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An Ongoing Series

Draw-over Anesthesia

Bringing the "Dark Art" Back Into the Light

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ABSTRACT

Draw-over anesthesia, once commonly used by military anesthetists, has become less familiar in high-income countries (HICs). With favorable properties of robustness, portability, and the ability of the user to service the vaporizer along with being unaffected by unreliable electricity supplies, these machines are still commonly used in low-middle income countries (LMICs) throughout the world. They are used to deliver a variety of anesthetic agents from ether and halothane to the more familiar isoflurane and sevoflurane. As Special Operations medical personnel operate within these remote locations, they will come across such equipment. This article aims to refresh their knowledge of draw-over equipment and the techniques used to operate them.

KEYWORDS: *draw-over; drawover anesthesia; anesthesia; austere; field hospital; Special Operations Surgical Team (SOST); unconventional medicine*

Introduction

Draw-over vaporizers and circuits, once the "go-to" anesthetic delivery system of most military anesthetists, have fallen out of favor in recent times. This is possibly due to the nature of recent operations being more protracted, resulting in a more robust logistic chain able to support the more familiar plenum anesthetic machines used in civilian practices, along with more interest in total intravenous (IV) anesthesia (TIVA) techniques. This has resulted in newer generations of anesthesia providers being unfamiliar with draw-overs, to the point of some regarding it as a "black art." However, a draw-over apparatus' light weight and robust mechanics and the ability of the user to trouble-shoot and service them lend it to being a valuable tool for the military anesthetist working in the more remote and austere setting.[1] With recent interest among Special Operations Forces (SOF) of deployments in indigenous environments, the augmentation of a host nation's medical system, and the possibility of deployments to less mature theatres, perhaps it is time to re-examine the use of this versatile piece of anesthetic equipment.

What Is Draw-over Anesthesia?

Draw-over anesthesia is a simplified method of delivering an anesthetic vapor to a patient, the vapor being the gaseous phase of anesthetic agent that sits above the liquid. Draw-over vaporizers were one of the earliest methods of delivering a volatile to a patient and have been used by many military anesthetists during the past 150 years.[2] On 16 October 1846, when William Morton first demonstrated ether anesthesia at Massachusetts General Hospital, he used a glass bulbous structure with two openings that he named the Morton Etherizer (Figure 1). One opening was connected to a mouthpiece and the second opening allowed air to be drawn in over a sponge soaked in ether.[3] This device used to deliver the first volatile anesthetic is a basic draw-over apparatus, without the ability to vary the concentration of inhaled vapor, compensate for temperature, or ventilate an apneic patient, but a

FIGURE 1 *"Ether Day, 1846" by Warren and Lucia Prosperi. This painting hangs in the "Ether Dome of Massachusetts General Hospital and shows William Morton Holding the etherizer he used to anesthetize Edward Gilbert Abbott. Image courtesy of the Massachusetts General Hospital, Archives and Special Collections.*

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draw-over vaporizer just the same. A modified version of this device would later be taken by the 3rd Dragoons surgeon, Dr Edward H Barton, to the Mexican-American War to deliver anesthesia to wounded soldiers in 1847.[4]

The delivery of an anesthetic agent by a draw-over vaporizer relies on the patient's respirations or the use of a manual ventilator such as a self-inflating bag (SIB) to draw a carrier gas across a volatile anesthetic. In its simplest form, the carrier gas can be atmospheric air; however, oxygen can be added to the carrier gas to increase the patients inspired oxygen concentration (FIO_2).

The air and oxygen mixture enters the draw-over vaporizer inlet before being split into two parts. The first part passes through a chamber containing air saturated with the anesthetic vapor, while the other bypasses this chamber. The percentage of anesthetic vapor delivered to the patient is adjusted by altering the ratio of gas bypassing the vaporizing chamber. This is called the splitting ratio. The carrier gas and anesthetic vapor mixture is administered to the patient via a simple circuit composed of an SIB and two one-way valves. The first valve, placed at the outlet of the vaporizer, prevents backflow of the carrier gas through the vaporizer when the SIB is squeezed. The second valve is placed at the patient end of the circuit and prevents rebreathing (Figure 2).

