Vaporized Anesthetic Utilizing a New Device during a Zero Gravity Parabolic Flight

Available online: November 19, 2016 Published: December 17, 2016

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Introduction:
Zero gravity anesthesia research has mainly focused on inject-able methods. A new 3D printable device is now available to deliver inhaled anesthetics. It is a handheld anesthesia device (HHAD) with four ports allowing for anesthetic injection, respirator pressure control, and scavenging of waste gases. It requires a standard silicone ventilation bag as a chamber for delivery of the anesthetic.

Methods:
The HHAD was attached to a CPR manikin on-board a modified Boeing 727 for parabolic flight. The respiration of the manikin was driven by an air compressor. Air from the cabin was pushed through the HHAD system and into the manikin’s lung. 7.5cc of sevoflurane was to be sprayed into the system and scavenged by an activated carbon filter and the air would be returned to the cabin. The spray of sevoflurane was monitored by a small camera inside the silicone bag attached to the HHAD. Each injection would occur at the beginning of the zero gravity portion of the flight and would be repeated three times during the flight. Anesthetic concentration was monitored by an infrared detector attached near the mouth of the manikin. HHAD’s adjustable pressure limiting (APL) valve was used to control airway pressure by a valve knob on the device. Cabin pollution was monitored by badges(x4) worn by the researchers.

Results:
The small internal camera showed adequate spray of the sevoflurane. All three times the IR gas monitor showed a predicted MAC of >2% and a ET of greater than >4%. Average cabin pollution was 2.14ppm for sevoflurane. Respiratory pressure ranged from 5 to 23.5cm H2O.

Conclusion:
Vaporized anesthesia with HHAD may be a safe and viable means of delivering anesthesia in an enclosed zero gravity.

Key Words: anesthesia, inhaled anesthetics, parabolic flight, sevoflurane, automatic respiration, zero gravity, microgravity, space

Disclosures
Dr. Naoyuki Ishikita is the patent holder for this device and received a grant from Japan’s Ministry of Economy, Trade and Industry.
Dr. John Sczepaniak received $1433.57 from Dr. Naoyuki Ishikita for engineering, organizing, analyzing, and producing this project.

This research was presented at ECAM in Oslo, Norway September 2016 as a poster.

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Figure 1 Setup for the CPR manikin. Sevoflurane is sprayed into the conventional ventilation bag and flows through the handheld anesthesia device toward the manikin’s lung. The waste gas then travels out from the lung to the activated charcoal filter.

attachment of a silicone ventilation bag (260g), an activated charcoal filter (418g), and a syringe containing the anesthetic. When the syringe is compressed the anesthetic will travel through a tube to a spray head inside the ventilation bag. Air or oxygen flow through the ventilation bag will act as a carrier gas. The gas will flow through the device and enter the lungs via a modified facemask, laryngeal mask airway, or intubation tube. (Figure 1)

The purpose of this study was to test the ability of HHADs to vaporize anesthetics in microgravity, to deliver sufficient anesthetic concentrations, and to control cabin pollution of waste gases.

Methods
This study was approved by the Zero Gravity Corporation and Federal Aviation Administration after a thorough safety evaluation. No human subjects were anesthetized so an institutional review board was not sought.

The HHAD (VapoJect™) was attached to a Paul Compact CPR Training Manikin on-board a modified Boeing 727 for parabolic flight(Figure 1).
respiration of the manikin was driven by an air compressor (Linear Ac 0201A Compressor). Air from the cabin was pushed through the HHAD system and into the manikin’s single plastic lung (Figure 1). The plastic lung on the manikin has a max volume of 5.4 liters that was reduced to 2.0 liters when installed. An elastic band attached to hard plastic rib cage over the lung provided elasticity. Exhaled air was filtered through an activated carbon filter (VaporGuard™) and returned to the cabin.

