DRAWOVER ANAESTHESIA REVIEW

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This paper discusses the equipment and role of drawover anaesthesia for the uninitiated 'plenum anaesthetist' while also delving into some of the finer aspects for experienced users.

Overview

Drawover anaesthesia is simple in both concept and delivery, has stood the tests of time, and travels well. The equipment is generally robust, versatile, easily maintained, and relatively inexpensive. Why, then, is it not more popular? Possible explanations are included in table 1.

History

Since the introduction of open drop volatile anaesthesia with ether, and later chloroform, anaesthetists have sought to refine vapour delivery in response to a variety of different clinical goals with different volatile agents. From an historical perspective, drawover and continuous flow (plenum) anaesthesia have been developed in parallel, ever since vaporisers first began to replace open drop methods at the turn of the 20th century.

What is drawover anaesthesia?

It is simply the act of drawing a carrier gas over a volatile liquid for the purpose of adding the vapour from that liquid to the carrier gas. This carrier gas/vapour mixture is then directed to the patient by a 'circuit'. In drawover systems the carrier gas is drawn through the vaporiser either by the patient's own respiratory efforts, or by a self-inflating bag or manual bellows with a one-way valve placed downstream from the vaporiser. Drawover systems operate at less than, or at ambient pressure, and flow through the system is 'intermittent', varying with different phases of inspiration, and ceasing in expiration. A one-way valve prevents reverse flow in the circuit.

This is different to plenum (Latin derivative, opposite to vacuum) anaesthesia in which a carrier gas is pushed through the vaporiser at a constant rate. In plenum circuits the anaesthetic is then collected in a circuit with a reservoir bag or bellows. Pressure fluctuations in the circuit caused by patient respiration, whether spontaneous or applied, do not involve or affect the vaporiser. Plenum systems operate at higher than ambient pressure.

The basic draw-over system is shown in figure 1.

Practical significance

Draw over systems are simple to assemble and use, and can operate without fresh gas supplies. They are lightweight and portable. Plenum systems are more technically complex, and need a well-regulated, constant, positive pressure gas supply. They require a more sophisticated anaesthetic 'machine' to support them. The transport of gas cylinders for plenum systems is both

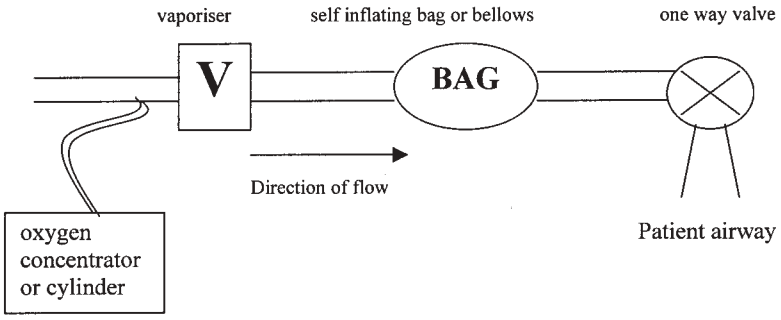

Figure 1: Basic draw-over components vaporise self inflating bag or bellows one way valve

Table 1 Drawover anaesthesia

Advantages	Disadvantages
Simplicity of concept and assembly, with inherent safety	Decreasing familiarity with the technique and equipment
No need for pressurised gas supply, regulators and flow meters	Vaporiser limitations
Minimum FiO_2 is ~21%	* Filling systems not agent specific (potential advantage)
Robust, reliable, easily serviced equipment	* Basic temperature compensation, affecting performance at extremes
Low cost (purchase and maintenance)	Less easy to observe spontaneous ventilation with self inflating bag
Portable, suitable for field anaesthesia	Cumbersome in paediatric use, unless lightweight tubing is available

expensive and potentially hazardous. Therefore drawover systems have obvious advantages in remote locations, in under-resourced countries, and in 'field/military' anaesthesia.

Supplemental oxygen?

