The desflurane Tec 6 vaporizer

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SUMMARY
A late development model of the Tec 6 vaporizer for the administration of desflurane vapour has been evaluated. It is heated electrically and has both electronic monitors of vaporizer function and alarms. The new filling system is a significant improvement over previous Tec filling systems. The vaporizer requires a warm-up period before it may be used, but when activated it provides an output that is approximately linear between 1 and 18% vapour concentrations, at flow rates between 200 ml min⁻¹ and 10 litre min⁻¹. (Br. J. Anaesth. 1994; 72: 470–473)

KEY WORDS

Desflurane is a fluorinated methylethyl ether. It has features that suggest it may be a significant advance compared with previous agents: (a) a low blood-gas partition coefficient (0.42) suggests a rapid onset of and recovery from anaesthesia, and more immediate control of anaesthetic depth. This also suggests greater efficiency if the drug were to be used in a low-flow circle system; (b) minimal metabolism; and (c) greater stability to heat, light and soda lime.

Although synthesized at about the same time as enfurane and isoflurane, the development of desflurane has been delayed by difficulties in synthesis and by two physical characteristics that detract from the above advantages. Desflurane is considerably less potent that isoflurane, with a MAC of approximately 6.0%, which would suggest a greater anaesthetic consumption rate and therefore greater cost; it also has a high vapour pressure (88.5 kPa at 20 °C) and a boiling point of 23.5 °C [1]. It is this latter problem that is the subject of this evaluation. Desflurane is an extremely volatile liquid in the conditions prevailing mainly in U.K. operating theatres, but in many climatic regions (or in neonatal anaesthesia), the ambient temperature may exceed the boiling point and the liquid changes to a gas. To combat this problem Ohmeda have developed the Tec 6 vaporizer to deliver desflurane under control. This report evaluates a late development model, which differs slightly from the eventual production device. It must be noted that all published studies have so far used a different system for delivering desflurane vapour, that of direct metering vaporization, a system where the anaesthetic vapour flow is measured directly using a flowmeter in a manner analogous to that of the copper kettle vaporizer.

DESCRIPTION
The Tec 6 is different in appearance from its predecessors (fig. 1). It is similar in width (11.0 cm) and height (24.5 cm) but substantially deeper in section (25.0 cm). It weighs 9.2 kg and is pale grey in colour except for the dial assembly, front panel display and the filling system, which are black. Each side bears a grille to allow free airflow around the electrical components. The Selectatec mounting system, mechanical interlocks and dial release systems are identical to those on the Tec 5 and similar to the Tec 4 vaporizer. The Tec 6 requires a mains electricity supply and will be available in both 220–240-V and...
100–120-V a.c. formats. It has been constructed to conform with IEC 601-1 and 601-2-13 regulations applying to a class 1 medical device.

PRINCIPLE OF OPERATION
Desflurane liquid is held within the vaporizing chamber (fig. 2) and is heated to 39 °C by two 100-W electrical heater elements. Two further heater elements warm the upper part of the vaporizer to prevent condensation. When operating temperature has been reached, the upper part of the vaporizing chamber contains desflurane vapour under pressure and solenoid-operated locks on the concentration dial and vaporizing chamber outflow are released. Fresh gas from the flowmeters enters the vaporizer and passes through a fixed flow-restrictor, to generate back-pressure, sensed by two independent pressure sensors. Desflurane vapour passes through a shut-off valve and a pressure regulating valve to the concentration selection dial. The pressure of the vapour is detected also by these pressure sensors and by control of the pressure-regulating valve the pressure may be matched to the back-pressure generated by the fresh gas flows. This allows one single dial setting to deliver fixed concentrations of desflurane vapour on the output side of the vaporizer at varying fresh gas flows; higher flowmeter flows produce a larger measured back-pressure, matched by a larger pressure of desflurane vapour, with a resultant greater flow of desflurane vapour from the vaporizer matching the increase in fresh gas flow. The concentration selector has a dial release bar on the back, which is compressed when initially setting a desired concentration. The dial is graduated in increments of 1% between 0 and 10%, and in increments of 2% between 10 and 18%. An interim stop is located at 12%, which requires depression of the dial release bar to bypass, in a manner similar to that used on the 7% Enfluratec 3 vaporizer.

