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Adaptation to the waste anesthesia gas system: Gaps in knowledge and opportunities for positive environmental impact

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ABSTRACT

Canisters containing activated charcoal are commonly used in the laboratory setting to collect waste anesthetic gas (WAG). This requires the weighing of the WAG canister after each use and for investigators to maintain an accurate time log of anesthesia duration. A typical rodent anesthesia station may include the use of 3 WAG canisters; one for the anesthesia induction box, one for the operative table, and one for gas monitoring. To simplify the anesthesia breathing circuit, we have developed a "T" connector that replaces the need for having multiple WAG canisters. The "T" connector directs the waste anesthetic from multiple sources; the anesthesia induction box, operative table and gas monitor into a single WAG canister. Use of the "T" connector appears to be a safe, acceptable device that conveniently directs waste gas while improving charcoal adsorption within the canister. In addition, this device may have a positive impact on the environment with a secondary benefit of possible cost savings associated with the purchase and disposal of the hazardous waste contents.

Keywords

Activated charcoal, Inhalation anesthetic, Isoflurane, Occupational Health, Rodent, Waste Anesthetic Gas

ARTICLE HISTORY

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INTRODUCTION

Halogenated inhalation anesthetics offer several advantages over injectable anesthetics when used during rodent surgery. Their use provides for rapid induction, greater adjustment of anesthetic depth, and a faster recovery period. In addition, physiological changes are minimal, with administration of appropriate concentrations, thus allowing for reproducible results and increased rodent survival. Despite these benefits, it was originally reported that chronic, exposure of humans to anesthetics has been associated with an increased incidence of neurologic and reproductive dysfunction, hepatic and renal toxicity, and neoplasia (Manley et al., 1980; Smith and Bolon, 2002, 2006). Occupational health and safety guidelines, from the American Society of Anesthesiologists (NIOSH, 1977), indicate that current data fail to demonstrate that trace concentrations of waste anesthetic gas are associated with any health hazards to exposed personnel. Acknowledging the inability of these studies to establish a causal relationship, the National Institute for Occupational Safety and Health (NIOSH) has specified that it is unable to identify a safe level of isoflurane exposure. It therefore recommends that the risk be minimized by "reducing exposure to the greatest extent possible" (NIOSH, 1977). In addition, the Occupational Safety and Health Administration (OSHA, 2006) has not established a permissible exposure limit, but has recommended that no worker should be exposed to greater than 2 ppm of any halogenated anesthetic agent.

Canisters containing activated charcoal are commonly used in the laboratory setting to collect the waste anesthetic gas (WAG). As the activated charcoal captures the waste gas, the canister becomes heavier with mass being somehow proportional to the amount of gas adsorption. One such product is marketed under the name Omnicon F/Air (AM Bickford, Wales Center, NY). Manufacturers of the F/Air canister indicate that no less than 50 gm of a pure halogenated anesthetic gas can be removed with an average use life of 12-15 h. It is their recommendation that canisters which exceed the specified accumulated weight or hours of use should be conveniently disposed (Bickford, 2012). This process requires the WAG canisters be weighed after each use and for investigators to maintain an accurate time log of anesthesia duration.

In our laboratory setting, a typical rodent operative station includes the use of 3 WAG canisters; induction box, stereotaxic nose cone, and physiologic gas monitor. To simplify the scavenging portion of the anesthesia breathing circuit, we have developed a "T" connector (**Figure 1**). This device eliminates the need for having multiple WAG canisters. The purpose of this paper is to report the results of a study that was designed to quantitatively assess the effectiveness of this "T" connector in directing waste gas into an Omnicon F/Air canister.

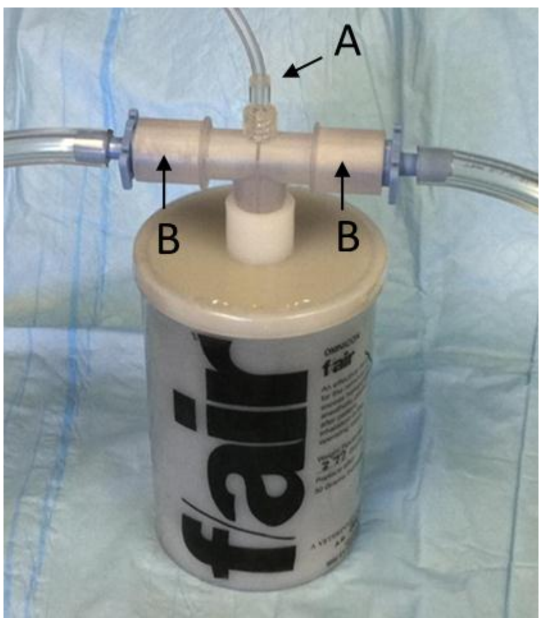

Figure 1: Profile of the "T" connector demonstrating the collection of waste gas from multiple sources. The arrow (A) represents the luer-lock connection for receiving waste anesthetic gas from the physiologic monitor. The arrows (B) represent the combined 19 mm/22 mm connections that receive the waste anesthetic gas from the induction box and operative table.

