



APPARATUS

The Diamedica Draw-Over Vaporizer: a comparison of a new vaporizer with the Oxford Miniature Vaporizer

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Summary

The Diamedica Draw-Over Vaporizer (DDV) has been developed as an alternative to the Oxford Miniature Vaporizer (OMV). Both can function as draw-over or plenum vaporizers. The performances of these two vaporizers were compared under conditions simulating intermittent positive pressure ventilation (IPPV) and continuous flow (CF). Series 1 experiments were conducted with the vaporizers in water baths at 20, 25 and 30 °C. Vaporizers were tested at dial settings of 1–4% over a range of minute volumes (1.75–6 l.min⁻¹) and flow rates (3–8 l.min⁻¹). Series 2 experiments compared output of the vaporizers over time at ambient temperatures of 20, 25 and 30 °C. A minute volume of 6 l.min⁻¹ (IPPV) and a gas flow of 8 l.min⁻¹ (CF) were used with a vaporizer setting of 2%. Vapour concentrations were recorded at 5-min intervals. In series 1 IPPV experiments, the DDV vaporizer was more accurate, producing significantly fewer vapour concentrations 0.5% more than or less than setting ($p = 0.013$). The OMV tended to produce more favourable results under continuous flow ($p = 0.42$). In series 2 experiments, the accuracy of both vaporizers was similar but consistency of output over time was better for the DDV and consistency of output according to differences in ambient temperature was better for the DDV. The OMV produced more vapour concentrations that were markedly higher than dial setting, particularly at high ambient temperatures. The DDV is a suitable alternative to the OMV with some distinct advantages. These include a larger reservoir, tendency towards greater accuracy during IPPV and improved consistency of output.

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In many parts of the developing world, compressed medical gases are not available [1]. Draw-over anaesthesia, using air, with or without added oxygen, avoids dependence on compressed gases [2]. It is an anaesthetic technique employed in both civilian and military anaesthesia [3]. Many types of draw-over vaporizers have been designed. Some, including the Oxford Miniature Vaporizer [4], (OMV, Penlon Ltd, Abingdon, UK) which has been in service for over 40 years, can also function as a

plenum vaporizer, where a continuous flow of carrier gas moves under positive pressure through the vaporizer. A new vaporizer, the Diamedica Draw-Over Vaporizer (DDV, Diamedica Ltd, Bratton Fleming, UK) has recently been developed as an alternative to existing vaporizers, including the OMV.

The characteristics of an ideal draw-over vaporizer are:
1 Output vapour concentrations should accurately reflect dial settings.

- 2 Output should remain consistent over time.
- 3 Output should not differ across clinically relevant ranges of minute volumes, flow rates or ambient temperatures.
- 4 The vaporizer should not under any circumstances produce dangerously high concentrations of vapour, regardless of dial setting.
- 5 When switched off, the vaporizer should produce no output.

In this laboratory study, the performance of the DDV and the OMV were compared according to these characteristics.

Specifications of the Diamedica Draw-Over Vaporizer

A photograph and accompanying diagram of the Diamedica vaporizer and its internal workings are shown in Figures 1 and 2. In common with all draw-over vaporizers, the DDV relies on mixing saturated vapour from the vaporizing chamber with by-pass gas. Vaporizer output is altered by the concentration dial that controls a moveable shuttle. Unlike the OMV, the DDV concentration dial is explicitly marked in percent.

The vaporization chamber is lined by a fine weave stainless steel mesh which provides a very large surface area for vaporization in a small volume and allows transmission of heat from the DDV walls to the vaporization site. The DDV has an agent reservoir of 150 ml compared to 50 ml for the OMV.

The body of the DDV is constructed of stainless steel. Its outer casing is over 8 mm thick and its very large thermal mass contributes to the stability of output over time. The empty vaporizer weighs 2.6 kg. Because the



Figure 1 Photograph of the DDV.