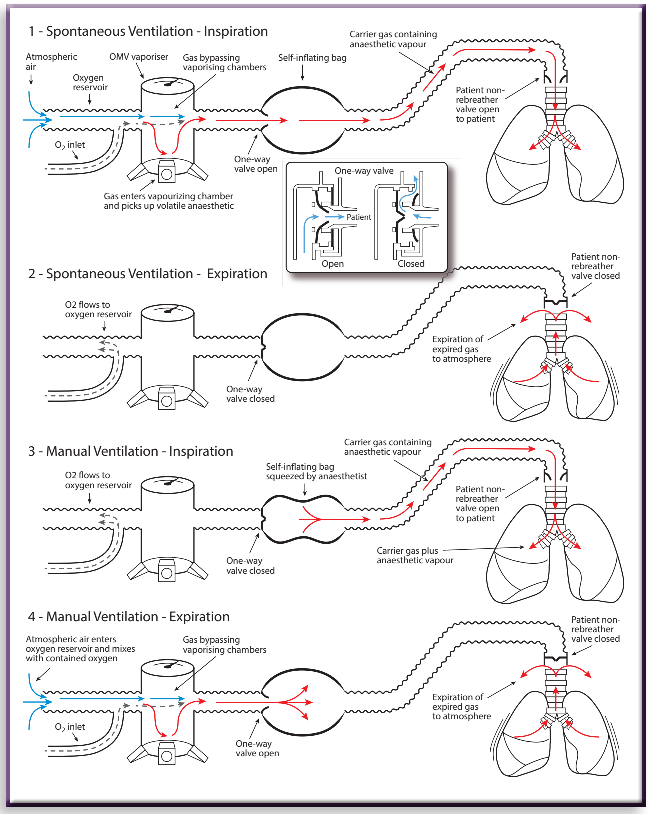
Draw-over anesthetic vaporizers operate at ambient pressure with intermittent flow through the system varying with the phases of respiration. Flow occurs only during inspiration. This is different from a plenum vaporizer on the familiar Boyle's anesthetic machine such as those used in HICs (Figure 3). These vaporizers operate at higher than atmospheric pressure (4 atm) and have a high internal resistance, requiring the use of bottles or tanks of oxygen, medical air, and nitrous oxide. The flow through a plenum vaporizer is at a constant rate selected by the use of flowmeters.[5] As the flow through the draw-over vaporizer is driven by the patient's respirations or ventilation from an SIB, it must have a low internal resistance in order to reduce the work of breathing.[6]

Advantages of draw-over anesthetic machines compared with plenum machines for use in the austere environment include;

1. Portable, robust, reliable, and lightweight
2. Inherent simplicity that enables trouble shooting and servicing by the anesthetic provider
3. No reliance on power or compressed gases
4. Ability to be used in extremes of temperature
5. Ability to use a variety of anesthetic volatile agents, from ether to sevoflurane

The draw-over method does have its disadvantages, however, with the main one being the lack of familiarity with the system by modern anesthetic providers. Other disadvantages are the small reservoir compared with a modern plenum vaporizer, which requires more frequent filling; lack of alarms to alert the anesthetist of an empty vaporizer and the bulkiness of the patient's one-way valve, which can be cumbersome, particularly in pediatrics.[7] The draw-over system also does not allow for rebreathing of expired gasses and while this has an inherent safety, making the delivery of a hypoxic mixture impossible, it results in increased consumption of volatile agent compared to a circle system. More importantly as the patient expires anesthetic agent into the surrounding environment volatile anesthesia is unsuitable for use in unventilated spaces such as an aircraft.

FIGURE 2 *Schematic diagram of an Oxford Miniature Vaporizer and Laerdal self-inflating bag showing the phases of spontaneous and manual ventilation.* **(1)** *Inspiratory phase spontaneous ventilation. Air mixes with oxygen contained in the oxygen reservoir, then travels through the vaporizer picking up anesthetic vapor that is then delivered to the patient through the nonrebreather valve.* **(2)** *Expiratory phase spontaneous ventilation. Expired air containing anesthetic vapor is exhaled from the patients lungs and exits to the environment through the expiratory valve of the patient non-rebreather valve. During this phase of ventilation oxygen flows through into the oxygen reservoir.* **(3)** *Inspiratory phase manual ventilation. As the self-inflating bag is squeezed air and oxygen containing anesthetic vapor is delivered to the patient through the inspiratory part of the nonrebreather valve. While this is occurring oxygen flows into the oxygen reservoir.* **(4)** *Expiratory phase manual ventilation. With the release of the self-inflating bag the negative pressure produced in the bag draws oxygen and air from the oxygen reservoir through the vaporizer and into the bag. At the same time recoil of the patients lungs allows the expiration of gas through the expiratory part of the non-rebreather valve.*



Commonly Used Draw-over Systems

The two most common draw-over systems used by militaries are the Universal Portable Anesthesia Complete (PAC)[8] (Figure 4), which is used by the US Military, and the Oxford Miniature Vaporizer (OMV), which is part of the British Triservice Anesthetic Apparatus[9] (Figure 5) and the Australian ULCO Box[10] (Figure 6).