In principle the 21% oxygen in air is diluted by the addition of vapour in the vaporiser, allowing a potentially 'hypoxic mixture' to be delivered to the patient. This is a theoretical issue, rather than a practical one, as the vapour concentration is small, and it is unlikely that the FiO_2 falls below 18%, the international standard for oxygen analyser alarms. It is more important to consider the respiratory physiological effects of general anaesthesia which tend to reduce ventilation and increase shunting of blood within the lung (V/Q mismatch). Therefore hypoxia becomes a clinical problem when using halothane or isoflurane with spontaneous ventilation (SV) in air, and supplemental oxygen is necessary [1,2]. The problem is reduced, but abolished, when applying intermittent positive pressure ventilation (IPPV). Ether can be delivered in air (without supplemental oxygen), in IPPV mode, presumably because it causes less intrapulmonary shunting and tends to stimulate ventilation, rather than depress it. When used in unsupplemented air with spontaneous respiration, some patients will desaturate.

In draw over systems supplemental oxygen is administered via a T-piece connection mounted to the intake port of the vaporiser. To maximise the inspired oxygen concentration (FiO_2) a 'reservoir tube' is attached to the T-piece, as shown in figure 1. A 1m length of corrugated tubing with an internal volume of 415ml allows an FiO_2 of at least 30% with an oxygen flow rate of 1.0 litre/min, and 60% at 4 litres/min, at normal adult minute ventilation[3]. With higher minute volumes the FiO_2 falls due to increased air dilution; at lower minute volumes the FiO_2 is higher. Oxygen may be sourced from cylinders, or an oxygen concentrator.[4,5,6]

The Houtonox oxygen flow control device is a simple, single stage reducing valve (regulator) that is suitably pin-indexed to fit directly to an oxygen cylinder. Adaptors for bull-nose connections are available. Flow rates that can be set are fixed at 1 and 4 litres/min, which are ideal in combination with draw over systems[7]. The device is accurate and sturdy, and allows maximum benefit from limited oxygen supplies.

Equipment used in Drawover Anaesthesia

Vaporisers

The ideal drawover vaporiser needs to have low internal resistance to gas flow to allow easy spontaneous ventilation, while vapour output should be constant for a given dial setting over a wide range of minute volumes and ambient temperatures. Other desirable qualities are that the circuit connectors comply with international standards and that chamber filling is visible. These requirements determine careful vapour chamber design. Wicks can be used to increase the area of the volatile liquid:carrier gas interface but their presence, size and complexity is limited by the internal resistance to gas flow created. The need for saturated vapour output is balanced against the resistance created, and is simply not achievable in all possible working conditions in draw over mode, particularly at extremes of tidal volume or in cold environments.

Plenum vaporisers, with their constant driving pressure and predictable flow rates can afford increased internal complexity and resistance. Modern plenum vaporisers still have performance limitations at extremes of flow rate and temperature, but they are generally more accurate than their draw-over counterparts.

As vapour is liberated the temperature of the liquid volatile agent falls due to the latent heat of vaporisation. This causes a fall in the saturated vapour pressure and lowers the output of the vaporiser. Temperature compensation is managed in two basic ways. The first is to provide a large heat-sink of conductive material (water bath or mass of metal), the dimensions of which are limited by size and portability. Heat is conducted from the heat-sink to the volatile liquid and minimises the fall in temperature of the liquid agent. The second method is to vary the vapour chamber output with temperature, so that more carrier gas is allowed to pass through the vapour chamber as the temperature falls, and less as it rises. This is achieved by bimetallic strips and ether-filled bellows in plenum vaporisers, but they cause an increase in the internal resistance. Some drawover vaporisers have basic thermo-compensation devices incorporated (EMO, PAC). In clinical practice a fall in vaporiser output may be compensated for by an increased dial setting.