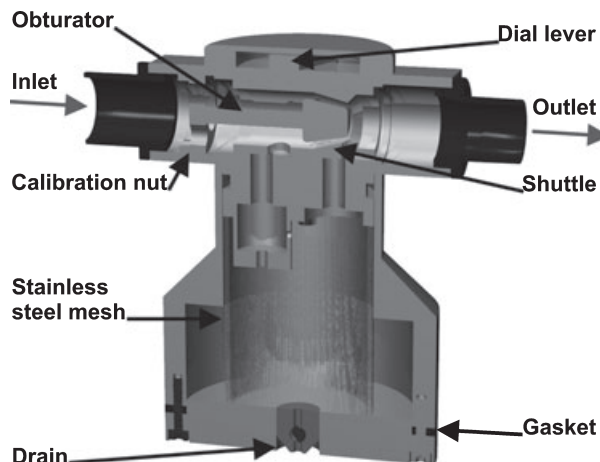


Figure 2 Illustration of the internal workings of the DDV.

base of the vaporizer is considerably wider than the top it is not prone to tipping over.

The DDV has been calibrated to deliver isoflurane and halothane. The vaporizer scale, which is suitable for both agents, has markings in 1% increments from 0% to 5%. The dial has a slit within it to remove parallax.

Methods

General

We compared the performance of the DDV and the OMV in a series of laboratory experiments. We used different configurations of breathing systems to simulate intermittent flow draw-over and continuous flow (Figs 3 and 4). Intermittent flow draw-over was simulated by use of a mechanical ventilator. A spontaneous ventilation intermittent flow draw-over model was not developed but we believe that vaporizer output would be similar to but not identical to intermittent flow draw-over in a patient undergoing mechanical ventilation. Differences would exist between mechanical ventilation draw-over and spontaneous ventilation draw-over because of differences in gas flows rates and wave forms during the inspiratory phase.

Continuous flow is rarely used with draw-over anaesthesia except in paediatric practice where the continuous flow model closely approximates to what happens during spontaneous breathing via an Ayre's T piece plus reservoir bag (Mapleson's E circuit with Jackson-Rees modification).

A range of combinations of tidal volume and respiratory rate for the intermittent flow model, and a range of flow rates for the continuous flow model were chosen to reflect adult and paediatric practice. The experiments were performed at 20, 25 and 30 °C to represent a range

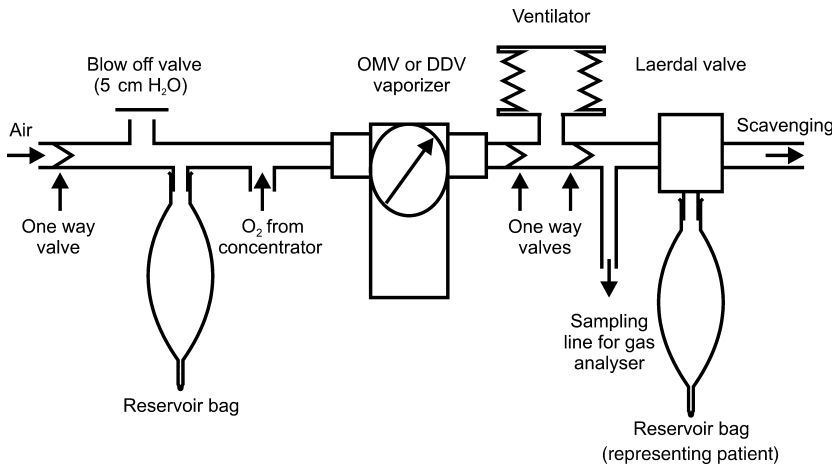


Figure 3 Intermittent flow model.

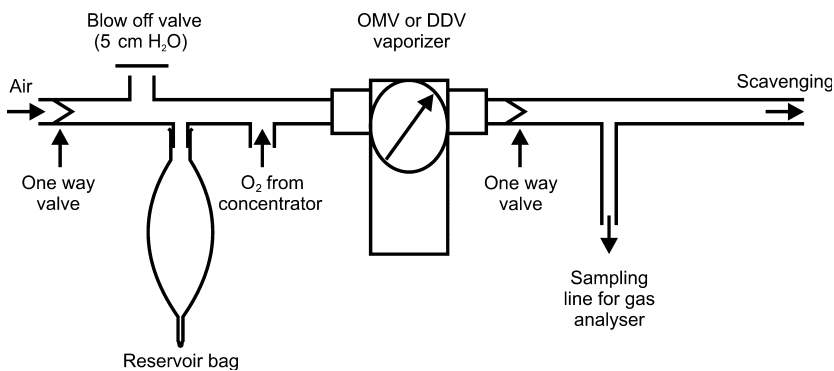


Figure 4 Continuous flow model.

of operating temperatures that may be experienced. Isoflurane was chosen as the anaesthetic volatile agent partly because of its widespread use globally and also because of the similarity of its vaporization characteristics to halothane, another volatile agent commonly used in the developing world.