OPERATION
Display and alarms
The display on the front of the vaporizer (fig. 3) provides information on operational status and quantity of desflurane in the vaporization chamber. During warm-up the display and alarms cycle through a check sequence, after which an amber light emitting diode (LED) adjacent to the vaporizing chamber content display is illuminated, this changing to green when the vaporizer is ready for use (it is necessary for the unit to be locked to a Selectatec mount before it is ready for use). Turning the concentration dial locks the unit to the backbar. The content indicator is a vertically mounted liquid crystal display comprising a series of narrow horizontal bars, to simulate a depth of liquid, and is driven by the output of a capacitative level indicator mounted vertically in the vaporizing chamber. To the right of this an arrow indicates the level at which the 450-ml vaporization chamber will accept a full 240-ml bottle of desflurane. When only one bar is visible on this display, an amber LED is illuminated, accompanied by an audible alarm. This indicates that the main part of the vaporization chamber is
Fig. 3. The new version of the Tec 6 display panel (reproduced, with permission, copyright held by the BOC group). This may be modified further on the clinical release vaporizers.

empty, leaving 50 ml in the lower part. The audible alarm may be cancelled by the operator if desired. If the vaporization chamber is not refilled at this stage, the remaining liquid is used up, and if the residual volume decreases to less than 20 ml another alarm sounds, accompanied by a red LED. This combination of alarms indicates that the unit is non-functional and that no vapour is being delivered. The alarm may only be silenced by turning the vaporizer to the standby position without which action, of course, a backbar equipped with Tec 4 or 5 vaporizers does not allow the use of an alternative anaesthetic vaporizer. This alarm pattern follows a natural progression; a green LED indicates normal operation, an amber LED suggests a warning that the operating limits have been approached and a red LED indicates that the unit is being operated beyond its safety limits, and has shut down. In this evaluation model, there is only a small difference in colour between the amber and green LED, which caused confusion at the co-located "warming up/ready" indicator. All other LED are alarms and hence only amber or red, which are readily distinguishable.

During the period of this evaluation, Ohmeda changed the design of the display (fig. 3) and these LED are now clearly separate and distinguishable. The warm-up cycle ends with an audible beep and can be checked easily by attempting to turn the concentration dial. If warm-up is not completed, such attempts are unsuccessful.

Causes of vaporizer shutdown
The solenoid-operated locks within the vaporizer require electrical power to remain in the open position and power failure results in a closing of these locks. Faults detected by the internal temperature and pressure monitors result in rapid shutdown and a red LED signal. A battery is provided, but it only powers the failure alarms; a "low battery" amber LED indicates the need for battery replacement and the batteries are expected to last more than 12 months in normal use.

Previous Tec vaporizers have been shown to alter output if tilted [2]. The Tec 6 incorporates a tilt detector, which shuts off the vaporizer if the tilt exceeds approximately 10°. As the vaporizer is available only in Selectatec or Dräger formats, tilting occurs only if the backbar fitting is distorted significantly. Since the solenoid-operated valves only open when the vaporizer is warmed up and locked onto the backbar, and turning the vaporizer on locks it onto the backbar, there seems little possibility of inverting the Tec 6 with the concentration dial set above zero.

Allowing the vaporizer to empty also results in shutdown as detailed above.