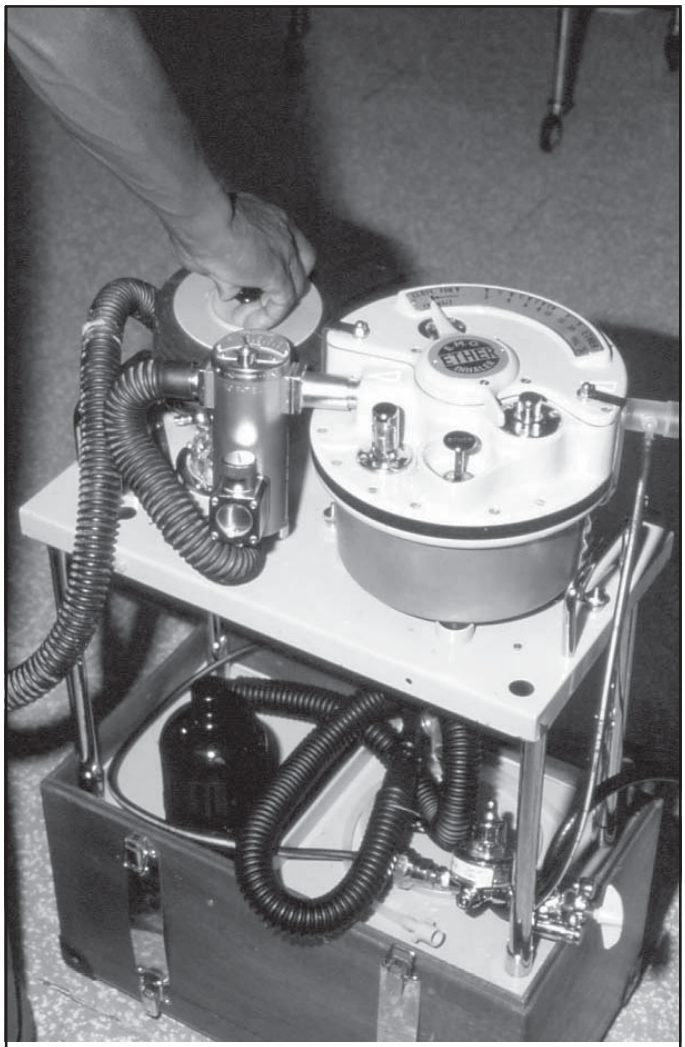

Figure 2. EMO and OMV being used for drawover anaesthesia

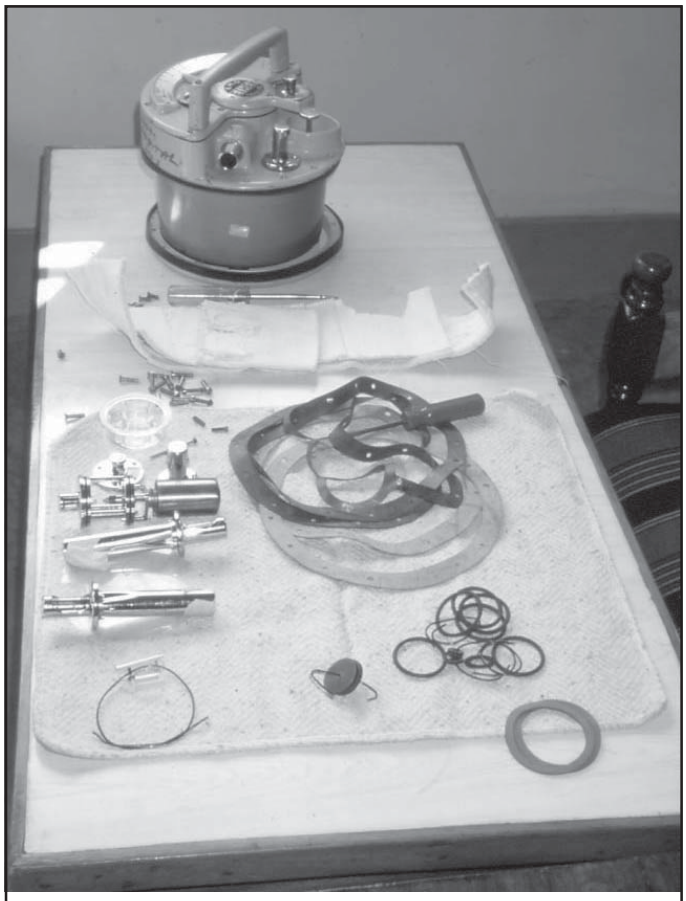

Figure 3: EMO stripped down for maintenance

Drawover vaporisers theoretically should not be used in plenum fashion, as the output may not reflect the dialled setting. This problem is more significant with some vaporisers, and is greatly influenced by both flow rate and temperature. This is considered under each vaporiser heading.

Most plenum vaporisers cannot be used for drawover anaesthesia because of their high internal resistance.

EMO (Epstein Macintosh Oxford; Penlon; figure 2) is a classic design, unmodified since the 1950's, which testifies to its design and capabilities [8]. It is designed for use with ether and is damaged by halothane. Stripping and maintenance is straightforward (figure3). A key component is the temperature compensating device, which is a sealed cannister containing liquid ether attached to a spindle, automated by opposing springs. The splitting system comprises two concentric brass cylinders with apertures, one of which rotates with the dial setter, thus altering the overall ratio between vapour chamber and bypass flow. An expensive setting gauge is available from Penlon to position the splitting device correctly. A 0.1 inch (2.6mm, 8 French gauge, 12 Stubs needle gauge) wire is an approximate substitute. To calibrate the dial properly one must loosen the central screw, and place the dial in the 6% position. The setting gauge is placed in the aperture, through the temperature compensator portal, and the screw is tightened until the gauge is lightly gripped. The vaporising chamber sits in a water bath, which acts as a heat sink. This can be emptied for transport[8]. The entire EMO set-up weighs over 10kg, limiting its potential for field use. In plenum mode the EMO only begins to perform reasonably accurately with flow rates around 10 l/min, and is therefore not ideal for paediatric use with a T piece, although circuit adaptations can be made[9,10]. If used in "pushover' fashion, with a ventilator or bellows placed upstream, the output can significantly exceed the dial setting.