Equipment

The configurations used to simulate intermittent and continuous flow are represented in the Figs 3 and 4. The first series of experiments were conducted with the vaporizers placed in water baths at temperatures of 20, 25 and 30 °C. These experiments were designed to compare the vaporizer output produced by various dial settings on the OMV and DDV at these temperatures. Water baths were employed because stable output from the vaporizers was not anticipated without them. Water baths were not used in the second series of experiments which were designed to test the output of both vaporizers over time. These experiments were performed at ambient temperatures of 20, 25 and 30 °C.

We used a Glostavent anaesthetic machine (Diamedica Ltd) [5]. The ventilator, Diamedica AP ventilator (Diamedica Ltd), is capable of delivering a range of tidal

volumes from 35 ml to 1000 ml at a rate of 1 to 40 breaths.min⁻¹. For the intermittent flow model, a Laerdal valve [6] was used to enable direction of gas flow from the exit port of the ventilator to a test lung and then on to the gas scavenging system. A calibrated gas flow and volume sensor was used before each experiment to ensure accuracy of flow rates, tidal volumes and respiratory rates (QA-VTM ventilator tester; Fluke Biomedical, Everett, WA, USA). This was calibrated to record the air/oxygen carrier gas mix used in all experiments. Flow rates and tidal volumes were adjusted so that the delivered rates and volumes were within 0.01 l.min⁻¹ and 0.01 litres respectively of that required. The gas flow and volume sensor was not included in the circuit during the tests. Gas analysis was performed using a calibrated Datex-Ohmeda gas analyser (Datex-Ohmeda, Madison, WI, USA). Ambient temperature, water bath temperature and anaesthetic agent temperature were monitored using a Datex-Ohmeda series 400 temperature probe (Datex-Ohmeda). Ambient and water bath temperatures were kept to within ± 0.5 °C of the target temperature. Anaesthetic agent temperature was allowed to equilibrate to within ± 0.5 °C of the target temperature between experiments. Water bath temperature was maintained by

adding increments of hot water to the bath as required during the experiments. Target ambient temperatures of 20, 25 and 30 °C were maintained using domestic electric heaters.

Series 1 experiments

Series 1 experiments were conducted with the vaporizers placed in water baths at temperatures of 20, 25 and 30 °C. For the intermittent flow model tests, a range of combinations of tidal volume and respiratory rate were used to reflect adult and paediatric practice (50 ml × 30 min⁻¹, 100 ml × 25 min⁻¹, 300 ml × 15 min⁻¹ and 600 ml × 10 min⁻¹). For each combination, the vaporizer was tested at dial settings of 1%, 2%, 3% and 4% consecutively. Once concentration of inspired anaesthetic agent, recorded to the nearest 0.1%, had been stable over a one-minute period for the dial setting used, the value displayed was recorded. After conducting one series of experiments at dial settings of 1% to 4% at a specific combination of tidal volume and respiratory rate, the temperature of the anaesthetic agent was allowed to equilibrate to within 0.5 °C of the water bath temperature prior to starting a new run of experiments at the next combination of tidal volume and respiratory rate. Once all tests at the initial test temperature were completed, the tests were repeated at the remaining two test temperatures.

The continuous flow model experiments were conducted in a similar fashion using flow rates of 3, 4, 5, 6 and 8 l.min⁻¹.

Series 2 experiments

Series 2 experiments compared the stability of the outputs from both vaporizers over time and were designed to reflect clinical practice. In these experiments, the ambient room temperature was maintained to within 0.5 °C of the target temperatures of 20, 25 and 30 °C. Prior to starting each experiment, it was confirmed that the temperature of the anaesthetic agent was within 0.5 °C of the ambient temperature.

These experiments were conducted using a minute volume of 6 l.min⁻¹ (tidal volume 600 ml, respiratory rate 10.min⁻¹) for the intermittent flow model and a gas flow of 8 l.min⁻¹ for the continuous flow model. Dial settings of 2% were used. Vaporizer output was recorded at 1-min intervals for the first 5 min and at 5-min intervals thereafter. The experiments were continued for a maximum of 50 min or until the OMV required re-filling. Re-filling of the vaporizer was not carried out during the course of an experiment as it was felt that re-filling the vaporizers with volatile anaesthetic agent at ambient temperature would confound the results.

