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Accelerating the Washout of Inhalational Anesthetics from the Dräger Primus Anesthetic Workstation

Effect of Exchangeable Internal Components

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Background: **To establish guidelines for the preparation of the Primus anesthetic workstation (Dräger, Lübeck, Germany) for malignant hyperthermia–susceptible patients, the authors evaluated the effect of replacing the workstation's exchangeable internal components on the washout of isoflurane.**

Methods: **Primus workstations were exposed to isoflurane, and contaminated internal components were replaced as follows: group 1, no replacement; group 2, new ventilator diaphragm; group 3, autoclaved ventilator diaphragm; group 4, autoclaved integrated breathing system; group 5, flushed integrated breathing system; group 6, autoclaved ventilator diaphragm and integrated breathing system. The fresh gas flow was set at 10 l/min, and subsequently reduced to 3 l/min when a concentration of 5 ppm was achieved. Isoflurane concentration was measured in the inspiratory limb of the circle circuit every minute.**

Results: **Washout times for isoflurane decreased in the following order: group 1 (67 ± 6.5 min) > groups 2 and 3 (50 ± 4.1 and 50 ± 5.7 min, respectively) > group 5 (43 ± 9.5 min) > group 4 (12 ± 1.5 min) > group 6 (3.2 ± 0.4 min). Isoflurane concentration increased approximately threefold when the fresh gas flow was reduced to 3 l/min.**

Conclusion: **Washout of isoflurane increased 20-fold with the use of an autoclaved ventilator diaphragm and integrated breathing system. To prepare the Primus for malignant hyperthermia–susceptible patients, the authors recommend replacing the ventilator diaphragm and integrated breathing system with autoclaved components, flushing the workstation for 5 min at a fresh gas flow of 10 l/min, and maintaining this flow for the duration of anesthesia.**

INHALATIONAL anesthetics can trigger malignant hyperthermia (MH) in susceptible patients, resulting in a potentially lethal hypermetabolic reaction in muscles. Inasmuch as the minimum anesthetic dose needed to trigger MH in humans is unknown, it is considered prudent to avoid exposing susceptible patients to even trace concentrations of inhalational anesthetics. Accordingly, the recommended intraoperative management of MH-susceptible patients includes the use of an anesthetic delivery system never exposed to inhalational anesthetics or one flushed using vapor-free fresh gas to remove residual anesthetic vapor.§ Older style anesthetic delivery systems could be effectively flushed in as little as 10 min, whereas the current generation of delivery systems requires considerably longer, in part because of the relative complexity of the internal breathing system circuitry and the presence of internal components made of plastic and rubber into which anesthetic agents can dissolve.[1–3] For example, studies evaluating inhalational anesthetic washout from the Primus workstation (Dräger, Lübeck, Germany) have shown that the time needed to decrease the anesthetic concentration in the breathing circuit to 5 ppm averaged approximately 70 min when using a fresh gas flow of 10 l/min.[3] Moreover, increasing the fresh gas flow to the maximum delivered by this workstation accelerated washout only moderately.[3] Consequently, preparation of such workstations for MH-susceptible patients can result in considerable delays to the surgical schedule. The Primus anesthetic workstation is marketed worldwide with the exception of the United States and Japan, where its counterpart, the Apollo workstation (Dräger), is marketed.

The internal breathing system circuitry of the Apollo is essentially identical to that of the Primus. The manufacturer provides no evidence-based guidelines for the preparation of these workstations for MH-susceptible patients.

In the current study, we sought to evaluate methods to accelerate the washout of inhalational anesthetics from the Primus and to determine which of the workstation's internal components are responsible for the prolonged washout. Specifically, we evaluated the effect of the workstation's exchangeable internal components (ventilator diaphragm and integrated breathing system) on the washout of isoflurane.

Materials and Methods

Dräger Primus anesthetic workstations were equipped with a 1.8-m long disposable circle breathing circuit (Bomi Med Inc., Winnipeg, Manitoba, Canada) and a model lung (Siemens, Solna, Sweden). To standardize exposure to isoflurane, the workstations were primed for 2 h with 1.5% isoflurane in air at a fresh gas flow of 2 l/min, and the model lung was ventilated using a tidal volume of 500 ml and a rate of 15 breaths/min. On completion of priming, the ventilation was stopped, the anesthetic vaporizer was removed, and the carbon dioxide absorber canister, circle circuit, and model lung were replaced with components

