table VI
**Relationship between the quality of the film series obtained and the technique of anaesthesia at normal arterial carbon dioxide levels (35–45 mm Hg).**

<table>
<thead>
<tr>
<th>Method</th>
<th>PaCO₂ (mm Hg)</th>
<th>Poor</th>
<th>Adequate</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled ventilation with and without added carbon dioxide (15 series in 9 patients)</td>
<td>Poor</td>
<td>2</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Spontaneous ventilation with trichloroethylene (16 series in 7 patients)</td>
<td>Adequate</td>
<td>7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>6</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

χ² = 2.3212; P > 0.15; i.e. no significant difference in techniques.
Thirty-four film series were obtained from the 14 patients in whom carbon dioxide was added to the fresh gas flow (table IV). These again show that high quality films are likely with low carbon dioxide tensions but a comparison of the quality of the films obtained at a carbon dioxide tension of over 45 mm Hg (table V) showed a greater proportion of good quality films in the patients who were being hyperventilated and given carbon dioxide. This could only be due to the mechanical effect of the ventilation on the central venous return as there was no significant difference in their $P_{\text{aCO}_2}$ distribution from those patients breathing trichloroethylene. That this is not due to the trichloroethylene is indicated by a comparison of the film quality in patients being ventilated with those breathing spontaneously at normal carbon dioxide tensions (35–45 mm Hg) (table VI). There was no significant difference in the distribution of the categories of the films taken in conditions producing normocarbia, irrespective of anaesthetic technique.

In adults breathing spontaneously and having a carbon dioxide tension of over 45 mm Hg, all the contrast medium had passed through the cerebral vascular bed in 5–6 seconds. This would appear to be due to dilatation of the cerebral arteries combined with an increase in cerebral blood flow produced by a normal or moderately raised blood pressure. This rapid flow resulted in dilution of the contrast medium giving fainter, less well defined angiograms and a rapid “wash-out” of the cerebral veins.

Controlled ventilation such that the carbon dioxide tension fell to 30–35 mm Hg caused the cerebral vessels to contract and resulted in sharp pictures with a cerebral circulation time of 7–8 seconds. Arterial pressure was not affected by the degree of ventilation needed to produce a fall in carbon dioxide tension of this order.

Hyperventilation such that the carbon dioxide tension fell to 20–30 mm Hg did not further affect the film quality, or further decrease the calibre of the cerebral vessels, but it was associated with prolongation of the cerebral circulation time to 10–15 seconds. This enabled more films to be taken of the arterial or venous phases, so demonstrating differential filling of tumour vessels more effectively or pin-pointing more accurately the origin of supply of aneurysms or angiomata. The increase in cerebral circulation time is presumably accounted for by a reduction in cardiac output following passive mechanical hyperventilation. The cardiac output and stroke volume of the heart have linear relationships to the arterial carbon dioxide tension (stroke volume = 0.669 $P_{\text{aCO}_2}$ + 35.8) (Prys-Roberts et al., 1967) and, at a carbon dioxide tension of 20–30 mm Hg, this resulted in an average fall in blood pressure of 15–20 mm Hg.

Raised intracranial pressure further prolonged the circulation time in all those cases in which this was present and extreme hyperventilation was not used in 6 cases with severe papilloedema. The older patients and those with cerebral arteriosclerosis showed less evidence of vasoconstriction and less slowing of the cerebral circulation, despite low carbon dioxide tensions.

Hyperventilation in the 4 young children was found to be particularly valuable as children normally have a very rapid cerebral circulation and the hyperventilation technique slowed the cerebral circulation substantially, enabling small lesions to be demonstrated which might otherwise have been missed.

**DISCUSSION**

Whilst the films obtained when angiography is performed under local analgesia are better than those obtained with general anaesthesia with spontaneous ventilation, the procedure is particularly distressing for young patients. In addition, movement of the head by patients unable to co-operate may produce a blurred radiographic image and so a missed diagnosis. General anaesthesia with spontaneous ventilation has been recommended for cerebral angiography (Geddes, 1952; Stark, 1958; Hunter, 1964) but the fact that local analgesia is still widely used might imply that, unless there is an inadequate anaesthetic service, the quality of the films thus obtained is judged superior. The quality of the films obtained varied throughout this study due to variations in radiological technique and the general physical status of the patient, e.g., age, local pathology, intracranial pressure, etc., as well as the anaesthetic technique used. Nevertheless, despite these random variations, the influences of the anaesthetic technique could be delineated.
In general terms the films obtained under general anaesthesia with controlled ventilation were better than those previously obtained at this Centre under local analgesia, and of a very much higher quality than those obtained under general anaesthesia with spontaneous ventilation. No measurement of arterial carbon dioxide tension was made on patients having angiograms under local analgesia because these only occurred as emergencies. No patient undergoing angiography under local analgesia could, therefore, be included in the study.