Before each zero gravity parabola, a prefilled syringe of sevoflurane was attached to the HHAD via a Luer-Lok needless system. Once release was called, the sevoflurane would be sprayed into a conventional silicone ventilation bag through a tube and spray head. The HHAD inlet port was modified with a rubber inlet to prevent back flow of sevoflurane from the tube between injections. Each trial occurred after approximately five parabolas to allow washout of the previously injected sevoflurane. CPR compressions were performed on the manikin during these intervening parabolas for a separate experiment. The first two HHAD trials used 7.5cc of sevoflurane and the last trial injected 10cc.

The injection was monitored by a small camera (Angel Eye) inside the silicone bag. The camera was attached to an HDMI cable that came out from the bag and attached to the display. Before injecting the sevoflurane, the record button on the display would be pressed to capture the stream of sevoflurane from the spray head.

Once the sevoflurane was pushed, concentrations were monitored by an infrared detector (VEO multigas monitor, AX+) attached near the mouth of the manikin. The software for the IR detector displayed the end tidal concentration (ET), fraction inspired agent (FI), and estimated mean alveolar concentration (MAC) for sevoflurane on the desktop of the onboard computer. The desktop was recorded using Cam Studio software version 2.7.2 (Build r326). Another IR detector was also attached to the lower left side of the manikin’s lung to detect sevoflurane movement.

Cabin pollution was monitored by badges (x4, media 574A) worn by the researchers. The two researchers had a badge on both suit pockets. Both researchers were in close proximity to the manikin throughout the flight (one at the head of the manikin and the other at the abdomen). One badge was closed after the first and third trial. The remaining two badges were closed after break down of the research project prior to descent. Badges were analyzed by Assay Technology, Inc. Livermore CA (Method Reference: MOD OSHA 103).

The HHAD’s adjustable pressure limiting valve was used to control airway pressure by a valve knob on the device. Attempts to measure respiratory pressure were made with a manometer (Mercury Medical disposable manometer, US Pat No. 5,557,049) and an electrical sensor using a MEMS Gauge Pressure Sensor (2SMPP-02) (Supplemental). For the electrical sensor, voltage changes were amplified and converted to a frequency. These frequencies were recorded on an Olympus digital voice recorder (vn-3200PC). Audio files were analyzed with Spek-Acoustic Spectrum Analyser (Version 0.8.2). Frequency was changed back to pressures using a calibration curve post flight.

Head camera videos were reviewed for pressure gauge readings, IR detection, and timing of injection. Video analysis was performed on Windows Movie Maker (Version 6.0.6002.18273 and Version 2012). Timing of events was accomplished by synchronizing sounds and clocks from the head cameras, angel camera, desktop clocks, etc. Desktop IR recordings were analyzed with Adobe Photoshop CS3 (Version 10.0) and Microsoft Excel 2007 to generate moment by moment IR sevoflurane measurements.

The temperature sensor (Thermochron, KN Laboratories) was allowed to float in the ventilation bag.

Results

The small internal camera showed adequate spray of the sevoflurane in microgravity (Figure 2).
greater than >4% (Figure 3). Badge values for the two researchers onboard were 0.48, 0.87, 3.3, and 3.9 ppm with a reporting limit of 0.26ppm. Average cabin pollution was 2.14ppm (Standard Deviation=1.71) for sevoflurane. Post flight manikin lungs were examined and a small leak was detected. The leak was around the additional IR detection port. Adjustable pressure limiting valve knob settings were not recorded (eg how many turns). Pressures from the manometer gauge were sporadically recorded on a head camera. Pressures were cycling from approximately 5 to 15cm of H$_2$O. Pressures recorded on the Mercury Medical gauge did not exceed 20cm of H$_2$O during the brief periods of video recording. Electronic recordings showed pressures given in figure 4 for the third trial. Pressures from the total electronic recording ranged from 6 to 23.5cm H$_2$O and respiratory rate ranged from 22/min to 48/min.

Temperature inside the ventilation bag dropped from approximately 30°C to 21.5°C after removal from stowage. Temperature spiked downward three times.

