THE USE OF VENTILATORS AND VAPORIZER PERFORMANCE

BY

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SUMMARY

The percentage concentration output v/v of a Fluotec Mark II vaporizer was measured whilst being used in conjunction with different ventilators. At the same time pressure changes within the vaporizing chamber were measured. In two of the ventilator systems, namely the Manley and the Barnet, high levels of pressurization were found in the vaporizing chamber and the percentage concentration output of the vaporizer was less than that expected from the dial setting.

The effect of intermittent positive pressure on the output of a vaporizer in a dosed circle system (the vaporizer being outside the circle) has been shown by Hill and Lowe (1962). Using a Bird ventilator and a fresh gas flow of 0.5 l./min through the Fluotec Mark II vaporizer it was found that the percentage concentration output (v/v) of the vaporizer was greater than that expected from the dial setting. The explanation put forward for this is that during the inspiratory phase of respiration the pressure in the system increases and the outflow from the vaporizing chamber is impeded, allowing a build-up of fresh gas to occur. During the expiratory phase, when pressure in the system falls, this additional gas, having picked up halothane vapour, is released into the bypass stream. The result is that the mean fresh gas flow through the vaporizing chamber is increased with a consequent increase in the percentage vapour concentration output.

By maintaining a continuous pressure inside the vaporizing chamber, by means of a needle valve placed distal to the vaporizer, Hill and Lowe (1962) showed that the effect of these pressure fluctuations on percentage concentration output could to a large extent be reduced. Edmondson and Hill (1962) made use of this principle in the design of a pressurizing valve for the Fluotec Mark II vaporizer in order to eliminate this problem. From these results it is obvious that pressure changes occurring within the vaporizing chamber are important in determining the output of the vaporizer.

Measurements were made of the pressure changes occurring in a Fluotec Mark II vaporizer whilst employing different ventilator systems, together with changes in the percentage concentration output from that expected. Both fluctuations in pressure and the range of pressure over which these occurred were measured.

METHOD

The Barnet, Manley and Blease P.11 ventilators were employed in conjunction with a Fluotec Mark II vaporizer not fitted with a pressurizing valve. The circuit was arranged as in figure 1. Fresh gas from a standard Boyle apparatus flowed to the vaporizer and on to the ventilator. A pressure tapping was placed just distal to the vaporizer outlet for, as shown by Hill and Lowe (1962), pressure changes at this point follow accurately changes in the vaporizing chamber. Gas samples were taken from the inspiratory limb of the ventilator (it being assumed that adequate mixing would have already occurred) and halothane concentration was measured using a Hook and Tucker ultraviolet halothane meter. Airway pressure changes were measured by means of a water manometer and a pressure tapping in the catheter mount.

Before the main investigation was carried out the halothane meter was first used to ensure that under steady flow conditions of 8 l./min the actual percentage concentration output of the vaporizer agreed with the output expected at any given setting of the dial. It was also confirmed...
that pressure changes recorded distal to the vaporizer outlet agreed with those occurring within the vaporizing chamber which were measured by a water manometer connected to the drain on the underpart of the vaporizer.

The ventilator system was then set up and under varied conditions the actual percentage concentration output of the vaporizer (sampled from the inspiratory limb of the ventilator) was measured over the range of its available dial settings. At the same time, pressure changes in the vaporizing chamber were measured via the lead just distal to the outlet of the vaporizer.

The investigation was repeated in order to determine the effect of change in gas flow through the system and of change in respiratory rate. The effect of change in compliance of the model lung was also determined; this consisted of a reservoir bag the compliance of which could be altered by appropriate adjustment of the weight (fig. 1).

Airway pressure was measured in all cases from the lead connected to the catheter mount on the bag.

In the case of the Barnet ventilator the effect of changing the inspiratory-expiratory ratio was also investigated.

Using a continuous gas flow of 8 l./min the mean pressure within the vaporizing chamber of a Mark II vaporizer was gradually increased by varying the resistance to outflow from the vaporizer by means of a screw clip. The percentage concentration output was then measured and related to the mean pressure within the vaporizing chamber.

**RESULTS**

*Barnet.*

Table I shows the actual percentage concentration output with any given dial setting under varying conditions of compliance of the model lung (columns 2 and 3) and flow rate (column 4).

<table>
<thead>
<tr>
<th>Table I: Percentage vapor concentration output.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airway pressure (cm H₂O)</td>
</tr>
<tr>
<td>Flow (l./min)</td>
</tr>
<tr>
<td>Vaporizer setting (%)</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Pressure fluctuations within vaporizing chamber (cm H₂O)</td>
</tr>
</tbody>
</table>

Respiratory rate constant at 12 b.p.m. The inspiratory-expiratory ratio is constant at 1.5:3.5. The decrease in output concentration of halothane from a Fluotec Mk. II vaporizer is seen when employing a Barnet ventilator. The effect of decrease in compliance of the system is shown (col. 3) and the effect of increase of flow rate through the system (col. 4).
TABLE II
Effect on pressure in vaporizing chamber of varying the inspiratory-expiratory ratio (I-E) of Barnet ventilator.