MATERIALS AND METHODS

Using rapid prototyping technology, we developed a "T" connector that directs waste anesthetic, from multiple sources, into a single WAG canister. This "T" connector has three, isolated channels (**Figure 2**) and is designed to utilize either an "inner" 19 mm diameter or "outer" 22 mm diameter connection with the capability to connect either a syringe or small diameter tubing to a luer-type fitting.

To initially test the safety of the WAG "T" connector, a 5% concentration of isoflurane with 1 l/min of O_2 was delivered, in succession, through each of the three isolated ports. A calibrated, physiologic, monitor (Datex-Ohmeda; GE Healthcare, Fairfield, CT) was placed in-line, to detect gas escape at any of the adjoining ports. No escaping anesthetic was detected and the product was felt to be safe for laboratory use. The Datex-Ohmeda physiologic monitor is capable of measuring isoflurane at levels <3%.

All procedures followed strict adherence to animal care and use protocols (ILAR, 2011). The WAG canisters were suspended below the operative table height and above the floor to allow for the passive collection of waste gas and proper venting of the canister. The recording of canister weight changes and duration of anesthetic use are standard practice and a requirement of our Occupational Safety and Environmental Health (OSEH) program.

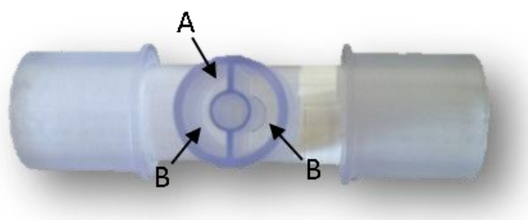

Figure 2: Bottom view of the "T" connector displaying the lumens of each of isolated channels. The center, circular, lumen (A) is the luer-lock connection from the physiologic monitor while the semi-circular lumens (B) direct waste gas from the induction box and the operative table into the charcoal canister.

A new, Omnicon F/Air canister was weighed using a Mettler PL3000 balance (Mettler-Toledo; Columbus, OH) and dated prior to use in the anesthesia circuit. These canisters contain approximately 200 gm of activated charcoal. Using the "T" connector, waste gas tubing from the induction box, nose cone at the operative table, and gas monitor were directed into a single F/Air canister. Following an approved animal use protocol, each rodent underwent isoflurane induction (2.5-3.0% volume of mixture) in a plexiglass induction box. The rodent was removed from the induction box and then securely placed into the nose cone on the surgical table where inhalational anesthesia (1.3-2.0% volume by mixture) was continued for the duration of the procedure. Afterwards, the rodent was recovered and monitored before being returned to its original bedding cage. The F/Air canister was removed from the anesthesia circuit, weighed and then vigorously shaken before being placed back into the circuit.

To obtain comparison data, the above procedures were performed with waste gas canisters individually connected to each the induction box, nose cone, and gas monitor. This provided an additional method to compare accumulated weight changes during both conditions; with and without use of the "T" connector.

All values for the canister weight, isoflurane concentrations and duration of anesthesia were recorded into an Excel© spreadsheet (Microsoft Corp.; Redmond, WA) following each procedure. Results are presented as the WAG canister accumulated weight change during the cumulative time of canister use. Canisters were removed from use when the accumulated weight of the canister plateaued or neared a total accumulated weight increase of the manufacturer's recommended 50 gm. Inhalational anesthesia was delivered through a calibrated isoflurane vaporizer (Ohio Medical Products; Madison, WI). The air exchange in the research room was measured at 17.7 air exchanges per hour.

The laboratory in which the device was tested has a 13 year history of rodent anesthesia using volatile anesthetics. During that time no individuals have complained of any physiologic or clinical effects attributed to an adverse exposure to a halogenated anesthetic. While the perception of odor, from a volatile agent, may be an unreliable indicator of an anesthetic leak, no reports of anesthetic odor, adverse events, or device failure attributed with use of the "T" connector or any of the canisters occurred during testing.

