Overfill testing of anaesthetic vaporizers

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Summary
We tested six anaesthetic vaporizers with keyed filler adaptors to see if it was possible to overfill them. For those vaporizers which could be overfilled, the maximum level of overfill was determined and the effect of overfilling on the vaporizer output concentration was measured. Three of the vaporizers, the TEC 4, PPV Mk 1 and MIE Vapamasta 5, could be overfilled. In the case of the TEC 4 and PPV vaporizers, overfilling by more than 100 ml caused a large increase in the vaporizer output concentration. Overfilling the Vapamasta 5 by this amount caused the output concentration to decrease. (Br. J. Anaesth. 1995; 74: 100-103)

Key words
Equipment, vaporizers.

Keyed fillers were developed as a safety feature on anaesthetic vaporizers to prevent accidental filling with the wrong agent. However, all users of keyed fillers are familiar with the problems which these devices caused. Air locks may make filling the vaporizer almost impossible and busy staff may be tempted to develop their own techniques to overcome this. Unfortunately, these “in-house” techniques, which are contrary to the manufacturer’s instructions on filling, may allow the vaporizer to be overfilled. A recent Safety Action Bulletin [1] pointed out that it is possible to overfill the Fluotec 4 vaporizer. The aim of this study was to examine several commonly used vaporizers which have keyed fillers to determine: (a) if overfilling of each vaporizer is possible; (b) to what extent each vaporizer can be overfilled; and (c) the effect of different levels of overfilling on vaporizer output.

Methods
VAPORIZERS
We examined the following vaporizers: (i) Fluotec 3 (halothane), (ii) Tec 4 (enflurane), (iii) Penlon Abingdon vaporizer (halothane), (iv) Penlon PPV (isoflurane), (v) Drager Vapor 19 (isoflurane) and (vi) MIE Vapamasta 5 (isoflurane).

It is clear from the above that the same anaesthetic agent was not used throughout the studies described in this paper, as we could only use vaporizers which were readily available to us. However, we have assumed that all vaporizers of a particular design will behave in a similar fashion when filled with other agents.

OVERFILLING TECHNIQUE
It is common practice for staff experiencing difficulties when filling vaporizers to turn them to the “on” position. We found that it was not possible to overfill any of the vaporizers by this manoeuvre alone if the filler cap formed a good seal with the bottle. Also, it was not possible to overfill the vaporizer by loosening the seal with the vaporizer turned “off”. However, if the connection between the bottle of agent and the filler cap was loosened while the vaporizer was turned “on”, overfilling was possible in some cases. In these instances, the use of an old filler cap which did not form a proper seal with the bottle would also allow overfilling if its vaporizer was turned “on”.

The vaporizers which could not be overfilled were the Abingdon vaporizer, Fluotec 3 and Drager Vapor 19. All of these vaporizers had drainage holes which caused excess liquid to drain out. Thus we studied only the TEC 4, PPV and Vapamasta vaporizers.

MAXIMUM OVERFILL LEVELS
In order to determine the maximum amount by which it was possible to overfill each of the remaining vaporizers, the test vaporizers were first filled to the “max” level using the manufacturer’s recommended technique. The “max” was defined as the maximum level of filling possible using the manufacturer’s recommended technique and was indicated by the marking on the sight glass. The volume of liquid required to reach this level was not measured. The agent bottle and filler cap were then weighed and the vaporizer overfilled maximally after which another weighing was carried out. It was found that overfilling progressed easily and rapidly at first until a point was reached where it became difficult to add more liquid. At this point it was necessary to tilt the bottle in the filler cap in order to introduce more liquid and only a few extra millilitres could be added in this way.
MEASUREMENT OF OUTPUT

The output of each test vaporizer was measured when filled to the “max” level and at various levels of overfilling. A flow rate of oxygen 4 litre min⁻¹ was used and the dial settings were 0.6, 1.0 and 2 %, v/v. A mass spectrometer (Centronics MGA 200) which had been calibrated for the vapour channel using a Riken refractometer was used to measure vapour concentrations [2]. A plot was made of vaporizer agent concentration output, as measured by the mass spectrometer, v/s overfill level at each of the dial settings. The variation in this output concentration with time was recorded on chart paper by connecting the output of the mass spectrometer to a Y-t pen recorder (Linear Corder Mark VII, Watanabe).

The output of each vaporizer was also recorded when switched off and at the 0 % dial setting.

Results

The maximum overfill level for each vaporizer was as follows: TEC 4 = 132 ml, PPV = 134 ml and Vapamasta = 131 ml. Figures 1, 2 and 3 show the outputs of the TEC 4, PPV and Vapamasta vaporizers at the 0.6, 1.0 and 2 % dial settings when overfilled to different levels. Readings were obtained 1 min after changing the dial setting since, particularly at high overfill levels, the output may vary with time. For all vaporizers the output remained constant for overfill levels up to 50 ml. The sections of the graphs for overfill volumes greater than 100 ml give only a qualitative indication of what happens at these volumes as output may be variable with time at these volumes.