<table>
<thead>
<tr>
<th>Flow rate (l./min)</th>
<th>Pressure fluctuation (cm H₂O)</th>
<th>I-E</th>
<th>Airway pressure (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>insp.</td>
<td>exp.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>54</td>
<td>1:4</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>50</td>
<td>1:5:3.5</td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>42</td>
<td>2.5:2.5</td>
</tr>
</tbody>
</table>

Effect of changing flow rate on vaporizer chamber pressure; compliance constant and respiratory rate 12 b.p.m.

<table>
<thead>
<tr>
<th>Flow rate (l./min)</th>
<th>Pressure fluctuation (cm H₂O)</th>
<th>I-E</th>
<th>Airway pressure (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>insp.</td>
<td>exp.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>20</td>
<td>50</td>
<td>1:5:3.5</td>
</tr>
<tr>
<td>10</td>
<td>28</td>
<td>60</td>
<td>1:5:3.5</td>
</tr>
<tr>
<td>12</td>
<td>40</td>
<td>75</td>
<td>1:5:3.5</td>
</tr>
</tbody>
</table>

Effect of changing compliance on chamber pressure (respiratory rate 12 b.p.m.)

<table>
<thead>
<tr>
<th>Flow rate (l./min)</th>
<th>Pressure fluctuation (cm H₂O)</th>
<th>I-E</th>
<th>Airway pressure (cm H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>insp.</td>
<td>exp.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>42</td>
<td>1:5:3.5</td>
</tr>
<tr>
<td>8</td>
<td>26</td>
<td>60</td>
<td>1:5:3.5</td>
</tr>
<tr>
<td>8</td>
<td>42</td>
<td>78</td>
<td>1:5:3.5</td>
</tr>
</tbody>
</table>

In each column is also recorded the pressure changes occurring in the vaporizing chamber and it can be seen that there is quite a marked degree of pressurization of the chamber which increases with reduction in compliance and with increase of flow rate through the system.

The actual percentage concentration output of the vaporizer using this system is shown to be lower in all cases than that expected from the dial setting. When an increase in pressurization of the chamber occurs due to reduction of compliance or increase in flow rate the vaporizer output is lowered even further.

Table II shows the pressure changes occurring in the vaporizing chamber under various working conditions of the Barnet ventilator. It can be seen that changes in the inspiratory-expiratory ratio produce little change in the pressure fluctuations and at the same time it was found that these changes produced no obvious variation in percentage concentration output of the vaporizer. It should be noted that the pressure in the vaporizing chamber is maximum during the expiratory phase of the ventilator and minimum in the inspiratory phase.

Manley.

With this ventilator a much higher degree of pressurization of the vaporizing chamber is seen than in the case of the Barnet. For example, using a gas flow of 8 l./min and an airway pressure of 10 cm H₂O the pressure in the vaporizing chamber was 115 cm H₂O during the inspiratory phase and 95 cm H₂O during the expiratory phase. As shown in table III, the actual percentage concentration output for any dial setting of the vaporizer is lower than that obtained with the Barnet. Increase of flow produced only small changes of pressure in the vaporizing chamber and had no obvious effect on vaporizer output. Change in compliance of the model lung with corresponding increase in airway pressure in contrast to the Barnet had no effect on the concentration output of the vaporizer.
TABLE III

Showing the decrease in percentage output concentration of halothane from a Fluotec Mk. II vaporizer when employing a Manley ventilator.

<table>
<thead>
<tr>
<th>Percentage setting on vaporizer</th>
<th>Percentage vapour concentration output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>1.0</td>
<td>0.6</td>
</tr>
<tr>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>3.0</td>
<td>2.5</td>
</tr>
<tr>
<td>4.0</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Flow rate was maintained constant at 8 l./min. The pressure in the vaporizing chamber was 115 cm H₂O during inspiration and 95 cm H₂O during expiration.

Blease P.11.

Much smaller pressure changes in the vaporizing chamber were obtained when using this ventilator. Using a flow of 8 l./min, with an airway pressure of 20 cm H₂O, the maximum pressure recorded in the vaporizing chamber was 14 cm H₂O during the inspiratory phase falling to 10 cm H₂O during expiration. No changes in chamber pressure were recorded on altering the flow rate or compliance of the model lung and the percentage concentration output of the vaporizer was in all cases that expected from the dial setting.