RESULTS

Two canisters were studied, in separate comparisons, using the "T" connector. In total, the "T" connector underwent 4788 min of testing (79.8 h) on 30 rodent procedures. During the initial trial, (**Table 1**) 16 procedures were performed. The average procedure time (induction time + experiment time) was 137.9 min (range; 22-238 min). The total duration of use for the first canister was 2207 min (36.8 h). During this time, the F/Air canister attained an accumulated weight increase of 51.4 gm over the baseline weight. Several procedures were performed in succession and weights were not immediately obtained, therefore, a slightly lesser number of data points are presented on the graph (**Figure 3**). The average weight change of the WAG canister per min was 0.023 gm/min (range; 0.018 to 0.036 gm/min). This canister was removed from use and properly discarded as hazardous waste.

Following the above methods, testing of the "T" connector was repeated using a new Omnicon F/Air canister. This canister displayed similar characteristics over the entire duration of its use. An additional 14 procedures were performed with an average procedure time (induction time + experiment time) of 184.3 min (range; 93–307 min). Isoflurane concentrations for induction and the experiment were unchanged. The total duration of canister use was 2581 min (43.0 h) with a corresponding accumulated weight increase of 52.2 gm over the baseline weight. The average weight change per min for the WAG canister was 0.020 gm/min (range; 0.014 to 0.034 gm/min). This canister was also removed from use and properly discarded.

Using separate charcoal canisters (without the "T" connector) in each condition; induction box, nose cone, and gas monitor, additional data was collected during two additional trials (**Table 1**). The first trial of 15 procedures totaled 2009 min (33.5 h). During this time, the F/Air canister for the nose cone had an accumulated weight increase of 55.6 gm over its baseline weight while the accompany canister for the gas monitor accumulated 50.7 gm (**Figure 4**). The average weight change, per min of time, was 0.027 gm/min and 0.025 gm/min respectively. Both canisters were removed from use and properly discarded.

Using "new" Omnicon F/Air charcoal canisters, the above process was repeated as a comparison. The comparison trial of 17 procedures totaled 2039 min (34.0 h). During that time the canister connected to the nose cone accumulated 47.7 gm over its baseline weight while the canister for the gas monitor accumulated 46.0 gm. The average weight change per min was 0.023 gm/min. and 0.022 gm/min, respectively. Again, both canisters were removed from use and properly discarded.

DISCUSSION

The results are discussed below relative to two questions this study was designed to answer regarding use of the "T" connector. 1) Can the "T" connector be used to combine waste gas, from multiple sources, into a single canister? 2) Should disposal guidelines for waste gas canisters be revised?