The Universal Portable Anesthesia Complete

The PAC, manufactured by Ohmeda, has had extensive use by forward surgical teams (FSTs) in the early stage of the Afghanistan campaign. Later, as the area of operations became more mature, it was replaced by bulky plenum machines such as the Drager Fabius Tiro. The PAC is now out of manufacture

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FIGURE 3 *Draeger anesthetic machine fitted with sevoflurane and desflurane plenum vaporizers at the Wollongong Hospital in Australia.*

FIGURE 4 *Ohmeda Universal Portable Anesthesia Complete (PAC).*

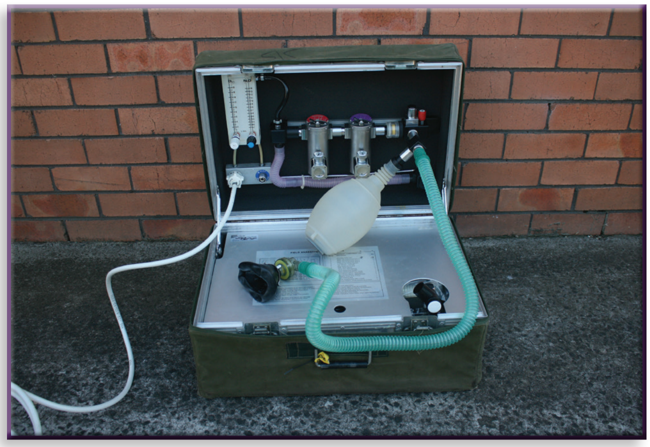
by Ohmeda, however a number of devices can still be found throughout the world and the maintenance manual is available on the company website (www.frankshospitalworkshop.com).[11]

The PAC is able to be used with all volatile anesthetic agents except desflurane. It has temperature compensation via a bimetallic strip that varies the amount of carrier gas traveling through the vaporization chamber with changes in temperature.[12] This compensates for increased flow rates seen with larger patients, as increased tidal volumes will vaporize more anesthetic agent, with a resulting decrease in temperature due to the latent heat of vaporization of the agent. With a decrease in temperature, the bimetallic strip inside the vaporizer bends, allowing more carrier gas to pass through the vaporizing chamber. The PAC has its own oxygen nipple on the vaporizer inlet port for the addition of oxygen and an internal one-way valve on the outlet port to stop expired gas from traveling back through the vaporizer.

The vapor output is controlled by a rotating dial on the top of the vaporizer connected to a rotating valve that alters the splitting ratio. One side of the dial is marked with graduations for isoflurane, and the other is marked for halothane. There is also a disc that can be used in place of the isoflurane or halothane scale with graduations marked from A through to F. These graduations refer to a table on the side of the vaporizer that shows the approximate output for diethyl ether, enflurane, halothane, and isoflurane (Figure 7). There are no

FIGURE 5 *Two Oxford Miniature Vaporizers (OMVs) in the British Tri-service Apparatus.*

FIGURE 6 *Australian ULCO Box containing two OMVs.*



markings for sevoflurane, but because sevoflurane's boiling point (58.5˚C)[13] is similar to enflurane's (56.5˚C), the enflurane scale can be used as an approximation. As the boiling points of isoflurane (48.5˚C) and halothane (50.2˚C) are less than sevoflurane's, use of the dial for these agents would result in an overestimation of the delivered sevoflurane concentration.

The vaporizer can be used in draw-over mode, where carrier gas is drawn through the vaporizer, or in push-over mode, where the carrier gas is pushed through the vaporizer by either an SIB or a mechanical ventilator.[14] When used in the push-over mode, the oxygen enhancement nipple should be blocked off by clamping the attached oxygen tubing or insertion of a bung to avoid ventilation leaking out through the outlet, reducing the tidal volume delivered to the patient.

The Oxford Miniature Vaporizer

The OMV was used by the British in the Falkland's war[15] and by both Australian and British anesthetists during the early phases of the Afghanistan war. It is lighter and smaller than the PAC at 1.65kg.

As with the PAC, the OMV is able to use multiple volatile agents, and removable scales are available for halothane, isoflurane, trichloroethylene, methoxyflurane, enflurane, chloroform, and sevoflurane. The vaporizer's output is controlled by a rotating lever on the top of the vaporizer that is connected to a valve controlling the splitting ratio of carrier gas. Rotating

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FIGURE 7 *Anesthetic output scale on the side of the Ohmenda PAC.*

the lever clockwise increases the output of the vaporizer. Turning the lever fully anticlockwise will completely close the vaporizing chamber, enabling the vaporizer to be transported without spilling any anesthetic agent.[16]