In the case of the TEC 4, enflurane output then began to decrease and reached a minimum at approximately 90 ml. After this there was a marked increase in the vaporizer output concentration. Figure 4 shows the output of the TEC 4 at the 0.6 % setting varied with time when the vaporizer was overfilled by 127 ml. (This was the initial level of overfilling. Obviously, as evaporation takes place the overall volume will reduce.) The output remained relatively constant at approximately 1.6 % v/v for approximately 14 min. The dial setting was then increased to 1 % and the output increased to 2.4 % over the next 1 min and then decreased suddenly to zero. After the output had remained at zero for 5 min, the flow of gas was increased slightly, by about 200 ml min⁻¹. This caused an increase in output for 1 min and the maximum output obtained in this period was more than 7 % v/v. The output then decreased to 0.2 %. When the dial setting was increased to 2 % the output was very variable between 0.4 % and 2 %, v/v, over the next 5 min and then stabilized at approximately 0.5 % v/v (fig. 4) when overfilled by 132 ml; at the 0 % setting, a bolus of gas containing more than 3 % vapour was seen for less than 10 s. When the dial was set to 0.6 %, output was initially less than 0.4 % but then increased rapidly and varied between 3 and 4 %. When the dial setting was increased to 1 %, output became very variable, between 4.5 and 7 %, for approximately 3 min when it decreased rapidly to about 0.4 % v/v with occasional small increases.

The PPV vaporizer behaved in a similar manner to
the TEC 4 but minimum output was obtained at 104 ml. Figure 5 shows the output of the PPV at a dial setting of 2.0% when overfilled by 105 ml. When the PPV was maximally overfilled, liquid was observed to be running from the tapers. When the vaporizer was switched off but maximally overfilled, the concentration was initially 22% v/v which decreased to 0% v/v over an 8-min period.

The output of the Vapamasta 5 remained constant up to an overfill level of 50 ml and then began to decrease until a maximum overfill of 131 ml was reached.

Discussion

It may be seen from the above results that it is possible to overfill some vaporizers which use keyed fillers. In the case of the TEC 4 and PPV, overfilling had little effect on output unless the overfill level exceeded 90 ml (TEC 4) or 100 ml (PPV). At these levels there was a marked increase in vaporizer output which could lead to dangerous concentrations of the agent being delivered to the patient. Both of these vaporizers showed a decrease in output as this critical level of overfilling was approached and around this critical level the output of the vaporizer was quite unpredictable (see figs 4 and 5).

An explanation for this might be that as the level of liquid increases to almost fill the vaporizing chamber, the resistance of the pathway through the chamber also increases and causes a decrease in output concentration; in addition, the area of wick which the gas passes over is reduced so that the gas may not be fully saturated with vapour. However, the pressure of the gas on the liquid surface may also force some liquid into the bypass, thereby causing an increase in output concentration, as illustrated in figure 5. Similarly, changes in gas flow may also cause this to occur (fig. 4). If, after filling the vaporizing chamber maximally, still more liquid is added, then this flows into the bypass causing extremely high output concentrations; this was seen with both of these vaporizers. It is also worth noting that emptying a vaporizer which has been filled to this extent does not remove excess liquid from the temperature compensation device, and so high concentrations of agent could still be given from an apparently correctly filled vaporizer until all of this liquid had evaporated. The user would be unaware of this unless the anesthetic circuit included an inspired anesthetic agent concentration monitor or the patient displayed abnormal clinical signs.

In the case of the Vapamasta 5, the output concentration decreased at overfill volumes greater than 50 ml and it was not possible to produce an increase in output concentration by overfilling. In contrast with the other two vaporizers, the temperature compensation device is in the vaporizing chamber. In the other two vaporizers the temperature compensation devices are in the bypass. This provides a volume into which excess liquid can flow when the vaporizing chamber has been filled. The bypass volume in the Vapamasta is very small and hence it is difficult to force liquid into it, and to generate enough pressure to force liquid out of the vaporizer and into the backbar.

It must be acknowledged that the exact output concentration of a vaporizer varies depending on the clinical conditions in use. The carrier gas composition and flow rate, and the use of a ventilator, all cause changes in the output concentration of a vaporizer [2, 3]. However, these output concentration changes do not reach the dangerous levels caused by overfilling as described above. It must also be acknowledged that it is difficult and time-consuming to overfill the TEC 4 and PPV vaporizers to the point where output becomes dangerous. In the case of isoflurane vaporizers, the excess volume which needs to be added to produce dangerous output levels is greater than the volume of a standard bottle of agent (100 ml). This reduces the likelihood of such overfilling occurring accidentally. However, it would still be possible for a staff member who did not realize the consequences and who also wished to save time to attempt to put as much agent as possible into a vaporizer. The standard bottles of halothane and enflurane contain 250 ml of liquid agent, and so accidental overfilling is more likely with these two agents. It is clear from our studies, and from the published warning from the Department of Health,
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that such levels of overfilling can occur if staff indulge in dangerous practices.

References