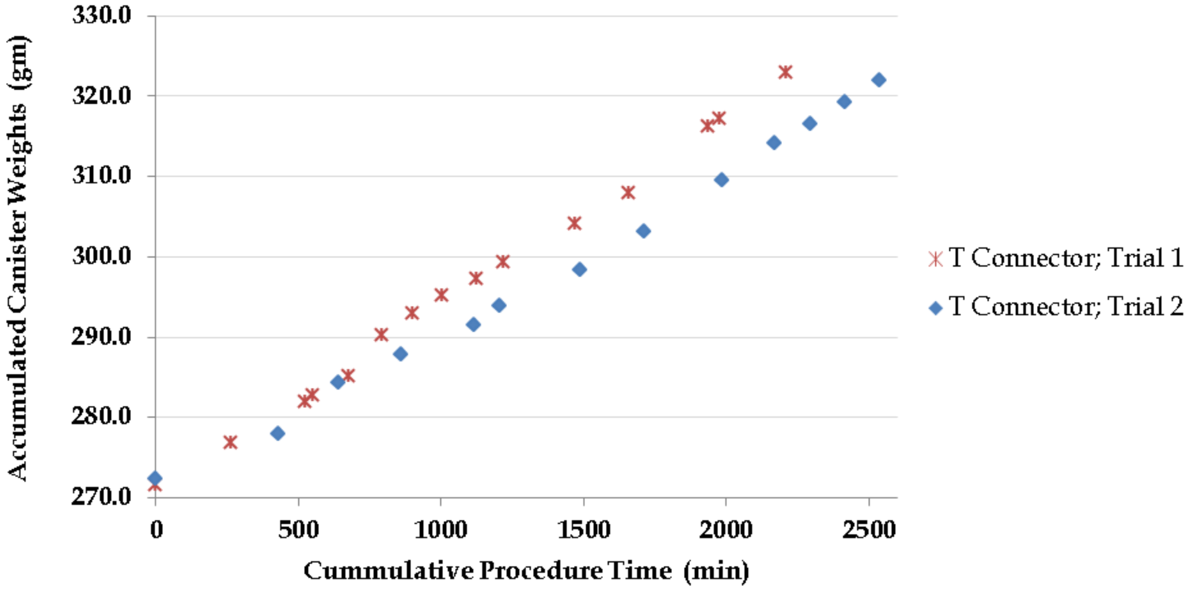

Figure 3: Accumulated canister weights using the "T" connector to direct waste anesthetic gas into a single charcoal canister. Plotted on the X-axis are the cumulative procedure times represented in min. On the Y-axis are the accumulated canister weights in grams.

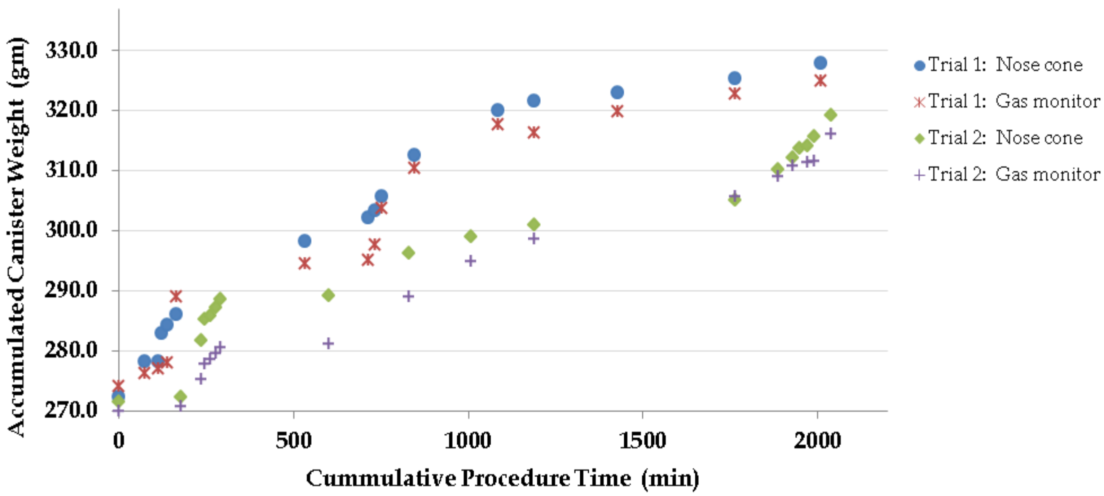

Figure 4. Accumulated canister weights using direct connection to individual charcoal canisters. In each trial, results are for the nose cone and the accompanying gas monitor.

Single canister use with multiple gas sources: Unlike the traditional aerosol "T" connector (Hudson RCI; Durham, NC), our design is unique in that each of the 3 openings are isolated. This prevents the communi-cation of waste gas through the adjoining openings and bypassing the charcoal canister. Although no scientific instrumentation was employed to test for isoflurane saturation or leakage from the F/Air canister, use of the "T" connector demonstrated reproducible results during the near 80 h of testing.

As expected, a linear increase in canister weights was observed during the 30 trials using the "T" connector. In addition, our indexed measure of canister weight change per min further demonstrates the stability of the canister to adsorb isoflurane over a prolonged period of time while using our novel device. We can only speculate that the use of a lower isoflurane concentration combined with the delivery flow rate or the vigorous shaking of the canister, to redistribute the charcoal, improved the longevity of the canisters. Although not tested, the possibility of a unique aerodynamic component, associated with the combination of multiple gas sources passing through the "T" connector, may have improved the adsorption characteristics of the WAG canister.

Single canister use with single gas source: Simultaneous measurements for the canisters for the nose cone and accompanying gas monitor showed

Table 1: Charcoal canister characteristics with and without use of the "T" connector.