The OMV is filled by unscrewing the filler cap located on the front of the vaporizer and pouring anesthetic agent into the filling orifice. The control lever should be turned to the off position before removing the filler cap because the patient's respiration will draw air directly through the vaporizing chamber resulting in the delivery of an excessive anesthetic mixture. The vaporizer can be drained by turning the filler cap upside down and using the notch on the top of the cap to unscrew the tap located inside the filling orifice.[17]

The OMV can deliver an output of up to 4% isoflurane and halothane[17] and around 2.5% to 3% of sevoflurane.[18] Both the British and Australian Defence forces deployed with two OMVs used in series. This setup was initially designed so that halothane and trichloroethylene could be used together (halothane for anesthesia and trichloroethylene for its analgesic qualities).[19] In more recent times, the two OMVs in series provided a benefit in delivering sevoflurane anesthesia, enabling the anesthetist to deliver 5% to 6% sevoflurane, which is adequate for a gas induction.[18]

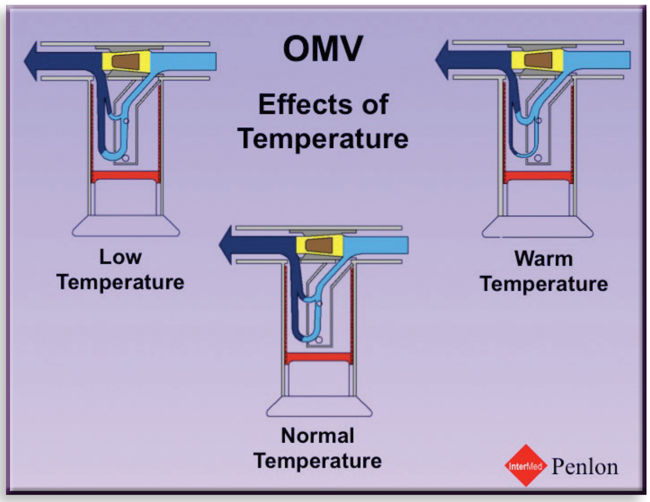
The OMV has an agent reservoir of only 50mL compared with the PAC's reservoir volume of 85mL. This small volume will allow up to 1 hour of continuous anesthesia with isoflurane and halothane[20] but only 30 to 40 minutes with sevoflurane. The twin vaporizer setup of the Triservice Apparatus allows the anesthetist to have a filled vaporizer ready in reserve for when the first vaporizer requires refilling.

Temperature compensation of the OMV is more rudimentary than that of the PAC. There is no active thermo-compensation such as a bimetallic strip, but the base contains antifreeze to act as a temperature buffer and some compensation occurs with changes in flow dynamics through the vaporizer with changes in temperature. With a fall in temperature (such as occurs with increased patient respiration), an increase in flow of the carrier gas is directed deeper into the OMV's vaporizing chamber where the vapor concentration is higher (Figure 8).

Other Draw-over Vaporizers

A large variety of vaporizers exist that are used in hospital throughout LMICs. Each has its own small differences but is set up using the same basic circuits as the above two vaporizers and are able to deliver much the same anesthetic agents.

FIGURE 8 *Diagram of gas flow through the OMV with changes in Temperature. Image courtesy of Penlon limited.*



The Epstein Macintosh Oxford (EMO) vaporizer was an early and widely used vaporizer, particularly in Africa. Originally designed for use with ether, it is one of the largest vaporizers with a 450mL anesthetic reservoir[21,22] (Figure 9). It is important that halothane is never used in this vaporizer as the thymol used as a preservative in halothane will irrevocably damage the vaporizer's internal controls.

FIGURE 9 *Epstein Macintosh Oxford vaporizer.*

A newer vaporizer that is being seen more and more in low-resource healthcare settings, particularly in Africa, is the Diamedica Vaporizer (Figure 10). It is commonly seen as part of the Glostavent anesthesia machine that is produced by the same company (www.diamedica.co.uk) and in a portable version that is currently in use by the British Military. The Diamedica is similar in design to the OMV but has the added advantage of a larger agent reservoir of 150mL. It can be used with halothane, isoflurane, or sevoflurane and can be used as a draw-over or push-over or, if compressed gasses are available, with continuous flow as a plenum vaporizer.[23]

When faced with an unfamiliar vaporizer, it is worthwhile to look online for a manual or an article on the specific device. However, if these are unavailable, the main points to identify, inspect, and understand are the

1. Anesthetic agent filling port
2. Agent reservoir level that indicates when the vaporizer is full and empty, and what is the volume of this reservoir

