VENOUS BLOOD AS AN ALTERNATIVE TO ARTERIAL BLOOD FOR THE MEASUREMENT OF CARBON DIOXIDE TENSIONS

BY

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SUMMARY

Simultaneous venous and arterial blood samples were taken under varying conditions during anaesthesia and operation, and their carbon dioxide tensions were measured. From the results of 146 pairs of samples it was found that it is possible to obtain "arterialized" venous blood from the back of the hand, the carbon dioxide tension of which was the same as or very close to that of arterial blood taken at the same time. Some of the conditions needed for this arterialization were determined and observations made on certain of the factors which may impair this.

Measurement of the carbon dioxide tension of arterial blood is of great use in the diagnosis and treatment of many respiratory disorders arising in the operating theatre and wards. In addition, any investigation requiring a detailed assessment of respiratory function is incomplete without this knowledge.

Some anaesthetists are reluctant to do arterial punctures because of the fear of complications. While we have had difficulty in tracing any specific reports, there remains in the minds of many anaesthetists an ethical objection to the performance of such a procedure purely for the purposes of research.

The literature contains many descriptions of indirect methods of measuring arterial carbon dioxide tensions using either expired air or blood from sites other than arteries. An approximation of the mixed venous and hence the arterial carbon dioxide tension (by subtraction of 6 mm Hg) can be obtained from a rebreathed and equilibrated gas sample collected according to the method of Campbell and Howell (1960). Rapid infra-red analysis of expired air will give the arterial carbon dioxide tension, provided the ventilation-perfusion ratio of the lungs is not disturbed. The use of capillary blood has become very common since Astrup introduced his micro-method of analysis in 1958, and comparisons of carbon dioxide tensions of capillary with arterial blood have been reported by a number of observers (Siggard Andersen et al., 1960; Cooper and Smith, 1961; Gambino, 1961; Knudsen and Hansen, 1962). The number of samples compared has been small, but it would seem from the results that the carbon dioxide tension of capillary blood is near enough to the arterial tension for clinical purposes, capillary blood from the ear being better than that from the finger. However, the measurements are likely to be unreliable if there is an upset of the autonomic nervous system, which may not be clinically detectable (Cooper and Smith, 1961). For research purposes the scatter of individual samples is very wide. In addition, capillary blood can only be analyzed by a micro-method. If the method of analysis requires larger samples (for example, by the Severinghaus electrode) arterial or venous blood must be used.

The carbon dioxide tension of venous blood varies with the metabolism of the tissues from which it comes, and the rate of blood flow through them. Veins on the back of the hand are usually chosen for the collection of "arterialized" blood. These veins drain tissues of low metabolism (chiefly skin and bone), and are easily dilated by warmth to increase the rate of blood flow through the hand. These two factors will decrease the difference between venous and arterial carbon dioxide tensions.

The first reference to the use of venous blood was in 1923. Dautrebande, Davies and Meakins measured the carbon dioxide content of blood...
taken from the median basilic vein in four experiments, and found a close correlation with that of arterial blood if the hand was immersed in hot water. In 1925 Goldschmidt and Light, using venous blood obtained from the back of a warm hand, also found a close correlation between arterial and venous carbon dioxide content.

There have been only a few reports in which the tension, as distinct from the content, of carbon dioxide has been compared in venous and arterial blood (Brooks and Wynn, 1959; Cooper and Smith, 1961; Paine, Boutwell and Soleff, 1961; Searcy, Gordon and Simms, 1963; Bergman, Coleman and Nunn, 1963). Again the number of samples was small and the conditions of sampling varied: Brooks and Wynn compared samples from heated and unheated hands both in the wards and theatre; Cooper and Smith used anaesthetized patients but without any warming, whilst Paine and his colleagues applied constrictions at the elbow and wrist before sampling. Searcy and his colleagues compared arterial and venous carbon dioxide tensions in only four cases, and the veins used were the superior and inferior venae cavae, whilst Bergman, Coleman and Nunn took five samples of venous blood and compared the carbon dioxide tension with that of arterial blood taken on another occasion. The mean differences between venous and arterial carbon dioxide tensions directly compared were as great as 8.6 mm Hg in some of these reports.

Our own investigation was undertaken to determine whether venous blood, sampled under carefully controlled conditions, was an acceptable alternative to arterial blood for the measurement of carbon dioxide tensions. Venous blood was chosen in preference to capillary blood because we wished to use the Severinghaus electrode.

METHOD

Thirteen patients were studied of whom ten were undergoing neurosurgical and two abdominal operations, while one patient was receiving artificial pulmonary ventilation on the ward 48 hours after craniotomy.

Of the patients operated on, eleven were given routine premedication. Anaesthesia was induced with thiopentone and a relaxant (tubocurarine for the neurosurgical cases and gallamine for abdominal surgery). After intubation, anaesthesia was maintained with nitrous oxide and oxygen, and pulmonary ventilation was controlled. The other patient breathed spontaneously with halothane, nitrous oxide and oxygen, from a circle system; induction and intubation was carried out with thiopentone and suxamethonium.