Conditions	Total Procedures Performed/ Canister	Accumulated Canister Weight Increase Over Baseline (gm)	Maximum Duration of Canister use (min)	Average Canister Weight Increase/ min (gm/min)	Average Canister Weight Increase/ Procedure (gm)
"T" Connector (Trial 1)*	16	51.4	2207 (36.8 h)	0.023	3.21
"T" Connector (Trial 2)*	14	52.2	2581 (43.0 h)	0.020	3.72
Trial 1 Nose Cone #	15	55.6	2009 (33.5 h)	0.027	3.71
Gas Monitor #	-	50.7	-	0.025	3.38
Trial 2 Nose Cone #	17	47.7	2039 (34.0 h)	0.023	2.80
Gas Monitor #	-	46.0	-	0.022	2.71

* Wase gas canister receives anesthetic gas from 3 simultaneous sources; Induction box, stereotaxic nose cone, and physiologic gas monitor

Waste gas canister receives anesthetic gas from a single source "T" Connector

some variability in recorded values over their duration of use. While incremental increases in accumulated weights were observed, the recorded weight changes were inconsistent. We suspect that the higher gas flow, through the nose cone tubing, when compared to the smaller diameter tubing of the physiologic gas monitor or an obstruction within the gas monitor may account for these variations in accumulated weights between the canisters.

Waste gas disposal recommendations: Two 1970's studies; one a survey of female nurse anesthetists, found 71/434 (16.4%) infants born to mothers who worked in the operating room during pregnancy had birth defects while 15/261 (5.7%) whose mothers did not practice during pregnancy had anomalies (Corbett et al. 1974). The second study (Pollution in the operating room, 1973; Bruce et al., 1974) exposed 20 paid male, medical / dental students, to 4 h of inhalation of 500 ppm of nitrous oxide and 15 ppm of halothane. Psychological tests given afterwards showed "a significant decrement in performance following the anesthetic exposure". Studies that attempted to replicate these results failed to confirm these findings (Smith and Shirley, 1978). The author (Bruce and Stanley 1983; Bruce, 1991) later recanted his original report by the statement "there is no longer any need to refer to our conclusions as controversial. They were wrong, derived from data subject to inadvertent sampling bias and not applicable to the general population. The NIOSH standards should be revised." As a footnote, Bruce (1991) served as a "Review Consultant" for the 1977 NIOSH waste anesthetic gases and vapors report. While we recognize that the above studies are "outdated" both are provided as supporting references in current Omnicon F/Air product literature (Bickford, 2012).

To add further uncertainty to the use of these charcoal canisters, the waste gas policy from the University of Michigan OSEH and an internet search of several other research facilities showed similar, but varied, interpretations of when a WAG canister should be discarded. Examples include; canisters that exceed 12 h of use or 50 gm of accumulated weight (whichever comes first) must be removed and placed in a pail for disposal through OSEH as a hazardous waste, University of Michigan OSEH Guideline, Anesthetic Gas Use Policy, 7/8/2009. Discard the F/Air canister after either 12 h of use or 50 gm increase in weight, Cornell University, Waste Anesthesia Gas Scavenging Systems, ACUP 712.01. Usage must be documented and accompanied by the method used to determine canister life as supplied by the manufacturer. For F/Air canisters this involves weighing the canister before and after use and discarding the canister when there is a 50 gm increase from the initial weight, Johns Hopkins University Animal Care and Use Committee. The F/Air canister should be replaced after 12-15 h of use or after 50 gm of weight is gained (whichever is reached first), Maintenance of Anesthetic Vaporizers 8.3.1.1, University of Texas (9/01/2011). All F/air canisters must be monitored by weight after each use. The canister is discarded when a 50 gm increase in weight has been achieved, University of Notre Dame Institutional Animal Care and Use Committee Policy on Anesthetic Gas Monitoring.

Recognizing that some WAG canisters may contain a mass of activated charcoal exceeding 200 gm, the OSEH at our institution has since revisited our disposal guidelines. Our institution's policy has been revised to "canisters that accumulate 25% of the active charcoal weight must be removed and placed in a labeled pail for disposal as a hazardous waste."

Smith and Bolon (2003) has previously demonstrated a marked variability in gas-scavenging characteristics that exists between different brands of commercially available activated charcoal canisters. Isoflurane levels $\geq$5 ppm but $\leq$100 ppm were detected from the exhaust ports of 10/37 (27%) F/Air canisters they tested. The effectiveness of a WAG canister to adsorb isoflurane is likely related to the total content of activated charcoal contained within the canister, the physical properties of the charcoal (Vaughan et al., 1973; Kim and Sircar, 1977; Burkhart and Stobbe, 1990) diffusion pathways that may develop within the charcoal (Bracken and Sanderson, 1955; Vaughan et al., 1973; Kim and Sircar, 1977; Smith and Bolon, 2003) the concentration of isoflurane delivered, and the flow rate at which the anesthesia is delivered (Smith and Bolon, 2003). There also exists the possibility that certain environmental conditions such as room temperature, humidity (Vaughan et al., 1973), air exchanges in the room (Smith and Bolon, 2003) or exposure of the WAG canister to direct sunlight might also affect its adsorption efficiency. We also speculate that the increase in gas flows, from combining waste gas, through the "T" connector may produce a slight back-pressure within the canister that may enhance the adsorption characteristics of the canister.