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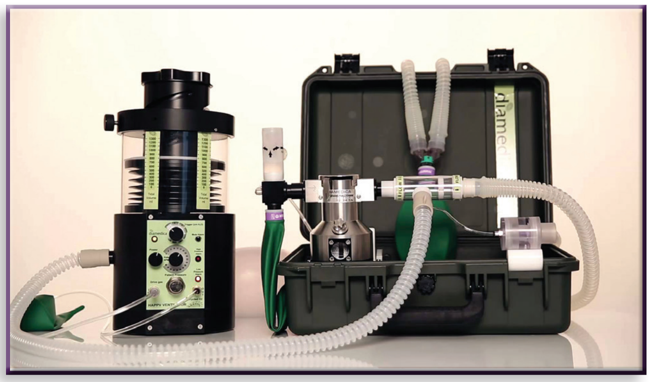
FIGURE 10 *Diamedica DPA 02 draw-over vaporizer and circuit. Image courtesy of Diamedica limited UK.*



3. Inlet port where air or gas enters the vaporizer
4. Outlet port where air or gas containing anesthetic vapor leave the vaporizer
5. Mechanism to control the percentage output of volatile anesthetic
6. Anesthetic output scale; in particular, is it the correct scale for the volatile anesthetic being used? If not, then knowledge of the different boiling points of volatiles can be used to estimate the output from the vaporizer. Note that most draw-over vaporizers do not have agent-specific filling ports, so it is important to determine the agent being used in the vaporizer.
7. Stability of the vaporizer. Does it have a firm base, or will you require some sort of stand to ensure it does not tip over, potentially allowing liquid volatile to spill into the patient circuit and deliver a sudden dangerous increase in anesthetic.
8. In addition, does the vaporizer have its own internal one-way valve? This can be identified by putting your mouth over the outlet port and trying to blow back through it. If the vaporizer has an integral valve, you will be unable to blow through it (this can also be performed by using a SIB).

The Draw-over Circuit

The draw-over circuit is used to connect the patient to the vaporizer. It also allows ventilation of an apneic patient and enhanced oxygen delivery and prevents the rebreathing of expired gases.

The main parts of a draw-over circuit are

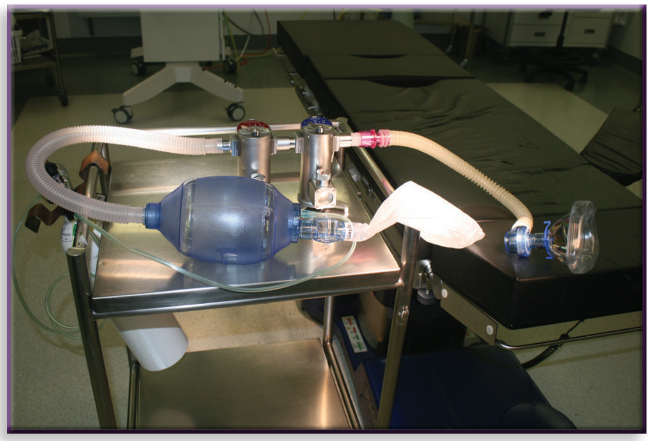
1. SIB
2. Anesthetic tubing
3. One-way valve
4. Expiratory valve
5. Oxygen reservoir

Self-Inflating Bag

The SIB is a ubiquitous piece of equipment, with various brands being carried by surgical teams along with medical providers in their medical packs. Commonly the US military deploy their PAC with an Ambu SIB on a T-piece and the British Defence Force deploy their Triservice OMV with a Laerdal SIB in series. These two types of reusable SIBs have an oxygen reservoir that can be disconnected to connect the SIB between the vaporizer and the patient. The oxygen inlet of the bag should be blocked by clamping a piece of oxygen tubing or taping it up as oxygen connected in this position will dilute the carrier gas from the vaporizer, resulting in a lower concentration of anesthetic agent delivered to the patient.

Some of the newer disposable SIBs have the oxygen reservoir attached permanently, preventing connection to the draw-over's outlet. With this type of SIB, the vaporizer should be used in a "push-over" mode, where the SIB's patient expiratory valve is removed and connected to the vaporizer outlet while the ventilator bag complete with oxygen tubing and reservoir is connected to the inlet port (Figure 11).

FIGURE 11 *Two OMV's with disposable SIB in push-over mode.*



Anesthetic Tubing

Attaching corrugated anesthetic tubing between the vaporizer, SIB, and the patient's nonrebreather valve allows the SIB and the vaporizer to be placed in a convenient position away from the patient. The tubing can be either nondisposable "elephant tubing" or the more common plastic disposable tubes. Anesthetic tubing can also be used to fashion an oxygen reservoir, as will be discussed later.