Effect of pressurisation of the vaporizing chamber on percentage concentration output.

The effect of increasing the mean pressure within the vaporizing chamber on percentage concentration output of the vaporizer using a continuous fresh gas flow of 8 l./min is seen in Table IV. For any given dial setting an increase of mean pressure within the vaporizing chamber resulted in a fall of the percentage concentration output of the vaporizer.

DISCUSSION

Increase of mean pressure within the vaporizing chamber as shown in Table IV caused a reduction in the percentage concentration output of the vaporizer. In order to try to explain this it is more profitable to discuss the problem in terms of the number of molecules of halothane passing to the patient per unit volume of carrier gas.

Figure 2 depicts a vaporizer receiving a flow of carrier gas at the rate of 4 l./min, the dial setting being such that there is a flow of 100 ml/min through the vaporizing chamber containing halothane. Let us imagine that the pressure inside the vaporizer is P mm Hg and the temperature remains constant. The number of molecules of halothane that each 100 ml of carrier gas pick up is dependent on the number of molecules of halothane vapour contained in the vaporizing chamber. This in turn depends on the saturated vapour pressure of the halothane and is constant for any given temperature. Let each 100 ml of carrier gas passing through the chamber pick up n molecules of halothane which will eventually mix with the remainder of the carrier gas. Every 100 ml of gas now passing to the patient will contain n × (100/4000) molecules of halothane.

Figure 3 shows the same vaporizer receiving a fresh gas flow of 4 l./min as before, but the pressure in the system has now been increased to P + p mm Hg by means of a resistance placed distal to the vaporizer (point A in figure 3). The number of molecules of halothane vapour in the

<table>
<thead>
<tr>
<th>Percentage setting on vaporizer</th>
<th>Percentage vapour concentration output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>1.0</td>
<td>0.9</td>
</tr>
<tr>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>4.0</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Chamber pressure (cm H₂O)

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A Fluotec vaporizer is shown diagrammatically. A fresh gas flow of 4000 ml/min is passing to the vaporizer and the pressure within the vaporizer is $P$ mm Hg. The dial setting is such that 3900 ml/min flow through the bypass and 100 ml/min flow through the vaporizing chamber. It is assumed that the saturated vapour pressure of the halothane is such that each 100 ml of carrier gas pick up $n$ molecules of halothane. Distal to the vaporizer every 4000 ml of carrier gas passing to the patient will now contain $n$ molecules of halothane.

This depicts a similar arrangement to that shown in figure 2 except that now a resistance to outflow from the vaporizer has been placed at the point A. The effect of this is to increase the pressure on the vaporizer side of the resistance from $P$ mm Hg to $P + p$ mm Hg (B). The volume of fresh gas flow to the vaporizer again is 4000 ml/min, and divided into a flow of 3900 ml/min through the bypass and a flow of 100 ml/min through the vaporizing chamber. Despite the increase in pressure within the vaporizing chamber to $P + p$ mm Hg, each 100 ml of gas flowing each minute through the chambers will still pick up $n$ molecules of halothane. Distal to the resistance, however, at point (C) the pressure now falls to $P$ mm Hg and each 4000 ml of carrier gas flowing per minute now expands to $4000 \times \frac{(P + p)}{P}$ ml. This latter volume and not 4000 ml now contains $n$ molecules of halothane which has thus undergone a proportionate reduction in its molecular concentration.
vaporizing chamber remains constant despite the increase in total pressure because the saturated vapour pressure does not change as long as the temperature remains constant. Every 100 ml of carrier gas now passing through the chamber will still pick up \( n \) molecules of halothane. Proximal to the resistance (point B) where the pressure is \( P + p \) mm Hg every 100 ml of gas will contain \( n \times (100/4003) \) molecules of halothane. At point C in figure 3, which is distal to the resistance, the pressure is now \( P \) mm Hg and the carrier gas has expanded. Every 100 ml of gas now flowing to the patient contains

\[
n \times \frac{100}{4000} \times \frac{P}{P+p}
\]

In other words, compared with the state depicted in figure 2 there has been a reduction in the molecular concentration of halothane and the percentage concentration output v/v of the vaporizer has been reduced. Other factors such as changes in density and viscosity of the carrier gas may, by changing the ratio of gas flowing through the vaporizing chamber, affect the percentage concentration output of the vaporizer.

Let us now consider a system in which a ventilator is employed in conjunction with a vaporizer, as in this investigation. The pressure inside the vaporizing chamber is not constant but fluctuates with the two phases of the respiratory cycle. The mean pressure inside the chamber will still be raised throughout, although quantitatively this could only be measured by plotting a pressure time curve during the complete respiratory cycle. This was outside the scope of the present paper.