Results

Series 1 results

Figures 5, 6 and 7 present the data from series 1 intermittent flow experiments at 20, 25 and 30 °C respectively. At 20 °C, both vaporizers produced vapour concentrations close to the set concentrations. The recorded vapour concentrations for the DDV tests at 20 °C were all within 0.5% of the set vapour concentrations and for the OMV all but one test produced recorded vapour concentrations within this degree of accuracy. In general, the output from both vaporizers varied little across the range of minute volumes when tested at this temperature. At 25 °C, the DDV proved more accurate. All of the recorded vapour concentrations for the DDV tests were within 0.5% of the set vapour concentrations. In addition, greater consistency of output was noted across the range of minute volumes tested. At 30 °C, the recorded vapour concentrations were nearly all greater than set concentrations for both vaporizers. In almost all the intermittent flow tests at 30 °C, the DDV produced recorded vapour concentrations closer to set concentrations than the OMV. Both vaporizers produced some recorded vapour concentrations much higher than set concentrations but for the DDV, unlike the OMV,

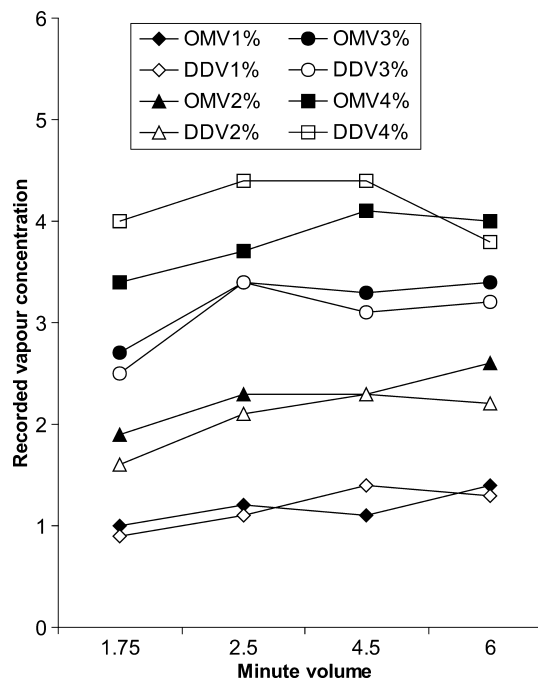


Figure 5 Graph representing recorded vapour concentration (%) and set vapour concentration during intermittent flow at different minute volumes (l.min⁻¹) at 20 °C for both OMV and DDV vaporizers.

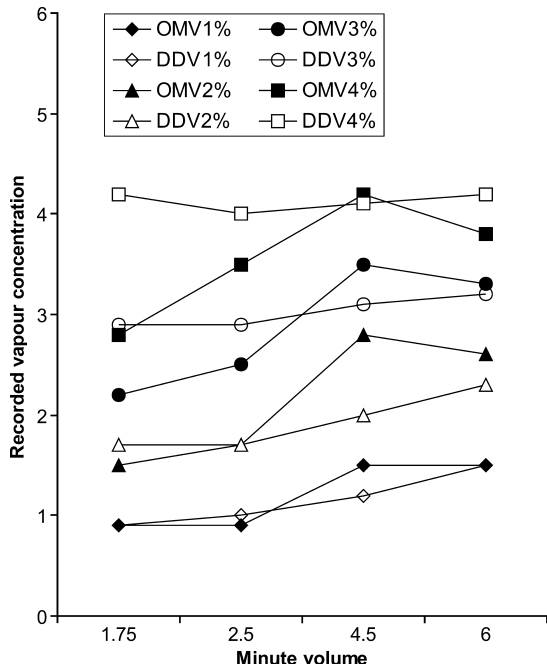


Figure 6 Graph representing recorded vapour concentration (%) and set vapour concentration during intermittent flow at different minute volumes (l.min⁻¹) at 25 °C for both OMV and DDV vaporizers.