One-Way Valve

A one-way valve is required between the draw-over vaporizer and the SIB to ensure one-way flow toward the patient. The valve provides two functions:

1. To stop back-flow of gas during positive pressure ventilation when the bag is squeezed, enabling the patient to be ventilated
2. To eliminate the pumping effect of pressure being delivered backward into the vaporizer, which would result in an increased output of anesthetic agent

Patient Nonrebreather Expiratory Valve

A nonrebreather expiratory valve attached to the patient's end of the circuit allows one-way flow of gas from the SIB to the patient during inspiration and expired gas from the patient out to the environment during expiration, thus preventing rebreathing. A low resistance valve should be used particularly during spontaneous ventilation in order to reduce the work of breathing. Both the Ambu-E and Laerdel valves (Figure 12) are commonly used. Pediatric models are available with a lower resistance for use in pediatric anesthesia. A positive end-expiratory pressure (PEEP) valve can be attached to these valves to improve patient

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FIGURE 12 *Patient one-way nonrebreather valves, the Ambu E valve on the left and the Laerdal valve on the right.*

oxygenation. A length of anesthetic tubing can also be attached to the expiratory end of the PEEP valve to vent expired gasses away from the surgical team, thus acting as a primitive scavenging system. This can be important if these devices are used for prolonged periods in poorly ventilated spaces to reduce the surgical team's exposure to expired anesthetic vapor.

Oxygen Reservoir

Volatile anesthetic agents have a number of effects on ventilation. They decrease tidal volume, depress the response to hypercarbia, inhibit hypoxic pulmonary vasoconstriction, and increase ventilation perfusion mismatching and pulmonary shunt. All of these effects can decrease oxygen saturation.[24] This is particularly relevant in patients with preexisting pulmonary disease or traumatic chest injury. When available, oxygen should be added to the carrier gas delivered to the vaporizer. Adding it upstream of the vaporizer will avoid diluting the anesthetic delivered to the patient.

Spontaneous and mechanical ventilation can be divided into the four phases of inspiration, expiration, and inspiratory and expiratory pauses. During inspiration, the peak inspiratory flow developed by an adult male is 300 to 500L/min,[25] well in excess of the flow available from an oxygen tank or concentrator. This is why it is impossible to deliver more than 35% to 40% F_{IO_2} using a Hudson face mask even with an oxygen flow rate of 15L/min. Using a draw-over without a reservoir, air will be drawn into the circuit, diluting down the added oxygen. An oxygen reservoir placed upstream of the oxygen inlet will catch the oxygen lost to the environment during the expiratory phase of respiration, allowing it to be delivered to the patient during inspiration. A reservoir can be made from the reservoir bag that comes with the Laerdal and Ambu SIB or from a length of anesthetic "elephant" tubing. One meter of this tubing has an internal volume of approximately 500mL. With an oxygen flow rate of 4L/min, a 500mL oxygen reservoir will deliver an F_{IO_2} to the patient of approximately 70% to 80%. At a flow of 1L/min, the resulting F_{IO_2} is approximately 30%.[26] A C-size oxygen cylinder will last up to 400 minutes with a flow of 1L/min.[27] Oxygen can be supplied to the circuit using either bottled oxygen or an oxygen concentrator. Most oxygen concentrators are able to deliver 5 to 6L of 95% oxygen.[28]

When using anesthetic tubing as a reservoir, it is important to ensure that the end of the tube is not blocked as this may result in negative pressure in the draw-over apparatus when the oxygen flow is less than the patient's minute volume, leading to a collapse of the SIB and loss of ventilation. A blocked reservoir with an oxygen flow greater than the patient's minute volume will result in pressurization of the draw-over vaporizer, leading it to act like a plenum vaporizer. The end of the reservoir should also be secured to avoid it dropping onto the floor where dust and contamination may be drawn up into the system and delivered to the patient's respiratory system.

Mechanical Ventilation

In the very austere setting, ventilation can be performed solely using an SIB. A nonskilled assistant can be readily instructed in the use of the SIB in order to free the anesthetist for more important tasks. However, the manual ventilation of a patient can become quite tiring over the duration of an anesthetic, and it is unlikely to produce as consistent a minute volume as a mechanical ventilator. This is of importance in the delivery of protective lung ventilation, which is of particular significance in the treatment of patients with pulmonary injury resulting from blast or inhalational injuries.[29]

A mechanical ventilator can be used with a draw-over vaporizer in either the draw-over or push-over configurations.[30] In the draw-over configuration, it is positioned between the vaporizer and the patient, and in the more common push-over configuration, the ventilator is attached to the vaporizer inlet in the place of the oxygen reservoir.[31,32] Both the PAC and OMV vaporizers can have a ventilator operated in both positions with minimal changes in the volatile output.[31] When using a ventilator in push-over mode, the SIB should be removed from the circuit in order to reduce the compliance of the system. The benefit of using the ventilator in the push-over position is that the internal mechanics and seals of the ventilator do not get exposed to volatile anesthetic, which can cause malfunction of some ventilators.[32]