OMV (Oxford Miniature Vaporiser; Penlon; figure 4). This vaporiser is the most portable and most versatile drawover vaporiser, but its size does impose performance limitations. The vapour chamber, which contains 50mls of volatile agent, empties quite rapidly when in use. It is suitable for a number of agents, a feature assisted by interchangeable dial scales, and has basic thermal buffering in the form of a small glycol (anti-freeze) reservoir within a metal heat sink[7, 11]. It suffers a reduction in vapour output at lower temperatures, with a maximum output varying from 2-4% with halothane between 0-30^{O}C, and higher above this. Made from stainless steel, it is resistant to corrosion by volatile agents. Metal mesh wicks increase the output without significantly increasing the internal resistance. The unit needs little regular maintenance. A common problem encountered with the OMV is that the dial becomes stiff from thymol being deposited in the mechanism during use with halothane. Thymol may be dissolved by putting ether in the OMV and shaking it whilst working the lever back and forward - remember to empty the unit afterwards! Alternatively strip and clean the mechanism (if you have been trained).

It is common to use 2 OMV's in series to augment the output, as is standard in the Triservice apparatus, which was originally used with trichloroethylene in one and halothane in the other. The standard field anaesthetic machine of the Australian Defence Forces uses two Oxford Miniature Vaporisers (OMV's) in series in either draw over or in true plenum mode (i.e. with continuous flow gases fed in upstream), depending on the circuit attached. It can operate efficiently as a plenum vaporiser in anaesthesia and

