Modification of a draw-over vaporizer for use with sevoflurane

T. Payne1*, R. Neighbour2 and R. Eltringham1
1Department of Anaesthesia, Gloucestershire Royal Hospital, Gt Western Rd, Gloucester GL1 3NN, UK
2Diamedica UK Ltd, Bratton Fleming, UK
* Corresponding author. E-mail: tompayne@doctors.net.uk

Editor’s key points
- Draw-over vaporizers are still widely used but are not calibrated for sevoflurane use.
- A modified draw-over for use with sevoflurane is evaluated here.
- Acceptable concentrations were achieved over a range of flows and temperatures.
- In a continuous flow mode, concentrations suitable for induction can be achieved.

Background. Draw-over anaesthesia is widely used throughout the developing world, in disaster areas and in military anaesthesia when the supply of pressurized oxygen is unreliable. To date, no draw-over vaporizer has been able to deliver sufficient concentrations of sevoflurane for use in inhalation induction of anaesthesia. A laboratory study to assess the performance of a new vaporizer (DDV2) to deliver sevoflurane in a wide range of situations is described.

Methods. In this study, the concentration of sevoflurane delivered at different dial settings (1–4%) and at different temperatures (20–40°C) in a draw-over mode was measured. The concentration of sevoflurane delivered at different dial settings with continuous flow (6 and 8 litre min⁻¹) at 20°C was measured. The maximum possible concentration of sevoflurane that can be delivered by the DDV2 was measured at a continuous flow rate of 8 litre min⁻¹ at 20, 30, and 40°C.

Results. Concentrations of sevoflurane delivered in the draw-over mode were within 0.5% of dialled setting up to 30°C. Above this temperature, higher levels of vapor were delivered. With continuous flow, concentrations of sevoflurane at 20°C were within 0.5% of dialled setting and were stable throughout the duration of the experiment. On the ‘induction’ setting, concentrations of sevoflurane of between 6.4% and 10.1% could be delivered with continuous flow.

Conclusions. The modifications to the DDV2 allow stable concentrations of sevoflurane to be delivered in draw-over and continuous flow modes over a range of temperatures. With continuous flow, concentrations of sevoflurane sufficient for induction of anaesthesia can be achieved.

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Although draw-over anaesthesia is now seldom used in modern well-equipped hospitals, it is still widely used throughout the developing world wherever the supply of pressurized oxygen is unreliable.1 It is also used in military anaesthesia and after natural disasters when normal support facilities may be unavailable.2

There are a number of draw-over vaporizers currently in use including the Oxford Miniature Vaporizer (OMV, Penlon Ltd, Abingdon, UK)3 and the Diamedica Draw-over Vaporizer (DDV, Diamedica UK Ltd, Bratton Fleming, UK).4 They are designed for use with halothane, isoflurane, or trichloroethylene but none of these vaporizers has been calibrated for use with sevoflurane.

Sevoflurane possesses several properties that make it an attractive agent for use in remote locations. Its relative insolubility allows for rapid onset and offset of anaesthesia, while it is non-irritant and sweet smelling, greatly facilitating its use for inhalation induction.5 The use of sevoflurane in draw-over anaesthesia has so far been limited by the inability of existing vaporizers to deliver sufficiently high concentrations for induction of anaesthesia.6,7 The DDV has been modified for use with sevoflurane for induction and maintenance of anaesthesia.

Laboratory studies to assess the performance of the new vaporizer (DDV2) over a wide range of situations are described.

Methods
The object of the study was two-fold:

(i) To measure the concentration of sevoflurane produced at different dial settings and temperatures in draw-over and continuous flow modes.
(ii) To measure the maximum concentration of sevoflurane that can be delivered by the DDV2 at an ‘induction’ dial setting.

Ethical approval was not required as this was an entirely laboratory-based study with no patient contact and was not carried out on NHS premises.

The vaporizer tested was the Diamedica Draw-over Vaporizer 2 (DDV2, Diamedica UK Ltd). This is a version of the original DDV vaporizer which has been modified for use with sevoflurane. The modification has entailed a resetting of the splitting ratio mechanism to increase the proportion of carrier gas passing through the vaporizing chamber at each division of the scale and thus deliver the higher concentrations required when using sevoflurane. This is necessary due to the lower vapour pressure of sevoflurane and the higher minimum alveolar concentration value. In addition to dial settings on a linear scale from 0% to 4% agent output, there is an additional setting marked ‘induction’. When the dial is in this position, the highest achievable volume of the carrier gas is diverted through the vaporizing chamber to increase the concentration of sevoflurane produced to a concentration suitable for gaseous induction (Fig. 1). This dial setting has been chosen to avoid cramping of numbers at the top end of the scale. In practice, concentrations of sevoflurane above 4% are seldom required for the maintenance of anaesthesia and would normally only be required for induction.