Monitoring the Patient

The use of capnography monitoring has vastly improved the safety profile of anesthesia[33] and the development of portable battery operated capnographs[34] means this technology is available for use with draw-over anesthesia when access to power is not guaranteed. Portable mainstream capnographs are available that can clip onto the end of an endotracheal tube and operate on a single AAA battery. Use of capnography reduces the risk of under or over ventilating a patient and, in addition, monitoring capnography adds the reassurance of apnea alarms warning of failed intubation, patient apnea, and disconnection.

End-tidal agent monitoring is also available in lightweight battery-operated devices. The multigas monitor by Acutronic gives graphic representation of volatile anesthetic concentration and CO_2 along with a pulse oximeter. The ability to monitor end-tidal anesthetic concentration allows the delivery of a precise level of anesthetic as opposed to estimating the delivered concentration based on vaporizer dial settings, temperature, and the patient's minute volume. This reduces the risk of delivery of too deep an anesthetic and the risk of awareness from inadequate volatile agent. Monitoring the end-tidal agent concentration should also provide a warning of an empty vaporizer, a significant benefit given the small

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agent reservoirs of draw-over vaporizers and the lack of internal low agent alarms.

However as draw-over anesthesia is most likely to be used in the austere environment, it is still feasible that agent and CO_2 monitoring might not be present due to either lack of resources or power failure. When not available the anesthetist requires a higher level of vigilance to reduce the risk of the above complications. This can be achieved by monitoring the patient's respiration using a precordial or esophageal stethoscope to auscultate heart and lung sounds, or through observing the movement of the patient chest or nonrebreather valve.[35]

Delivering a Draw-over Anesthetic—The Practicalities

Equipment Check

As with all anesthetic equipment, prior to use the Operator should do a full equipment check including drugs, suction, monitoring, oxygen supply, and the draw-over itself.[36] To check a draw-over system, I start with a quick visual inspection of the vaporizer, check the type of volatile anesthetic contained within, and check that the correct scale is attached. I then rotate the vaporizer mechanism on and off through its full range of movement to check that the output adjustment works smoothly. I finally check the circuit to ensure that I am able to ventilate the patient. This is similar to the checks performed on an SIB.

Draw-over Circuit Check

1. Connect test lung to patient nonrebreather valve.
2. Operate the SIB and observe for flow of air through the patient valve to the test lung.
3. Empty test lung to ensure expired air exits through expiratory portion of patient valve out to the environment.
4. Place hand at the inlet port of the vaporizer and operate the SIB ensuring, no back-flow of air passes through the vaporizer.
5. Remove test lung and block the patient valve's 15mm connector with a finger.
6. Operate SIB to ensure no leaks in any of the connectors or tubing and the SIB's one-way valve is working with no back-flow of air through the vaporizer (pressure in the SIB should be maintained for 10 seconds while squeezing it).
7. Test for leaks in the vaporizer by blocking the vaporizer inlet, turning on the vaporizer, and squeezing the SIB. The SIB will remain collapsed if there are no leaks.

Testing of the content of the vaporizer can be difficult. If you have agent monitoring, it can identify the agent; otherwise, the Operator is only able to check the labels on the anesthetic bottles and perform a sniff test to see if they can identify the scent of the volatile. If in doubt, drain the contents of the vaporizer and refill the chamber with new volatile from a labeled bottle.

Anesthetic Plan

Before anesthetizing a patient, an anesthetic plan needs to be made depending on the patient's condition, type of surgery, length of surgery, and medical logistics. Logistical constraints may include equipment availability including vaporizer, ventilator, oxygen, and monitoring. Consumable stores including the current holding of drugs, availability of resupply, and options of locally sourced medications should also be considered. Decisions should be made with specific consideration to:

1. Anesthetic induction—choice of IV versus volatile induction or volatile and IV co-induction. An unfasted unstable patient will require an IV rapid sequence intubation (RSI); however, with a pediatric fasted patient, the anesthetist may decide on a volatile gaseous induction.
2. Ventilation—a choice of either controlled ventilation versus spontaneous. The surgical technique may demand muscle relaxation in order to optimize surgical access, as is the case in abdominal surgery. In this situation, it will be necessary to ventilate the patient using either an SIB or a mechanical ventilator.
3. Percentage of oxygen in the carrier gas—If oxygen is available, it should be used. However, if supplies are limited and resupply is not guaranteed, then the anesthetist may elect to use only air for the anesthetic. In this situation, a patient who could have been anesthetized maintaining their own respirations may require assisted ventilation to maintain adequate oxygenation.
4. Depth of anesthesia required—this decision will be based on patient factors such as how hemodynamically stable the patient is, as a shocked patient will require less volatile anesthetic to achieve the same depth of anesthesia. Added to this, excessive anesthesia will further reduce an already compromised patient's cardiac output. Logistical constrains may come into this decision; for example, if the stores of volatile are low, a decision might be made to reduce the level of volatile anesthetic given while supplementing it with IV agents such as ketamine, opiates, benzodiazepines, or other sedatives.
5. Ability to monitor end-tidal CO_2 and volatile agent.