From what has been said, the higher this mean pressure inside the vaporizing chamber the lower will be the mean percentage concentration output of the vaporizer. The output of the vaporizer also depends, however, on the volume of fresh gas flowing through the chamber per unit time and now the amount of fluctuation of pressure in the vaporizing chamber becomes important. Hill and Lowe (1962) showed that pressure fluctuations inside the vaporizing chamber, by allowing build-up of fresh gas to occur during the peak pressure period, cause an increase of mean flow of gas through the chamber and allow more halothane to enter the bypass stream. This will tend to cause an increase in the percentage concentration output of the vaporizer. The greater the degree of pressure fluctuation the greater this effect will be.

In using any ventilator system which gives rise to pressure fluctuations in the vaporizing chamber, the resulting percentage concentration output of the vaporizer will depend on the interplay of these two factors. One, by increasing the mean pressure in the vaporizing chamber, tends to reduce the percentage concentration output whereas the other, by increasing the mean fresh gas flow through the chamber, tends to increase it. It was not to be expected that the latter effect would be marked in this investigation in which gas flows of 8 l./min or more were usual, as compared with the results obtained by Hill and Lowe where small gas flows of 0.5 l./min were employed.

A situation can be envisaged wherein the pressure fluctuations are such that these two effects could cancel each other out and the percentage concentration output is that expected from the dial setting. As seen from the results using the ventilators in this investigation the pressure fluctuations in the vaporizing chamber were such that the percentage concentration output was never greater than that expected from the dial setting, and in the case of the Barnet and Manley ventilators was always less.

This may not apply with all systems, however, and when employing other ventilators such as the Bird with a flow of 0.5 l./min (Hill and Lowe, 1962) and the Engström (Gordh et al., 1964) in conjunction with a Fluotec Mark II vaporizer, the percentage concentration output was higher than expected from the dial settings.

REFERENCES


ACKNOWLEDGEMENT

I would like to thank Dr. J. A. Thornton for his helpful criticism during the preparation of this paper.
RENDEMENT DES VAPORISATEURS UTILISES AVEC DIVERS VENTILATEURS

SOMMAIRE

Nous avons mesuré la concentration en volumes pour-
cent à la sortie d’un vaporisateur Fluotec Mark II
utilisé avec divers ventilateurs, ainsi que les change-
ments de pression à l’intérieur de la chambre de vapor-
sation. Avec deux sortes de ventilateurs, à savoir les
types Manley et Barnet, nous avons trouvé des pres-
sions élevées dans la chambre de vaporisation et la
concentration en pour-cents à la sortie du vaporisateur
était moins élevée que celle qu’indiquait le cadran.

BOOK REVIEW

Editor Peter Safar. Published by Blackwell, Ox-
ford. Pp. xiii+419; illus.; indexed. Price 40s.

In the preface to this monograph the “‘cook-book’
approach to therapy” is deprecated, and it must be
said that those who have a fondness for therapeutic
cook-books will find this volume a disappointment.
Thus there is no immediate answer on the treatment,
for example, of severe status asthmaticus. The guiding
principles are here in various parts of the text, and
they are presented on informed and scientific lines by
workers who can write on their subjects with
authority. There is the usual peripatetic quality of
the multiple-authorship book, but the general standard
is quite excellent, and the text lucid.

It has not been the intention to reduplicate the
existing literature but the work is, nevertheless, fairly
comprehensive, though the sections on the physio-
logical basis of the subject are short. The chapter on
prolonged artificial ventilation is written by Safar (who
eits the book) and Kunkel, and these workers have
treated over 1,000 such cases, experience enough to
daunt all but the most waspish of critics. The com-
mon emergency situations (including asphyxia neo-
natorum) are treated without the vagueness which
often occurs in descriptions of this type of work, and
the essentials of safe practice are clearly described.
Other very familiar subjects are covered in sections
on the management of the comatose patient, post-
operative respiratory complications, and oxygen
therapy; but many anaesthetists will find the accounts
of nebulization therapy and intermittent positive pres-
sure breathing therapy particularly interesting since
they are generally neglected in this country. The
chapter on the management of chronic respiratory
failure is more within the province of the physician
than the anaesthetist but is one of the most stimulating
in the book. For those interested in running intensive
care units there are sections on organization, steriliza-
tion of equipment, and on physiotherapy.

Most workers in what has now come to be called
respiratory therapy are addicted to nostrums, and this
is hardly surprising in a new discipline. They will
doubtless find much with which to disagree but they
would have to be grossly prejudiced not to admit the
excellence of this work. Candidates for the second
part of the F.F.A., knowing the devotion of their
examiners to the more peripheral subjects in the
speciality, will find many of the chapters a useful
supplement to the standard textbooks.

J. E. Utting