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that had not been exposed to inhalational anesthetics. In addition, fresh Amsorb® (Armstrong Medical, Coleraine, Northern Ireland) was placed in the carbon dioxide absorber canister. To study the washout of isoflurane, the fresh gas flow was set initially at 10 l/min, ventilation was recommenced using the same minute ventilation as during priming, and the concentration of isoflurane in the inspiratory limb of the circle circuit was measured every minute (early washout phase). The washout time for isoflurane was defined as the time from initiating a fresh gas flow of 10 l/min until a concentration of 5 ppm was achieved in the inspiratory limb of the circle circuit. When the concentration of isoflurane reached 5 ppm, the fresh gas flow was reduced to 3 l/min to simulate a clinically relevant flow, and the concentration of isoflurane was measured every minute for an additional hour or until the concentration reached 5 ppm again (late washout phase). A Miran SapphIRe 205B Series Portable Ambient Air Analyzer (Thermo Electron Corporation, Waltham, MA) was used to measure the concentration of isoflurane in the inspiratory limb. This device has an accuracy of ±5% and a sensitivity of 0.1 ppm. A zero calibration was performed in a remote location outside the operating room immediately before each experiment. A calibration filter (North Safety Products, Cranston, RI) was attached to the entry port of the Miran analyzer before the zero calibration.

Six Dräger Primus anesthetic workstations were studied in each of the following groups. For each group, the specified change to the internal components was made immediately before the start of the early washout phase.

Group 1: None of the internal components was changed (control group).

Group 2: The ventilator diaphragm was removed and replaced with a diaphragm that had never been exposed to anesthetic vapor (new ventilator diaphragm).

Group 3: The ventilator diaphragm was removed and replaced with a diaphragm that had been exposed to 1.5% isoflurane for 2 h in another Primus workstation and subsequently autoclaved at 132°C for 10 min (autoclaved ventilator diaphragm).

Group 4: The integrated breathing system was removed and replaced with one that had been exposed to 1.5% isoflurane for 2 h in another Primus workstation and subsequently autoclaved at 132°C for 10 min. To remove residual water after autoclaving, the integrated breathing system was flushed using a forced-air gun (autoclaved integrated breathing system).

Group 5: As a control for group 4, the integrated breathing system was removed and replaced with one that had been exposed to 1.5% isoflurane for 2 h in another Primus workstation and then flushed thoroughly using a forced-air gun as in group 4, without being autoclaved (flushed integrated breathing system).

Group 6: Both the ventilator diaphragm and the integrated breathing system were removed and replaced with components that had been exposed to 1.5% isoflurane for 2 h in another Primus workstation and subsequently autoclaved at 132°C for 10 min. To remove residual water after autoclaving, the integrated breathing system was flushed using a forced-air gun (autoclaved ventilator diaphragm and integrated breathing system).

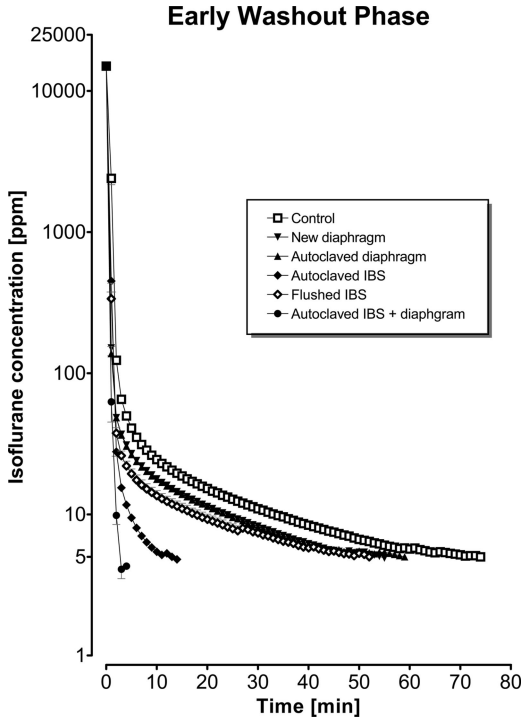

Fig. 1. Early washout profiles for isoflurane in the Dräger Primus anesthetic machine. In the control group (group 1), isoflurane concentration decreased to 5 ppm after 67 ± 6.5 min of washout. When the ventilator diaphragm and integrated breathing system (IBS) were replaced with autoclaved components (group 6), washout time for isoflurane decreased 20-fold, the concentration reaching 5 ppm after only 3.2 ± 0.4 min of washout ($P < 0.001$ compared with control). Data are mean ± SD.