In addition, due to the higher outputs that the new splitting mechanism allows, an agent-specific filler for sevoflurane has been added. This is a novel connector supplied with the vaporizer. This eliminates the risk of accidental filling with other agents and allows filling without removal of the filler cap. The level of the filler agent should always be visible through the sight glass so that overfilling is avoided.

To simulate draw-over ventilation, a Glostavent anaesthetic machine (Diamedica UK Ltd) was used with the Diamedica AP ventilator capable of delivering tidal volumes from 35 to 1000 ml at a rate of 1–40 bpm (Fig. 2).

The accuracy of flow rates, tidal volumes, and respiratory rates was ensured using a calibrated gas flow and volume sensor (QA-VTM ventilator tester; Fluke Biomedical, Everett, WA, USA). This was calibrated to record air/oxygen carrier gas mix used in all experiments. Oxygen was used as the carrier gas in all calibrations and experiments. Flow rates and tidal volumes were adjusted so that the delivered rates and volumes were within 0.01 litre min$^{-1}$ and 0.01 litre, respectively, of that required before each experiment.

The concentration of the sevoflurane produced in each setting was analysed using a Datex-Ohmeda gas analyser (Datex-Ohmeda, Madison, WI, USA). The calibration of the

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**Fig 1** The Diamedica Draw-over Vaporizer 2 (DDV2).

**Fig 2** The anaesthetic circuit used to simulate draw-over and continuous flow.
analyser was checked before and after each experiment to ensure accuracy. All experiments were conducted using two vaporizers.

Vaporizer temperature was maintained using a temperature-controlled water bath. Water bath temperature and anaesthetic agent temperature were monitored using a Datex-Ohmeda series 400 temperature probe. Water bath temperatures were kept 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.

This method of using a water bath to simulate an ambient temperature was chosen as it has been used in an earlier paper on the DDV and OMV to evaluate the output of the different vaporizers. In addition, maintaining accurate ambient temperature of air is complex as it has to be done without generating significant air flow, as air flow will cause large temperature fluctuations around the vaporizer and render results inaccurate.

As a comparative measurement, the performance of the vaporizer was observed at a dial setting of 2.3% and a continuous flow of 6 litre min⁻¹ in ambient air temperature over 1 h. At an ambient temperature of 21°C, the vaporizer in air temperature decreases by 3.1°C from 21.3 to 18.2°C and sevoflurane concentration output decreased by 0.3% from 2.4% to 2.1%.

The experiments were carried out at a temperature range of 20–40°C. It is recognized that in military use, it may be required to function in temperatures below this when the output is likely to be less than that shown on the concentration scale. In such circumstances, the use of a temperature stabilizer, produced by Diamedica, is recommended. This is a small battery-driven heating pad thermostatically controlled to maintain the temperature at 20°C which can be provided with the anaesthetic machine.

Three experiments were undertaken to assess the performance of the new vaporizer in different circumstances.

Experiment 1
To measure the concentration of sevoflurane produced at different dial settings and at different temperatures in a draw-over mode.

In this experiment, the concentration of sevoflurane was measured over a period of 3 min, with the concentration recorded at 15 s intervals. The ventilator was set at 600 ml Vt at 10 bpm. This was repeated at dial settings of 1%, 2%, 3%, and 4% and at water bath temperatures of 20, 30, and 40°C.

Experiment 2
To measure the concentration of sevoflurane produced at different dial settings in a continuous flow mode.

In this experiment, the concentration of sevoflurane was measured over a period of 20 min, with the concentration recorded at 5 min intervals. The ventilator was off and continuous flow rates of 6 and 8 litre min⁻¹ were delivered. This was repeated at dial settings of 1%, 2%, 3%, and 4% at a water bath temperature of 20°C.

Experiment 3
To measure the maximum concentration of sevoflurane that can be delivered by the DDV2 at different temperatures.