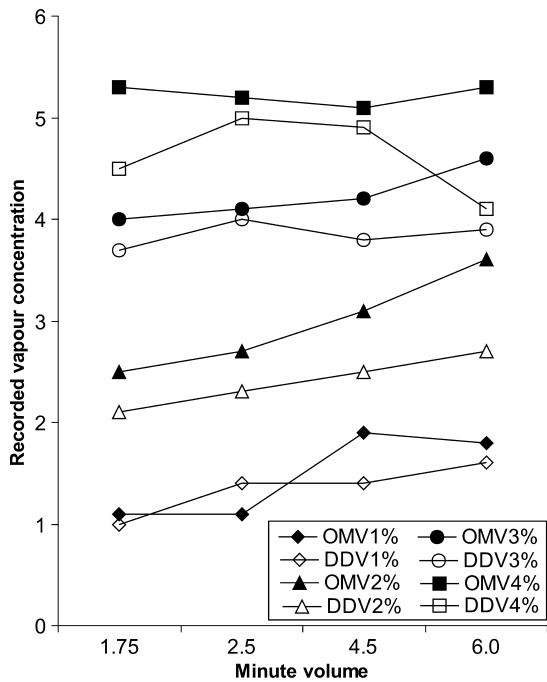


Figure 7 Graph representing recorded vapour concentration (%) and set vapour concentration during intermittent flow at different minute volumes (l.min⁻¹) at 30 °C for both OMV and DDV vaporizers.

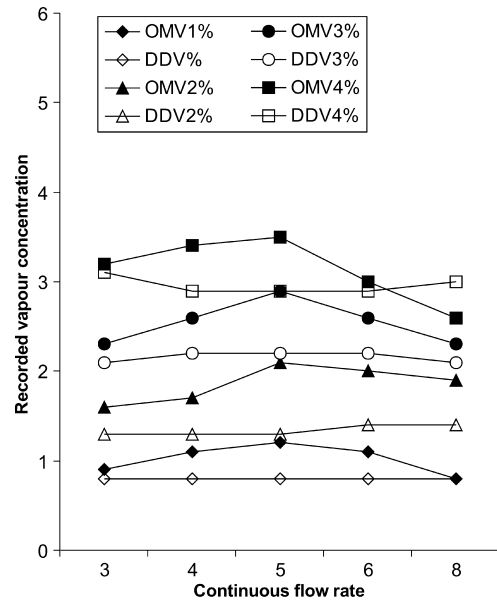


Figure 8 Graph representing recorded vapour concentration (%) and set vapour concentration during continuous flow at different flow rates (l.min⁻¹) at 20 °C for both OMV and DDV vaporizers.

this was not generally the case for vaporizer settings of up to 2%, which represents the more usual clinical range.

Figures 8, 9 and 10 present the data from series 1 continuous flow experiments at 20, 25 and 30 °C respectively. At 20 °C both vaporizers almost always produced recorded vapour concentrations less than set concentrations. This difference was more pronounced for the DDV but there was less variation in the accuracy of DDV across the range of continuous flow rates tested. At 25 °C similar findings were observed. The difference between recorded and set vapour concentrations was greater for the DDV than the OMV but again there was less variation in accuracy according to continuous flow rate for the DDV. At 30 °C both vaporizers produced very similar recorded vapour concentrations for tests performed with dial settings of 1% and 2% but the DDV was noted to over-read at higher vaporizer dial settings at this temperature.

Statistical tests were performed to investigate the differences between the vaporizers. Chi-squared tests were performed to compare the frequency with which the recorded vapour concentration differed from the set concentration by more than or less than 0.5%. For all series 1 tests conducted under intermittent positive pressure ventilation, 8/48 (17%) of the DDV tests yielded a recorded vapour concentration of 0.5% more than or 0.5% less than the set vapour percentage. For the OMV the corresponding figure was 19/48 (40%). This observed