Statistical Analysis

Data are expressed as mean ± SD. Washout times and isoflurane concentrations were compared using one-way analysis of variance and the Student Newman-Keuls *post hoc* test. $P < 0.05$ was considered statistically significant.

Results

Early Washout Phase

The concentration of isoflurane in the inspiratory limb of the circle system decreased exponentially during the early washout phase in all groups (fig. 1). In the control group, isoflurane concentration decreased to 5 ppm after 67 ± 6.5 min of washout. Isoflurane concentration decreased only moderately faster when a new ventilator diaphragm was used, reaching 5 ppm after 50 ± 4.1 min of washout ($P < 0.001$ compared with control). A similar washout time, 50 ± 5.7 min, was achieved with the use of an autoclaved ventilator diaphragm ($P < 0.001$

Table 1. Washout Times (Early Washout Phase) and Maximum Rebound Concentrations (Late Washout Phase)

Group	Early Washout Phase, Time to 5 ppm, min	Late Washout Phase, Max Concentration, ppm
Group 1: control	67 ± 6.5	16.0 ± 1.6
Group 2: new diaphragm	50 ± 4.1*	17.3 ± 0.8
Group 3: autoclaved diaphragm	50 ± 5.7*	16.8 ± 0.5
Group 4: autoclaved IBS	12 ± 1.5*	13.5 ± 0.6†
Group 5: flushed IBS	43 ± 9.5*	16.1 ± 0.8
Group 6: autoclaved diaphragm and IBS	3.2 ± 0.4*	12.8 ± 2.1†

The washout time for isoflurane was defined as the time from initiating a fresh gas flow of 10 l/min until a concentration of 5 ppm was achieved in the inspiratory limb of the circle circuit.

* $P < 0.001$ compared with control. † $P < 0.01$ compared with control.

IBS = integrated breathing system; Max = maximum.

compared with control). Washout profiles for the new and autoclaved diaphragm were almost identical. The use of an autoclaved integrated breathing system accelerated the washout of isoflurane considerably, resulting in a clinically significant reduction in washout time. When an autoclaved integrated breathing system was used, isoflurane concentration decreased approximately fivefold faster than in the control group, reaching 5 ppm after 12 ± 1.5 min of washout ($P < 0.001$ compared with control). Flushing the integrated breathing system with forced air, as had been done to dry the integrated breathing system after autoclaving, did not achieve as rapid a washout as with the use of an autoclaved integrated breathing system, the isoflurane concentration reaching 5 ppm after 43 ± 9.5 min of washout ($P < 0.001$ compared with control and $P < 0.001$ compared with autoclaved integrated breathing system). Isoflurane washout was most rapid when both the ventilator diaphragm and the integrated breathing system were replaced with components that had been autoclaved. In the latter group, isoflurane concentration in the inspiratory limb of the circle circuit decreased 20-fold faster than in the control group, reaching 5 ppm after only 3.2 ± 0.4 min of washout ($P < 0.001$ compared with control and $P < 0.05$ compared with autoclaved integrated breathing system). Washout times are summarized in table 1.

Late Washout Phase

During the late phase of the washout, we observed a rebound increase in the concentration of isoflurane in the inspiratory limb of the circle circuit in all groups (fig. 2). In the control group, the isoflurane concentration increased approximately threefold to a maximum of 16.0 ± 1.6 ppm and then decreased slowly, remaining above 5 ppm for the duration of the experiment. Isoflurane concentration increased to a maximum of 17.3 ± 0.8 and 16.8 ± 0.5 ppm with a new and autoclaved ventilator diaphragm, respectively, and remained above 5 ppm for the duration of the experiments. The use of an autoclaved integrated breathing system resulted in a significantly lower maximum concentration (13.5 ± 0.6 ppm) compared with the control group ($P < 0.01$). Flushing the integrated breathing system with forced air alone was ineffective in reducing the maximum isoflurane concentration reached during the rebound (16.1 ± 0.8 ppm). When both the ventilator diaphragm and the integrated breathing system were replaced with autoclaved components, the isoflurane concentration increased to 12.8 ± 2.1 ppm ($P < 0.01$ compared with control), returning to 5 ppm after 47.6 ± 7.0 min of washout in three of six workstations; in the three remaining, isoflurane concentration was greater than 5