In this experiment, the concentration of sevoflurane was measured over a period of 5 min, with the concentration recorded at 15 s intervals. The ventilator was set to the ‘induction’ setting. This was repeated at water bath temperatures of 20, 30, and 40°C. The experiment was also repeated at flow rates of 4, 6, and 8 litre min⁻¹ at an
ambient room temperature of 21.8°C to further investigate the effects of flow rate and cooling on high-concentration outputs.

Results

Experiment 1
The concentrations of sevoflurane delivered in a draw-over mode over 3 min at dialled concentrations of 1–4% at 20 and 30°C were within 0.5% of the dialled figure and remained stable throughout the time tested. At 40°C, the concentrations delivered were higher than the dialled figure, but the concentrations remained stable after the initial 30 s (Figs 3 and 4). The variation in the concentrations at 30 s and 3 min was 5.6%, 2.8%, 2.0%, and 10.5% for dial settings of 1%, 2%, 3%, and 4%, respectively.

Experiment 2
The sevoflurane output at 20°C with dial settings 1–4% in a continuous flow mode showed that all concentrations delivered were within 0.5% of the dialled concentrations between 1% and 4% at flow rates of 6 and 8 litre min⁻¹ (Table 1).

Experiment 3
The sevoflurane concentrations delivered at the ‘induction’ setting over 5 min at 20, 30, and 40°C showed that the initial concentrations delivered were between 8.4% and 10.1% and remained above 6.4% for the duration of the experiment (Fig. 5). At lower flow rates, the concentration of sevoflurane was slightly higher, with an output range of 6.3–8.6% at 6 litre min⁻¹ and 7.4–8.8% at 4 litre min⁻¹. As expected, the temperature decrease was less at lower flow rates: 1.1°C at 6 litre min⁻¹ and 0.6°C at 4 litre min⁻¹.

Discussion
Draw-over breathing systems are still widely used in those parts of the world where the supplies of oxygen and electricity are unreliable and they have been used successfully in military conflicts for many years. With the recent improvements in equipment for draw-over anaesthesia, it is likely to retain its popularity wherever anaesthesia has to be administered under difficult circumstances. The results found with this vaporizer correlate with similar behaviour in previous experiments.
studies of draw-over vaporizers. Following a recent debate among British military anaesthetists, 39 out of 40 who expressed an opinion voted for the retention of draw-over equipment. Despite its continuing popularity, one of the most persistent problems of draw-over anaesthesia has been the difficulty in achieving a sufficiently high concentration of volatile agent for inhalation induction of anaesthesia. However, because of its physical properties, sevoflurane is now generally preferred for inhalation induction of anaesthesia in the UK and North America. A concentration of 8% is commonly used but this has not previously been achievable from a draw-over vaporizer. Even when two OMVs were used in series, the maximum concentration delivered was 5.9% under similar conditions.

The modifications to the DDV have facilitated its use with sevoflurane by increasing the proportion of carrier gas passing through the vaporizing chamber and therefore the concentration produced. The ‘induction’ setting greatly increases the concentration delivered to allow gaseous induction. This has, however, resulted in an increase in the resistance to breathing to a level which may be unacceptable to some patients, for example, the frail and elderly who may have difficulty generating sufficient negative pressures and in small infants. To overcome this difficulty, the DDV2 can be used in a continuous flow mode during the induction phase changing to a draw-over mode when induction is complete. If the continuous flow provided is greater than the patient’s minute volume, the resistance throughout the circuit is effectively zero. Intraoperatively, in the draw-over mode, resistances are acceptable for all patient groups.

This scenario is readily achievable when the DDV2 is used with the Glostavent anaesthetic machine which has been specifically designed for use in either continuous flow or draw-over modes. Whenever the flow of supplementary oxygen exceeds the patient’s respiratory minute volume, the pressure within the reservoir increases, the gas flow to the patient becomes continuous, and the effect of the increased resistance is nullified. As soon as induction is complete and the high concentration of sevoflurane is no longer required, the supplementary oxygen flow rate can be reduced below the patient’s minute volume and draw-over anaesthesia is resumed.

In conclusion, modifications have been made to the Diamedica draw-over anaesthetic vaporizer to enable it to be used for both induction and maintenance of anaesthesia using sevoflurane. The high concentration required for gaseous induction can be achieved by using the continuous flow mode during induction and changing to the draw-over mode thereafter.

Declaration of interest
R.N. is the Managing Director of Diamedica UK Ltd.

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