Halothane has not been used for angiography at this Centre for the past two years at the specific request of the radiologists as it was found that arterial puncture was often difficult and in some cases impossible. This was attributed to undue relaxation of the arterial wall by the halothane. Lewis and Moore (1968) also consider halothane to be an unsuitable agent for use in cerebral angiography especially in patients with cerebrovascular lesions, because of the marked decrease in systolic blood pressure associated with this technique. They recommend local analgesia for patients in whom a cerebrovascular lesion is suspected.

Edmonds-Seal, du Boulay and Bostick (1967) in their study initially found no significant correlation between arterial carbon dioxide tension and the quality of the films but, as their patients were being ventilated with halothane with tubocurarine relaxation, and because this combination is likely to disturb cardiac output significantly, the mechanical effects of controlled ventilation were likely to predominate. However, they later found that the carbon dioxide level did influence their results.

Grange, Hawkins and Samuel (1967) recommend lowering the arterial carbon dioxide tension to enhance the definition of intracranial tumour vessels. This enhancement is postulated as a result of the differential sensitivity of normal and abnormal cerebral vessels to the carbon dioxide tension. At a low tension normal vessels constrict more than abnormal vessels and there is thus a relatively greater flow through the abnormal vessels which will therefore contain a greater proportion of the contrast medium injected. By the same reasoning patients with a recent cerebrovascular accident and associated local vascular spasm might be expected to benefit from a lowered carbon dioxide tension provided that there is no lowering of the systolic blood pressure. The constriction of the vessels in the undamaged areas of the brain should result in improved perfusion of the areas supplied by the vessels in spasm. The Cambridge team (Samuel, Grange and Hawkins, 1968) do not agree with this and confine their use of hyperventilation to those patients with suspected intracranial tumours. Gliomas are demonstrated by the differential vasoconstriction described above, whereas meningiomas are selectively perfused by an increase in the flow through the external carotid artery resulting from the reduced flow through the internal carotid artery.

It seems, therefore, that moderate hyperventilation producing an arterial carbon dioxide tension of 30–35 mm Hg is never contraindicated in cerebral angiography and will result in high quality films in the majority of cases. This technique has been of great value in demonstrating intracranial lesions. We believe that pathology is less certainly shown, or even missed, on poor films resulting from a high carbon dioxide tension due to spontaneous ventilation.

The technique of curarization and hyperventilation with nitrous oxide and oxygen resulting in a fall in systolic blood pressure and slowing of the circulation has also proved of value in the procedure of arch aortography. In this procedure a catheter is introduced into the aorta via a femoral artery so that its tip lies in the ascending aorta. Injection of contrast medium then enables the vessels arising from the arch of the aorta to be visualized and the presence or absence of atheromatous plaques to be determined. Even with an automatic film changer taking not less than three films a second, only fleeting visualization of the arteries is often obtained when the patient is breathing spontaneously. Hyperventilation at a minute volume of 15 l./min slows the circulation so that a greater number of useful films is obtained in any given film series.

**ACKNOWLEDGEMENTS**

We wish to thank Dr. P. J. Tomlin of the Department of Anaesthesia, University of Birmingham, for advice and statistical analysis and Miss J. M. Stock, B.Sc., of the Department of Pathology, The Midland Centre for Neurosurgery and Neurology, for blood-gas analyses.
REFERENCES


KONTROLLIERTE VENTILATION FÜR DIE ZEREBRALE ANGIOGRAPHIE

ZUSAMMENFASSUNG

Bei 60 Patienten, die sich einer zerebralen Angiographie zu unterziehen hatten, wurden verschiedene Methoden der Narkose untersucht, um die jeweiligen Einflüsse von arterieller Kohlendioxyd-Spannung, kontrollierter Ventilation und Trichlorathylen auf die Qualität der erhaltenen angiographischen Filme zu bestimmen. Sowohl die geringe Kohlendioxyd-Spannung als auch die kontrollierte Ventilation vergrößerten die Wahrscheinlichkeit, Filme von besseren Qualität zu erhalten. Durch die Anwendung von Trichlorathylen schien die Qualität der Filme nicht beeinflußt zu werden. Die Anästhesie für die zerebrale Angiographie wird diskutiert, und es wird festgestellt, daß sich bei mäßiger Hyperventilation unter Lachgas-und Tubocaritina-Narkose Filme von höherer Qualität und größtem diagnostischen Wert erzielen lassen.

MIDLAND SOCIETY OF ANAESTHETISTS

Programme for 1969-70

OCTOBER 15 (Wednesday) 7.30 p.m. at Warwick Hospital. Communication between Industry and the Medical Profession: Professor J. S. Robinson (Cape Engineering); J. F. Richards (Bayer Pharmaceuticals).

JANUARY 20 (Tuesday) 7.30 p.m. at East Birmingham Hospital. Registrar's Papers.

MARCH 18 (Wednesday) 7.30 p.m. at Good Hope Hospital. "Hot Air Night."

JUNE 13 (Saturday) at Hereford Hospital. Annual All-day Meeting. Detailed programme to be announced.