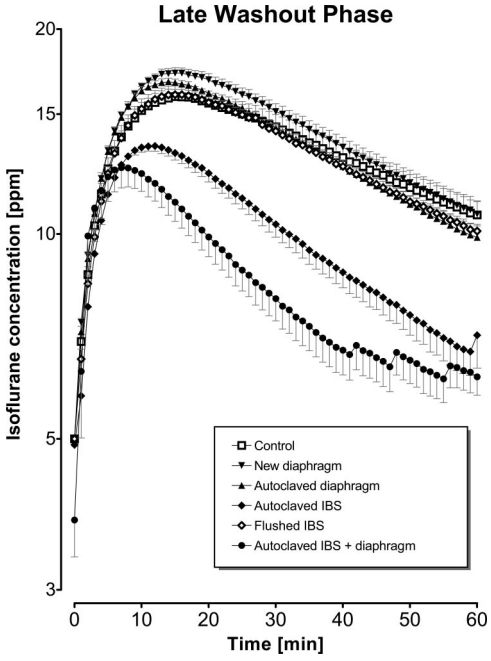

Fig. 2. Late washout profiles for isoflurane in the Dräger Primus anesthetic machine. When the fresh gas flow was reduced from 10 l/min to 3 l/min, we observed a rebound increase in the concentration of isoflurane in the inspiratory limb of the breathing circuit. In the control group (group 1), the isoflurane concentration increased approximately threefold to a maximum of 16.0 ± 1.6 ppm and then decreased slowly, remaining above 5 ppm for the entire 1-h duration of the experiment. When the ventilator diaphragm and integrated breathing system (IBS) were replaced with autoclaved components (group 6), the isoflurane concentration increased to 12.8 ± 2.1 ppm ($P < 0.01$ compared with control), returning to 5 ppm after 47.6 ± 7.0 min of washout in three of six machines; in the three remaining, isoflurane concentration was greater than 5 ppm at 1 h. Data are mean ± SD.

ppm at 1 h. Maximum rebound concentrations are summarized in table 1.

Discussion

The washout of inhalational anesthetics from the current generation of anesthesia workstations is relatively slow and unaffected by an increase in fresh gas flow or minute ventilation.[2,3] To our knowledge, alternative methods to accelerate anesthetic washout from the current generation of anesthesia workstations have not been investigated. In the current study, we evaluated the effect of replacing the Primus' exchangeable internal components on the washout of isoflurane. Our results demonstrate that replacing the ventilator diaphragm and integrated breathing system greatly speeds the washout of isoflurane, decreasing the time to achieve a concentration of 5 ppm in the circle breathing circuit by approximately 20-fold. Inasmuch as the internal circuitry of the Apollo, including the ventilator bellows and integrated breathing system, is identical to that of the Primus, these results are applicable to the Apollo workstation as well.

The slow washout of inhalational anesthetics from the workstations can be attributed to several factors.[3] The breathing system circuitry internal to the workstation comprises plastic and rubber components into which inhalational anesthetics can dissolve, the rate of absorption depending in part on the anesthetic concentration, the partition coefficients, and the surface area exposed.[4] The internal circuitry is also compartmentalized, resulting in the potential for pockets of fresh gas containing relatively high anesthetic concentrations that can be flushed out only slowly. In addition, to prevent dependency of tidal volume on fresh gas flow, the Primus uses a principle referred to as fresh gas decoupling,[5] in which the ventilator and the inspiratory part of the internal circuitry are decoupled from the fresh gas flow during the inspiratory phase of positive pressure ventilation (fig. 3). Thus, fresh gas passes to the reservoir bag *via* the carbon dioxide absorber in inspiration and is subsequently fed directly into the breathing system together with the stored volume *via* a nonreturn valve (fresh gas decoupling valve) in expiration (fig. 3). Accordingly, the internal breathing system circuitry is flushed only intermittently during the respiratory cycle, suggesting that it might act as a reservoir for inhalational anesthetics when the workstation is being prepared for MH-susceptible patients. The current data confirm this prediction by showing that replacing the integrated breathing system when contaminated greatly speeds anesthetic washout. That thorough flushing of the integrated breathing system with forced air was relatively ineffective in accelerating isoflurane washout suggests that compartmentalization and fresh gas decoupling are of lesser importance than the solubility of isoflurane in the plastics (polyphenylensulfide and polyphenylensulfone) of the breathing system.