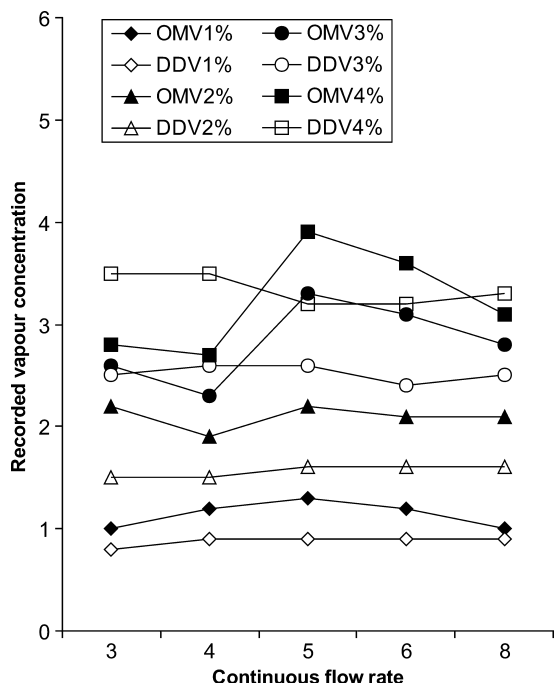


Figure 9 Graph representing recorded vapour concentration (%) and set vapour concentration during continuous flow at different flow rates (l.min⁻¹) at 25 °C for both OMV and DDV vaporizers.

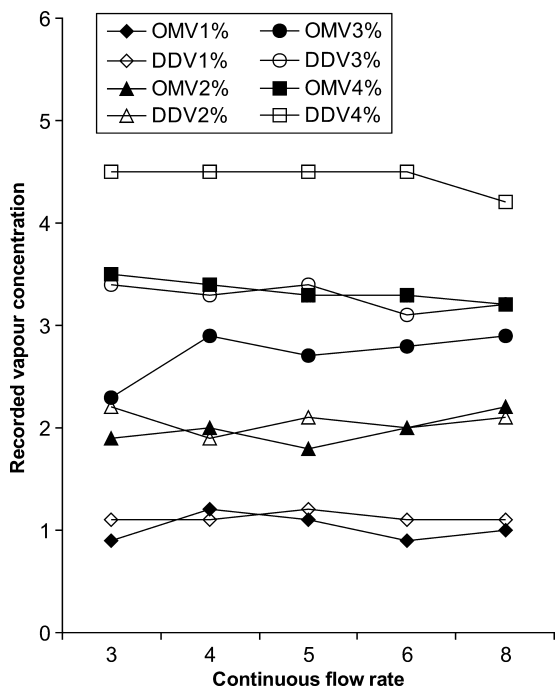


Figure 10 Graph representing recorded vapour concentration (%) and set vapour concentration during continuous flow at different flow rates (l.min⁻¹) at 30 °C for both OMV and DDV vaporizers.

difference was significant ($p = 0.013$, two tailed chi-squared test).

For all series 1 tests conducted under continuous flow, 19/60 (32%) of the DDV tests yielded a recorded vapour concentration outside these limits. For the OMV, the corresponding figure was 15/60 (25%). This observed difference was not significant ($p = 0.42$, two tailed chi-squared test).

Series 2 results

Figures 11 and 12 present the data from series 2 intermittent flow experiments at 20, 25 and 30 °C. Comparing these graphs it is clear that the DDV exhibited better consistency of output for the duration of series 2 intermittent flow experiments at all three test temperatures. The stability of output of the vaporizers in the series 2 experiments was formally assessed by calculation of the gradient of the slope of recorded vapour concentration when plotted against time as in Figs 11 and 12. This gradient was calculated from 5 min after the start of the

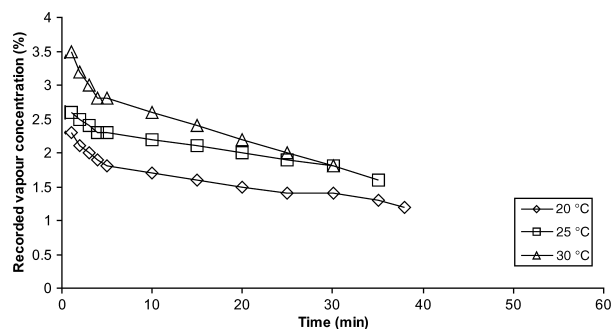


Figure 11 Graph representing recorded vapour concentrations (%) delivered during intermittent flow with minute volume of 6 l.min⁻¹ and at ambient temperatures of 20, 25 and 30 °C by the OMV with dial set at 2 against time.