Draw-over Technique Examples

1. Unstable patient requiring trauma laparotomy

The draw-over anesthetic technique would involve intubation via an RSI, and maintenance of anesthesia with volatile anesthetic and positive pressure ventilation. This could be achieved using the following steps.

1. Optimize monitoring.
2. Obtain adequate IV access and initiate blood products for resuscitation if required.
3. Preoxygenate using a mask and SIB connected to bottled oxygen or an oxygen concentrator.
4. Perform an RSI using IV ketamine and rocuronium.
5. Confirm endotracheal tube placement by ventilating with the SIB.
6. Connect the patient expiratory valve from the SIB to the outlet port of the draw-over vaporizer using corrugated tubing and set the desired volatile concentration.
7. Connect a transport ventilator to the inlet port of the vaporizer in push-over mode.
8. Adjust the ventilator settings to achieve normocarbia.
9. Volatile anesthetic concentration required will depend on the hemodynamic stability of the patient.

2. Stable, fasted patient requiring elective or semielective surgery

If the surgical technique does not require muscle relaxation or a definitive airway (i.e., an endotracheal tube), the anesthetist can elect to use a supraglottic airway such as a laryngeal mask airway (LMA) and allow the patient to breath spontaneously. A spontaneous ventilation technique when agent monitoring is unavailable will reduce the risk of patient awareness, because

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if the anesthetic becomes too "light," the patient will start to "breath up" or move, giving the anesthetist an indication that the patient requires more volatile. The technique could involve the following;

1. Application of monitoring
2. Obtain IV access
3. Preoxygenation with SIB connected to the draw-over vaporizer using either bottled oxygen or oxygen concentrator
4. IV induction using propofol or ketamine (an IV/inhalational co-induction could also be performed by turning on the vaporizer to allow the patient to inhale volatile anesthetic—note this requires a well-fitting face mask and a good seal or the patient will not draw any gas through the vaporizer)
5. Insertion of LMA
6. Connect patient nonrebreather valve to the LMA
7. Adjust vaporizer output control to deliver desired level of anesthetic volatile concentration
8. Monitor for level of anesthetic using patients vital signs eg pulse, BP, respiratory rate and depth, and adjust vaporizer output control accordingly
9. Adjust inspired oxygen concentration in order to achieve adequate oxygen saturation
10. If the patients respiratory system needs support this can be performed by assisting their respirations using the SIB or through the use of a PEEP valve connected to the patient valve.

3. Fasted child requiring elective or semielective surgery

It is possible to perform an inhalational induction using draw-over equipment. The two things to keep in mind are;

1. Without a complete seal of the face mask the carrier gas will not be drawn through the vaporizer, resulting in no volatile anesthetic being delivered to the patient
2. The maximal output from draw-over vaporizers is less that most plenum vaporizers (5% to 6% sevoflurane from two OMVs in series compared with 8% from most plenum vaporizers). This will prolong induction.

If a perfect seal is not able to be obtained then volatile can be delivered to the child by squeezing the self-inflating bag to draw the carrier gas through the vaporizer. If the supply of oxygen is not an issue another option is to block the end of the oxygen reservoir and increase the flow of oxygen to the vaporizer to greater than the child's minute respiration volume. This will drive the oxygen through the vaporizer and circuit to the face mask, effectively operating as a plenum vaporizer.

Conclusion

With a renewed interest among SOF of operations in austere environments and the support of indigenous forces, medical support elements need to be able to operate with a lighter footprint and be less reliant on the logistics chain and dedicated evacuation assets. In order to achieve this all medical specialties will need to look at how they provide medical care and in particular prolonged field care with lighter equipment and less consumables. Draw-over anesthesia was a vital instrument for anesthetic providers located in FSTs during the mobile phases of the Afghanistan campaign. Its light weight, portability, inherent robustness, and the ability to use multiple anesthetic agents including ones that may be able to be sourced locally makes it a worthy instrument to be included in the modern SOF medical armamentarium.

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Author Contributions

Both authors approved the final manuscript.

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