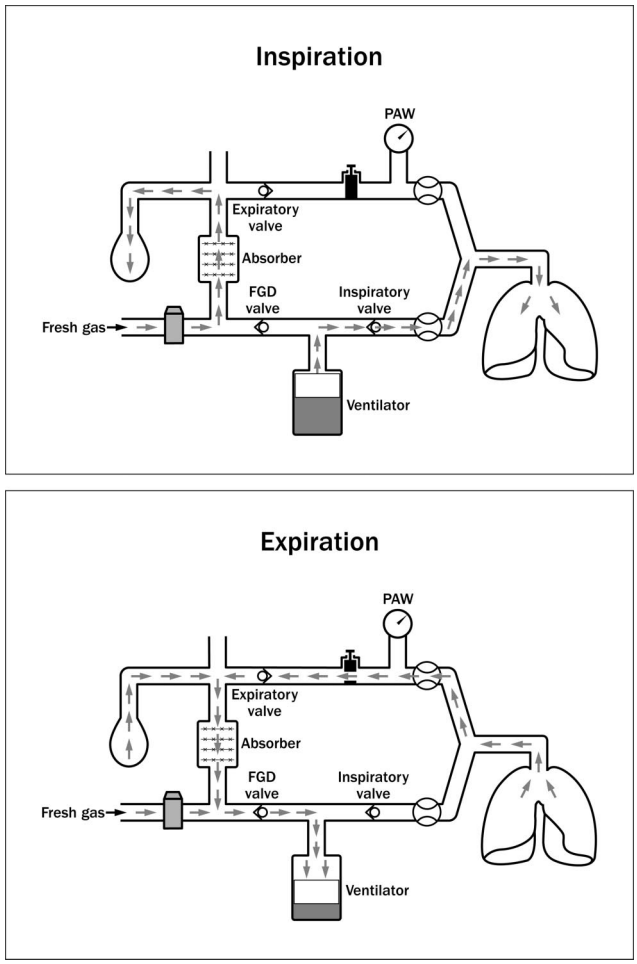

Fig. 3. Diagram showing the principle of fresh gas decoupling (FGD). During positive-pressure ventilation, the ventilator and the inspiratory part of the internal circuitry are decoupled from the fresh gas flow in inspiration. Thus, fresh gas passes to the reservoir bag *via* the carbon dioxide absorber in inspiration and is subsequently fed directly into the breathing system together with the stored volume *via* a nonreturn valve (fresh gas decoupling valve) in expiration. PAW = airway pressure.

The ventilator diaphragm and integrated breathing system are easily accessible and replaceable as described in the workstation's user manual.[6] In brief, the handle of the integrated breathing system is held and the unit is pulled out; the three sealing screws (fig. 4A) on the ventilator cover are loosened a quarter turn using the key supplied by the manufacturer; the integrated breathing system is removed from the ventilator module exposing the ventilator diaphragm, which is then removed (fig. 4B); the autoclaved ventilator diaphragm and integrated breathing system are inserted into the ventilator module; the three sealing screws are tightened and the integrated breathing system is reinserted into the workstation until it engages. This step-by-step procedure is easy to learn, is simple to perform, and can be completed in less than 5 min. A routine workstation check should follow the procedure.

Both the ventilator diaphragm and integrated breathing system can be autoclaved.[6] However, the flow sen-

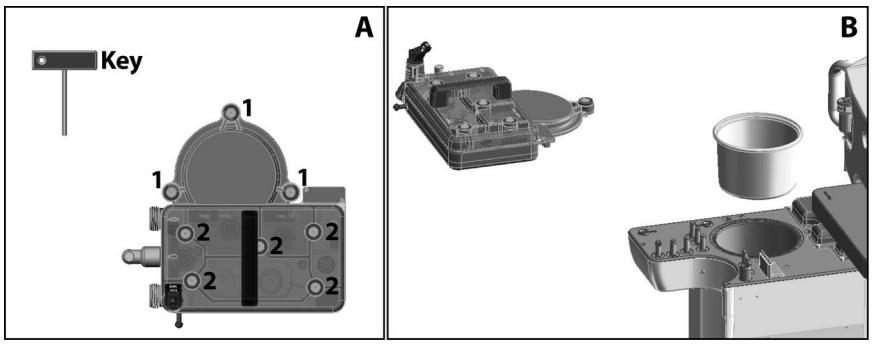

Fig. 4. The Dräger Primus integrated breathing system and ventilator diaphragm. To remove the integrated breathing system from the ventilator module, three sealing screws (labeled 1) on the ventilator cover are loosened a quarter-turn using the key supplied by the manufacturer (*A*). Removing the integrated breathing system exposes the ventilator diaphragm, which is then removed (*B*). To prepare the integrated breathing system for autoclaving, it is separated into its three components by loosening five sealing screws (labeled 2) a quarter-turn using the key supplied by the manufacturer (*A*). Modified with permission from Reference 6.