The ward patient was a boy who had stopped breathing prior to craniotomy for a cerebral abscess. He was able to breathe spontaneously for short periods but ventilation was easily controlled without the need for relaxants.

Sampling procedure.

This was similar in all cases. An indwelling Cournand needle was inserted into the radial artery after induction of anaesthesia. A Guest cannula with a stilette was used for the collection of venous blood except for a few samples which were obtained from the forearm by intermittent venepuncture. The cannula was placed in a vein on the back of the same hand as that used for the arterial needle. No constricting bands were allowed on the sampling arm, which was placed in such a position that there was no venous obstruction. The temperature of the back of the hand was measured by means of a thermocouple. In the operating theatre, body temperature was measured by a lead in the oesophagus or nasopharynx, and in the ward by a clinical thermometer in the axilla. After use the thermocouples were calibrated against a mercury thermometer.

The venous sample was always taken first, because it was found difficult under some of the sampling conditions to obtain a free flow in the vein. As soon as a reasonable venous sample was obtained an arterial sample was taken, in most cases within 30 seconds. A reasonable sample was regarded as one of at least 2 ml in volume, withdrawn without any air bubbles entering the syringe.

When arterialization of the venous blood was desired, the hand was wrapped in an electric warming pad which had a maximum temperature of 60 °C. The thermocouple was insulated from the pad by a layer of foam plastic.

Venous samples were taken from the back of the hand as follows:

1. At the beginning of the anaesthetic with the hand cold, (i) with venous obstruction, (ii) without venous obstruction.
(2) During anaesthesia: (a) with the hand cold, (i) with venous obstruction, (ii) without venous obstruction; (b) with the hand at body temperature, (i) with venous obstruction, (ii) without venous obstruction.

In addition a few samples were taken from sites other than the back of the hand.

Samples were taken into 2-ml syringes lubricated with silicone. The deadspaces of the syringes were filled with heparin solution of a strength of 1,000 units per ml. The nozzles of the syringes were capped with soldered needle hubs. After sampling, the syringes were stored in an ice-and-water mixture. Samples were analyzed up to 3½ hours after withdrawal. Preliminary studies showed that the carbon dioxide tension did not alter significantly when the blood was kept in this way for up to 4½ hours. The carbon dioxide tensions of the samples were measured using a Severinghaus electrode (Severinghaus and Bradley, 1958) maintained at 38°C and calibrated against two mixtures of carbon dioxide and oxygen of known composition. The method used and the precautions observed were those described by Lunn and Mapleson (1963). No corrections have been made for body temperature as only a comparison between similarly treated samples of arterial and venous blood was required.

To estimate the experimental error of the sampling and analysis procedure, a series of samples was taken in rapid succession from a single blood vessel. The samples were analyzed in the usual way, interspersed with other samples drawn during the course of the same operation.

The standard deviations about the means of the individual observations in three such series were 0.8, 0.85, and 0.53 per cent. The average standard deviation was 0.73 per cent of the mean. Therefore, in the main results a deviation of more than 1.5 per cent (twice the SD of the mean) of the venous carbon dioxide tension from that of arterial blood may be regarded as statistically significant. This means that, at an arterial carbon dioxide tension of 40 mm Hg, a measured difference of ±0.6 mm Hg in the venous sample will be significant.

RESULTS

One hundred and forty-six pairs of samples were taken from the thirteen patients. Figure 1 shows a comparison of the carbon dioxide tensions in all the paired venous and arterial samples. Although the venous and arterial carbon dioxide tensions are very close in some instances, in others the discrepancies are great. Figures 2-4 illustrate the conditions under which these variations occur. Figure 2 compares forty-eight paired samples taken from eleven patients. In some, the hand was cold and venous obstruction was produced, in others the hand was cold without venous obstruction, whilst in a third group, the hand was warmed to body temperature but venous obstruction was produced before sampling. The differences between venous and arterial carbon dioxide tensions are shown in table I. The smallest differences in these forty-eight paired samples were in those taken at the beginning of anaesthesia with the hand below body temperature but without venous obstruction; this is presumably due to initial peripheral vasodilatation accompanying the induction of anaesthesia.
Venous and arterial carbon dioxide tensions in 48 paired samples from 11 patients, where sampling conditions were not ideal.

Venous and arterial carbon dioxide tensions in samples taken from a patient undergoing hypothermia with induced hypotension. (Arfonad = trimetaphan.)

Venous and arterial carbon dioxide tensions in samples taken from 5 patients at the end of operation.

Venous and arterial carbon dioxide tension in 51 paired samples taken from 11 patients, where sampling conditions were ideal. The middle line indicates where the points would lie if the venous and arterial tensions were identical; the other two lines indicate the limits of the deviations which can be attributed to experimental error (see text).
VENOUS BLOOD AS AN ALTERNATIVE TO ARTERIAL BLOOD

TABLE I
The differences between venous and arterial carbon dioxide tension, when sampling conditions were not ideal.