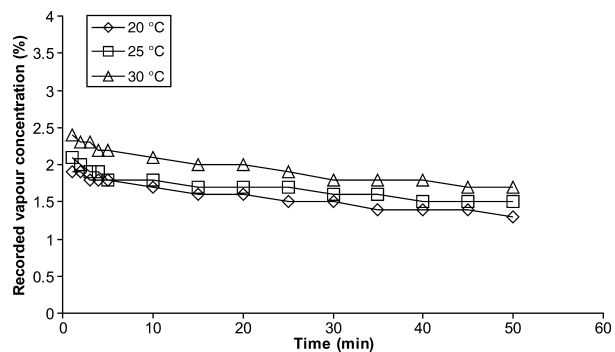


Figure 12 Graph representing recorded vapour concentrations (%) delivered during intermittent flow with minute volume of 6 l.min⁻¹ and at ambient temperatures of 20, 25 and 30 °C by the DDV with dial set at 2% against time.

Table 1 Gradients of vapour concentration plotted against time in series 2 intermittent flow and continuous flow experiments.

	20 °C	25 °C	30 °C
OMV intermittent flow	-0.018	-0.023	-0.040
DDV intermittent flow	-0.011	-0.007	-0.011
OMV continuous flow	-0.017	-0.024	-0.036
DDV continuous flow	-0.006	-0.007	-0.009

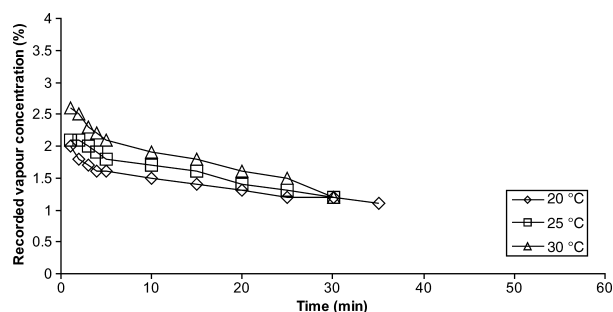
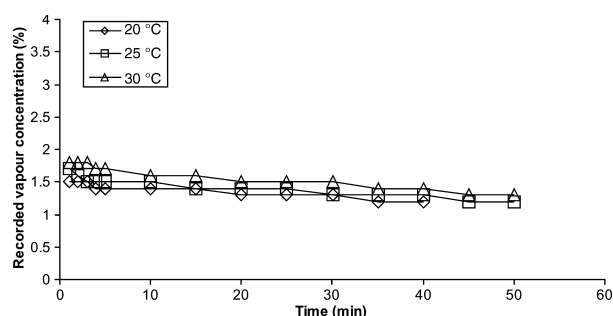
experiment until the time at which the experiment was stopped because the OMV had emptied. A gradient of 0 would exist if there was absolute stability of output from the vaporizer for the duration of the test. The gradients for series 2 intermittent flow experiments, displayed together with the continuous flow data in Table 1, confirm that the DDV had improved stability of output. In clinical practice the stability of the output of the OMV is further impaired compared to the DDV in longer operations because the OMV will require more frequent topping up with volatile agent due to its smaller vaporization chamber. Topping up the up the vaporizer with volatile agent that is considerably warmer than the residual agent remaining in the vaporization chamber would lead to increased variation in the output of the vaporizer.

There was less variation in output for the DDV in series 2 intermittent flow experiments according to differences in ambient temperature. Also much less high maximum vapour concentrations were recorded for the DDV compared to the OMV at 30 °C. In the series 2 IPPV experiment conducted at 30 °C, with a dial setting of 2, the OMV produced a peak vapour concentration of 3.5% at 1 min that had dropped to 2.6% by 10 min. In contrast, the DDV under the same conditions produced a peak concentration of 2.4% at one minute that dropped to 2.1% at 10 min.

Accuracy of the vaporizers during the series 2 experiments was assessed by calculation of the mean differences between the actual and set vapour concentrations. In order to allow a direct comparison between the two vaporizers, comparisons were only made for the 5 min time intervals for which data was available from both vaporizers. The results, given in Table 2, confirm the

Table 2 Mean differences between actual and set vapour concentrations (%) in series 2 intermittent flow experiments.

	20 °C	25 °C	30 °C
OMV	-0.51	+0.19	+0.5
DDV	-0.44	-0.3	-0.1

**Figure 13** Graph representing recorded vapour concentrations (%) delivered during continuous flow rate of 8 l.min⁻¹ and at ambient temperatures of 20, 25 and 30 °C by the OMV with dial set at 2 against time.**Figure 14** Graph representing recorded vapour concentrations (%) delivered during continuous flow rate of 8 l.min⁻¹ and at ambient temperatures of 20, 25 and 30 °C by the DDV with dial set at 2% against time.

greater accuracy of the DDV at two of the three temperatures tested.