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**Figure 3** IR detection data for sevoflurane during the three test parabolas. Trial 1 and 2 used 7.5cc of sevoflurane and trial 3 used 10cc.
during the flight after each sevoflurane injection followed by a return to in-flight baseline around 21.5°C. Drops were 8, 3.7, and 6.7°C in magnitude respectively.

**Discussion**

Vaporized anesthesia with a HHAD seems to be a safe and viable means of delivering anesthesia in zero gravity for an intubated patient. It can be performed in an enclosed environment with high efficiency filters at pollution levels near the Occupational Safety and Health Administration standard of <2 ppm for halogenated anesthetics.\(^\text{11}\)

The leak in the lung may have contributed slightly to the pollution results. The breakdown of the project may have led to the two larger pollution values 3.3, and 3.9 ppm sevoflurane.

There was a very small loss of sevoflurane during syringe exchange between trials. This potential pollution source can be controlled by limiting the need to switch out syringes. Depending on the length of anesthesia required, a larger syringe or a bottle with an internal pressure bladder may be used to push sevoflurane into the HHAD system.\(^\text{4}\)

This research flight simulated an intubated patient in microgravity. Intubation can be successfully performed by the free-floating or strapped down techniques.\(^\text{3}\) There have also been significant advances in Laryngeal mask technology that may assist in the use of inhalational anesthesia.\(^\text{2}\)

One of our researchers did not have the anesthesia software setup properly leading to the curves presented in figure 3. The software for the IR detector was set to detect desflurane instead of sevoflurane. Desflurane does have some similarities to the IR absorption spectrum of sevoflurane so the values may approximate sevoflurane. The software took 2-3 seconds to recognize that anesthetic was sevoflurane and not desflurane. Trial 1 and 2 switched to an average reading mode for approximately 5 sec before starting continuous measurements of sevoflurane. The researcher also failed to set the scale for %sevoflurane to 10% instead of 5%. It is important to run a ground based rehearsal prior to loading the experiment to ensure ideal data collection. A rehearsal will also benefit this research by providing a terrestrial comparison.

Respiratory rate and pressures differed in zero gravity when compared to higher gravity levels. Adjustment of the adjustable pressure limiting (APL) valve may be necessary from the terrestrial settings, especially when dealing with a paralyzed patient.

**Advantages**

Sevoflurane minimizes hypotension and maintains spontaneous ventilation.\(^\text{8}\) Recovery may also be more rapid than intravenous procedures, which would be important for aerospace personnel. IV methods of general anesthesia require an IV pump in zero gravity and the potential for gas embolism.\(^\text{7}\)

**Cautions**

Care must be taken not to fully close the adjustable pressure limiting valve on the HHAD as it will smother the patient. There are obvious concerns with using
halogenated anesthetics including impaired cardiovascular stability, increased dysrhythmias, malignant hyperthermia, and vomiting.\(^5\)

**Future Research**

This study did not look at the various modes of HHAD attachment to the manikin. A well fitting mask, LMA and intubation tube may be utilized in further studies to look at pollution levels. Various pollution control measures such as a larger syringe or a bottle may be tested on subsequent parabolic flights to limit the number of system reloads.

Further research is also required on a >3 minute space flight to use inhalational anesthesia in a human participant. A pilot study may take place in a human centrifuge simulating a commercial space flight.\(^1\) Focus on Intracranial pressure measurements are of particular concern as inhalational anesthetics raise ICP \(^10\).

Additional research is also needed on mass/efficacy comparisons to other anesthetics.

**References**


**Acknowledgements**

Thank you to NewTon, co., ltd. for technical support.

Thank you to Peter and Alan Sczepaniak for technical support.

Thank you to Kyle Freiman for ground assistance at the flight in Orlando.

Thank you to Chungbin Yoo for abstract writing and ECAM coordination.

Thank you to everyone else who helped make this project possible.

Financial support in-part from the Japan Ministry of Economy, Trade and Industry. The Ministry had no role in study design or collection, analysis or interpretation of the data. The Ministry had no role in our decision to conduct this study or publish this work.


*These were gifts to Dr. Sczepaniak and not to the project. They expected no reward or recognition but their help made this project financially possible.