<table>
<thead>
<tr>
<th>Venous minus arterial (carbon dioxide tension) (mm Hg)</th>
<th>Number of pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>0.5</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5 or more</td>
<td>4</td>
</tr>
</tbody>
</table>

Table II shows the differences between the paired samples.

<table>
<thead>
<tr>
<th>Venous minus arterial (carbon dioxide tension) (mm Hg)</th>
<th>Number of pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>26</td>
</tr>
<tr>
<td>0.5</td>
<td>14</td>
</tr>
<tr>
<td>1.0</td>
<td>5</td>
</tr>
<tr>
<td>1.5</td>
<td>4</td>
</tr>
<tr>
<td>2.0</td>
<td>2</td>
</tr>
<tr>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>51</td>
</tr>
</tbody>
</table>

Mean difference = 1.3 per cent or 0.5 mm at 40 mm SD 1.8 per cent or 0.7 mm at 40 mm.

Figure 3 shows the results obtained in a woman aged 42, undergoing craniotomy with hypothermia and induced hypotension. At the beginning of the operation, while trimetaphan was being given, the venous and arterial carbon dioxide tensions were very close, but later, when trimetaphan administration was stopped and haemorrhage was considerable, discrepancies were great despite warming of the hand and lack of venous obstruction. In these circumstances (hypothermia and haemorrhage) there is a peripheral venous stasis which would affect flow in the veins in the same way as a local constricting band.

Figure 4 compares the arterialized venous, and arterial, carbon dioxide tensions in eight pairs from five patients taken at the end of operation just before and after the re-establishment of spontaneous respiration. These are the only pairs in which the venous carbon dioxide tension was lower than that of the arterial. This was probably due to the fact that the arterialized venous sample was taken before its corresponding arterial sample at a time when the arterial carbon dioxide tension was rising rapidly.

Figure 5 shows the results obtained with fifty-one pairs of samples taken under ideal conditions from eleven patients. The venous samples were taken from a warm hand without stasis and without any obvious difficulties. The mean difference between the arterial and the venous tension was 1.3 per cent of the arterial tension (or 0.5 mm Hg at 40 mm Hg) with a standard deviation of 1.8 per cent (0.7 mm Hg at 40 mm Hg). Table II shows the differences between the paired samples.

It will be noted that there was no venous-arterial difference greater than 2 mm Hg.

In one patient only the arterial carbon dioxide tension was below 20 mm Hg. In eight venous samples taken from this patient without stasis and with the hand at body temperature the carbon dioxide tensions were greater than the arterial by 1–2 mm Hg, i.e., a difference of up to 12 per cent at this level of carbon dioxide tension. At the end of the operation when the arterial tension rose to 28 mm Hg the venous sample was identical with the arterial although sampling conditions were unaltered. This might be explained by the extreme hypocarbia, causing peripheral constriction unaffected by warmth.

CONCLUSIONS AND RECOMMENDATIONS
These results show that if venous blood is taken under certain specified conditions, its carbon dioxide tension will be identical with or near enough to that of the arterial blood for clinical and most experimental purposes. These conditions are as follows:

1. The venous blood must be taken from the back of the hand.
2. The hand must be warmed to at least body temperature.
3. There must be no stasis or obstruction to the flow of blood in the vein before or during sampling.

These are firm and, we feel, irrefutable conditions which must be strictly adhered to if venous blood is to be substituted for arterial blood. In addition, we would add the recommendations that the car-


bon dioxide tension must not be below 20 mm Hg (fig. 1) and that the peripheral circulation must not be impaired (fig. 3). Admittedly these two recommendations are based on one patient each, and cannot be regarded as proven, but the results in these two patients certainly suggest that discrepancies between arterial and venous blood will be very great if these two conditions are not fulfilled.

ACKNOWLEDGMENTS

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REFERENCES


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LE SANG VEINEUX POUR REMPLACER LE SANG ARTERIEL DANS LA MESURE DES TENSIONS DU CO₂

SOMMAIRE

Des prises de sang veineux et artériel ont été faites simultanément dans diverses conditions au cours d'anesthésies et d'interventions, et on a mesuré leur tension en CO₂. D'après les résultats de 146 paires d'échantillons, on a trouvé qu'il était possible d'obtenir du sang veineux "arterialisé" au niveau du dos de la main, dont la teneur en CO₂ était la même, ou très voisine, de celle du sang artériel prélevé au même moment. On a déterminé certaines des conditions nécessaires pour cette arterialisation et fait des observations sur certains des facteurs qui peuvent l'altérer.

VENÖSES BLUT ALS EINE ALTERNATIVE ZUM ARTERIELLEN BLUT FÜR DIE BESTIMMUNG DER KOHLENSTOFFDIOXYDSPANNUNGEN

ZUSAMMENFASSUNG