Figures 13 and 14 present the data from series 2 continuous flow experiments at 20, 25 and 30 °C. Comparing these graphs, it is clear that the DDV exhibited better consistency of output for the duration of series 2 continuous flow experiments at all three test temperatures. This greater stability of output of the DDV was confirmed by comparing the gradients of the slopes of recorded vapour concentration plotted against time (Table 1).

As in the corresponding intermittent flow experiments, there was less variation in output for the DDV in series 2 continuous flow experiments according to differences in ambient temperature.

Accuracy of the vaporizers during the series 2 continuous flow experiments was again assessed by calculation of the mean differences between the actual and set vapour concentrations. The mean differences, given in Table 3, are of broadly similar magnitude for both vaporizers.

Table 3 Mean differences between actual and set vapour concentrations in series 2 continuous flow experiments.

	20 °C	25 °C	30 °C
OMV	-0.67	-0.5	-0.37
DDV	-0.67	-0.58	-0.43

Discussion

One of the most important contributions that developed countries can offer to the developing world is the design of new equipment to help them overcome the additional problems that they encounter [7]. These experiments compared the performance of a new draw-over vaporizer, the DDV, with that of the OMV with reference to the ideal characteristics of a draw-over vaporizer. The experiments were performed using models simulating intermittent flow draw-over and continuous flow over a range of clinically appropriate minute volumes, flow rates and temperatures.

Accuracy and consistency of the DDV

The performance of the DDV is comparable to that of the OMV. In the series 1 intermittent flow experiments, the DDV produced recorded vapour concentrations closer to set vapour concentrations than the OMV at all three test temperatures. Compared to the OMV, significantly fewer of the DDV series 1 intermittent flow tests yielded a recorded vapour concentration 0.5% more than or 0.5% less than the set vapour concentration. In addition, the accuracy of the DDV varied less than the accuracy of the OMV according to differences in minute volume at the two higher temperatures tested.

In series 1 continuous flow tests, the accuracy of the DDV also varied less than the accuracy of the OMV according to differences in continuous flow rate at two of the three temperatures tested. Although the OMV was observed to produce recorded vapour concentrations closer to set vapour concentrations than the DDV in series 1 continuous flow tests, the observed difference between the vaporizers in terms of the number of tests in which each vaporizer produced a recorded vapour concentration 0.5% more than or 0.5% less than set vapour concentration was not significant.

In series 2 intermittent flow tests, the DDV had improved accuracy in terms of reduced mean difference between recorded and set vapour concentrations at two of the three temperatures tested. The DDV exhibited better consistency of output for the duration of series 2 intermittent flow tests at all three test temperatures. In addition, there was less variation in the output for the

DDV according to differences in ambient temperature. Because the DDV has a larger vaporization chamber, it requires less frequent filling than the OMV under the same conditions. It is anticipated that in clinical practice this will lead to further improved stability of output of the DDV compared to the OMV. Stability of output during use and lack of variation in vapour concentration according to ambient temperature are key features for any vaporizer.

In series 2 continuous flow experiments, the accuracy of both vaporizers, assessed by calculation of the mean differences between the recorded and set vapour concentrations were broadly similar. In all series 2 experiments, stability of output was better for the DDV than the OMV and again less variation in output according to differences in ambient temperature was noted for the DDV.

Safety of the DDV

In series 2 experiments, the OMV tended to produce vapour concentrations that were higher than the DDV, especially under intermittent flow. Some vapour concentrations that were much higher than dial setting were noted. Importantly, neither vaporizer when tested produced any vapour output when switched off.

Summary

Draw over vaporizers are still commonly used and will remain part of the anaesthetists armamentarium in any region of the world in which the supply of compressed gases is unreliable.

The DDV is a suitable alternative to the OMV with some distinct advantages. It has greater accuracy during intermittent flow, greater consistency of output during both intermittent flow and continuous flow and it is less affected by differences in ambient temperature. The DDV also has fewer tendencies to produce vapour concentrations which are much higher than set concentrations during intermittent flow at higher ambient temperatures and it requires less frequent filling with volatile agent because of its larger agent reservoir.

Conflict of interests

Mr R. Tully is an employee of Diamedica Ltd.

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