In the United States Patent Office (USPTO) application for the Omnicon F/Air canister, it states that the canister was developed primarily to allow the "smaller" veterinary clinics, without access to air scavenging systems typically found in hospitals, to capture the WAG (Burkhart, 1991). These canisters fulfill that need since they are compact, inexpensive, and allow for anesthesia to be delivered outside of the traditional operating room. It is unclear how the average use of 12-15 h or the 50 gm of accumulated weight increase was determined. However, the USPTO application does reference the prototype experiment [18] where 2.5 kilograms (5.5 pounds) of a powered activated "fish aquarium" charcoal should provide about 100 h of service life when using a 1.0% concentration of Halothane at a flow rate of 3.0 l/min.

Potential environmental impact: While representatives of AM Bickford have provided statements suggesting that their product can be conveniently discarded into the trash, our institution does not allow this practice. To further assess the "traditional trash" disposal recommendation of the manufacturer, we retrospect-tively measured, with use of a Miran SapphiRe 1-B analyzer (Foxborro Co., Foxborro, MA), isoflurane levels in 3 conditions; a saturated F/Air canister (with 50 g of accumulated weight), the same canister with the contents emptied into a plastic bag, and the contents of our hazardous waste container with 11 saturated F/Air canisters. Our results suggest that a saturated, un-tampered, F/Air canister does emit about 1.7 ppm of isoflurane through its openings. However, when the contents, of this same canister were opened and emptied into a plastic bag, isoflurane levels were recorded at >25 ppm. Lastly, isoflurane, from within our hazardous waste container, exceeded 130 ppm upon opening.

By combining the waste gas from several sources, use of the "T" connector will reduce the time to regularly collect, weigh, document, and replace each canister. Significant savings might also be realized if current "time-of-use" guidelines, for canister disposal, are eliminated. This recommendation is based entirely on our results which demonstrate, at our concentrations and flow rates, an F/Air canister with and without use of the "T" connector accumulates approximately 20 gm of weight at 12-15 h of use. Additionally, since canisters are constructed from bulky and slowly degrading materials, reducing canister disposal volume will have a positive impact on the environment. The present finding encourages a future study designed to quantify the environmental effects secondary to any off-gassing from disposed canisters.

We recommend that all WAG canisters should be shaken vigorously after each weighing. This may prevent the formation of low-resistance pathways within the charcoal canister thereby possibly extending the efficacy of the product. This technique is described within the USPTO application (Burkhart, 1991) and Burkhart's (Burkhart and Stobbe, 1990) article but not within the Omnicon product literature (Bickford, 2012).

Recommendations by Omnicon F/Air for canister disposal, following an accumulated 50 gm weight increase, are satisfactory guidelines. However, due to the high levels of isoflurane found within discarded F/Air canisters, that are stored within a hazardous waste container for a later pick-up, we recommend that all WAG canisters containing a volatile anesthetic should be immediately disposed of as hazardous waste.

LIMITATIONS

While we did determine the patency of the "T" connector, with a 5% concentration of isoflurane, use of a Miran SapphiRe analyzer was not used to confirm this. The Miran analyzer could also have been used to measure any breakthrough of isoflurane through the WAG canister during our testing process. This might have provided additional value to the data by precisely determining when the WAG canister was saturated or no longer effective in capturing isoflurane. Due to the duration of data collection, the cost to purchase or lease an infrared analyzer was cost prohibited. However, observing trends in both the accumulated weights and the weight change per min might prove beneficial in determining when a WAG canister has reached its maximal capacity to adsorb isoflurane.

CONCLUSION

What our study has shown is use of the "T" connector appears to be a safe, acceptable device that will reduce the numbers of WAG canisters in place. Our findings further indicate that use of the "T" connector does not result in a waste canister that saturates faster when compared to the conventional use of 3 waste canisters. In addition, incorporation of this device, into our laboratory environment, has greatly improved the available operative workspace and has re-emphasized employee safety awareness of inhalational anesthesia use. Given this information, we strongly encourage that further research into the application of this "T" connector should be undertaken. Secondly, uniformity among research facilities regarding disposal guidelines of these WAG canisters should also be revisited.

CONFLICT OF INTEREST

The Authors do not report any conflict of interest.

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