Filling system
Desflurane will be available in brown glass bottles, labelled Suprane, containing desflurane 240 ml, which are plastic coated to protect against pressure effects in the event of damage to the bottle. There is no need for preservative in desflurane and the inert nature of the compound helps minimize the need for frequent cleaning of the vaporizer. The bottles will be complete with a bayonet fitment. This is inserted, against a spring, into the filling port on the left front of the vaporizer and the bottle rotated upwards. This opens a channel into the vaporizer sump and the bayonet fitment is locked in place while the filling takes place. To release the bottle, it is rotated back to the starting position and the spring forces the bottle free. While this positive action is desirable, the possibility exists that the unwary may be surprised, with the bottle being dropped as a consequence. The coating on the bottle protects against the risk of splintering in the event of damage to a warm, pressurized bottle of desflurane (accidental and deliberate breakage of a number of bottles during this evaluation has suggested that the plastic coating is likely to be an effective protection, even if the bottles are pressurized at the time of damage). The vaporizer can be filled readily while in operation. A drainage facility is provided on the base of the vaporizer for service use only and cannot be activated accidentally.

Performance
The vaporizer has been evaluated in both bench tests and clinical use. The content of a full vaporizer is such that even at moderate fresh gas flow rates of 2-3 litre min⁻¹ and delivering concentrations of 3-6% v/v, it is unlikely that refilling should be required in a single operating session. If required, the vaporizer may be filled whilst in use; from
the fill-up mark a full bottle could be emptied into the vaporizer in 125-130 s. This time is reduced if the vaporizer is cold or not being used and a re-designed filling system reportedly allows a bottle to be emptied into the vaporizer in about 70 s [Ohmeda, personal communication]. During testing with a fresh gas flow of 5 litre min\(^{-1}\) and delivering a concentration of 3 %, the output of the vaporizer was unchanged during filling. A warm-up period is necessary before use of the vaporizer and this obviously depends on the liquid capacity and initial temperature of the vaporizer at that time. Nevertheless, the warm-up time for a full vaporizer in these tests was 190-220 s, this being reduced to 125-140 s when it contains only 200 ml, and this should not prove unnecessarily restrictive in practice, although if the ambient temperature was extremely low a prolonged warm-up time (perhaps 10 min) may be required [Ohmeda, personal communication]. Similarly, if the vaporizer should need to be moved into the operating theatre from the anaesthetic room with the patient, the warm-up time on reconnection of the electrical supply is reduced to about 20 s and this is largely the result of the electronic self-checking which occurs whenever the vaporizer is powered up.

The Tec 6 is a plenum vaporizer, but despite the inclusion of flow-restrictors, operation of the vaporizer has no observable effect on the flows indicated on the flowmeter of the anaesthetic machine. The outputs of the vaporizer at high, medium and low fresh gas flows and using oxygen or 67 % nitrous oxide in oxygen were measured using a Datex Capnomac, updated to measure desflurane, and precalibrated with gas standards. The output deteriorates a little at the limits of fresh gas flow, but the inclusion of the electrical heating prevents further deterioration of this performance with time. At all points, the concentration of desflurane delivered at a selected dial setting was smaller with a nitrous oxide-oxygen mixture compared with oxygen. As the back-pressure generated by a gas flow through a resistance depends on the physical characteristics of that gas, this is not surprising. The differences were not great and should have little effect in clinical practice.

In conclusion, the Tec 6 is a robust, but admittedly rather heavy, vaporizer, requiring a Selectatec mount, and care should be taken with older modifications of anaesthetic machines with limited rigidity. It has a new filling system, which represents a substantial improvement over previous keyed filling devices and is still being improved. Its output is approximately linear over the full operating range of 0-18 % v/v and with flow rates of 500 ml min\(^{-1}\) to 10 litre min\(^{-1}\). Although heated electrically it has a rapid warm-up time and can be moved between anaesthetic room and operating theatre with little extra delay. The requirement for an electrical device on the backbar may initially disturb many anaesthetists, who may fear power failure stopping delivery of anaesthesia or electrical safety, but this has not prevented the successful introduction of electrically driven ventilators and monitoring systems onto the modern anaesthetic machine. The inclusion of internal monitoring circuitry allows for greater precision and consistency of vapour delivery and these seem likely to be incorporated into future generations of vaporizer.

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REFERENCES