sors cannot be autoclaved and must be removed from the breathing system before autoclaving by unscrewing the inspiratory and expiratory ports. To prepare the integrated breathing system for autoclaving, it is separated into its three component parts by loosening five sealing screws (fig. 4A) using the key supplied by the manufacturer. The cover is then removed from the metal valve plate, which in turn is removed from the base, and each part is autoclaved.

In the current study, we standardized the circuit configuration, isoflurane concentration, period of exposure, method of measurement, and fresh gas flow. A priming concentration of 1.5% was used for 2 h to evaluate the washout of a clinically relevant concentration of isoflurane. A Miran SapphIRe 205B Series Portable Ambient Air Analyzer, which uses infrared spectroscopy, measured the concentration of isoflurane in real time. The fresh gas flow of 10 l/min used for the early washout phase is commonly recommended for flushing anesthesia delivery systems.§ In the late washout phase, we decreased the fresh gas flow to 3 l/min to simulate a clinically relevant flow. The threefold increase in isoflurane concentration observed during the late washout phase is consistent with published data.[2,3] The exact cause of the rebound increase in concentration is unclear. Anesthetics elute slowly from the plastic and rubber components of anesthetic delivery systems, the rate depending on the amount dissolved and the partition coefficient.[7] That the use of autoclaved components had little effect on the maximum concentration attained during the rebound suggests that autoclaving might not have completely eliminated dissolved isoflurane and/or that other reservoirs are responsible for the rebound increase in concentration. Whether exposure to the anesthetic concentrations found during the rebound can trigger MH is unknown. To avoid unintentional exposure of MH-susceptible patients to inhalational anesthetics, we recommend maintaining a fresh gas flow of 10 l/min for the duration of the anesthetic.

We flushed the Primus until an isoflurane concentration of 5 ppm was achieved. Because the minimum anesthetic concentration necessary to trigger a reaction in MH-susceptible humans is unknown, endpoint concentrations in previous studies have been variable and range from 1 to 10 ppm.[1–3,8,9] Evidence suggests that MH-susceptible swine do not develop MH when exposed to 5 ppm of halothane (Denise Wedel, M.D., Mayo Clinic, Rochester, Minnesota, October 2, 2006, personal communication). In addition, ambient anesthetic concentrations were frequently in the range of 1 to 5 ppm before waste gas scavenging became standard in the operating room, and to our knowledge, there are no reports of MH reactions in healthcare workers exposed to the operating room environment. Accordingly, we used a vapor concentration of 5 ppm as a valid measurement endpoint.

These findings have important fiscal implications. Many anesthesia departments purchase an anesthesia workstation that is reserved for use with MH-susceptible patients. It is often difficult to justify the cost of these "clean" workstations given the infrequency of their use. The current findings indicate that the Primus, when equipped with an autoclaved ventilator diaphragm and integrated breathing system and flushed for 5 min, provides an alternative anesthetic delivery system for MH-susceptible patients. Given the results of this study, the authors' department now stocks a ventilator diaphragm and integrated breathing circuit specifically for use with MH-susceptible patients. These components are autoclaved after each use. Given that approximate current costs for the Primus' ventilator diaphragm and integrated breathing system are US $125 and $5,300, respectively, the use of autoclaved components is an economical alternative to a dedicated MH anesthetic workstation.

In summary, we have shown that the Primus' ventilator diaphragm and integrated breathing system act as important reservoirs for inhalational anesthetics when preparing the workstation for use with MH-susceptible patients. Replacing the ventilator bellows and integrated breathing system with autoclaved components greatly speeds anesthetic washout. To prepare the Primus for MH-susceptible patients who present for elective surgery, we propose the following guidelines: (1) remove all vaporizers, (2) replace the ventilator diaphragm and integrated breathing system with autoclaved components, (3) ventilate a model lung for 5 min using a new external disposable breathing circuit and a fresh gas flow of 10 l/min, and (4) maintain this fresh gas flow for the duration of anesthesia.

We submit that this method of preparation is a safe and economical alternative to the use of a dedicated workstation for MH-susceptible patients.

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