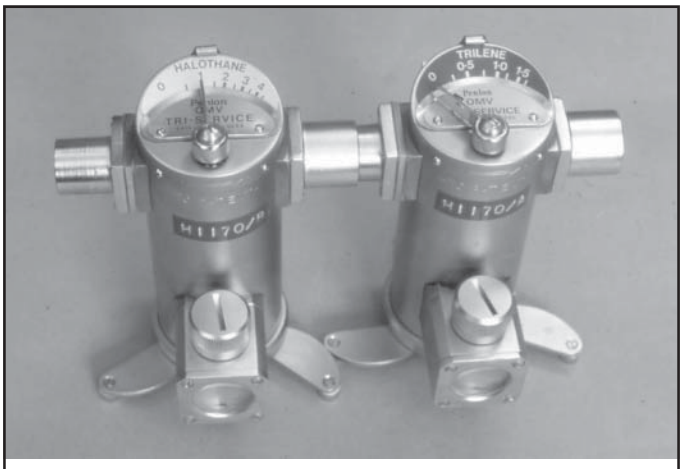

Figure 4: Oxford miniature vaporisers - Triservice nodels

ICU[12,13]. Output reflects dial settings at 25^{o}C, in either continuous flow or draw over use, but falls dramatically at 150^{o}C, and rises steeply when above 35^{o}C[14]. The reduction in output associated with the fall in vaporiser temperature during use may require an increase in dial setting, as determined clinically. Keeping the vaporiser topped up with fresh liquid at room temperature helps maintain the output.

The OMV is reasonably accurate over a wide range of flow rates and tidal volumes and, in particular it performs well at small tidal volumes, making it suitable for paediatric anaesthesia [14,15]. The OMV has also been used in a circle system. However due to its efficiency it is capable of producing very high concentrations and is not recommended for this use.

PAC (Portable Anaesthesia Complete; Datex-Ohmeda. Now called TEC). Originally released as a series of individual vaporisers designed for specific volatile agents[16]. A multi-agent version, the Ohmeda Universal PAC, is now also available suitable for use with halothane, isoflurane, enflurane, and diethyl ether. The apparent intention was to manufacture the draw-over vaporiser with the best (linear) output performance profile over a wide range of conditions, and that task has been achieved in adult use. Accuracy is enhanced by a bimetallic strip temperature compensating device, and there is a built in T-piece for oxygen supplementation. Unfortunately the output is less accurate at small tidal volumes, or when used as a plenum vaporizer with gas flows below 2-4l/min. Therefore it is not as useful for paediatric anaesthesia.[14,16] It comes in a sturdy carrying case, and has for many years been the standard issue field vaporiser used by the US military and has been very widely used in Malawi[17,18]. In summary it is an excellent vaporiser, particularly for adult draw over use. Regular servicing is recommended.

Self Inflating Bags/Bellows

Oxford Inflating Bellows (OIB) come as standard with the EMO system (figure 2). The bellows sit vertically with a residual internal volume maintained by a spring. This arrangement allows movement of the bellows during spontaneous respiration providing a useful indicator of breathing. The OIB was originally designed for use with a simple spring loaded valve (eg Heidbrink valve). To facilitate gas flow through the OIB there are two one-way valves in the form of metal discs on circular seats. This arrangement works well for spontaneous ventilation (SV), but is less than satisfactory for intermittent positive pressure ventilation (IPPV) as adjustment of the Heidbrink valve must be constantly revised. Non-rebreathing valves of either the Laerdal or Ambu type (figure 5) can be used more effectively at the patient end of the draw over circuit to facilitate IPPV, and are equally suitable for SV.

One note of caution is that with this adaptation the OIB is prone to jam unless the downstream valve on the OIB is disabled with the magnet provided (figure 6). When the OIB jams the patient cannot exhale as an air-lock develops between the non-rebreathing valve and the OIB valve. The patient must be disconnected from the circuit to allow exhalation. This problem is more common with IPPV, but may also occur in SV use. When in use the magnet holds the distal OIB flap valve in the open position and stops the air-lock developing. Some anaesthetists even remove the downstream disc to prevent this problem. A simpler, single flap valve bellows called the Penlon Bellows Unit, PBU, has been developed to address this issue, and to avoid confusion concerning when the magnet should, and should not be used. If in doubt, it is useful to remember that when using MODERN valves, use a MAGNET.

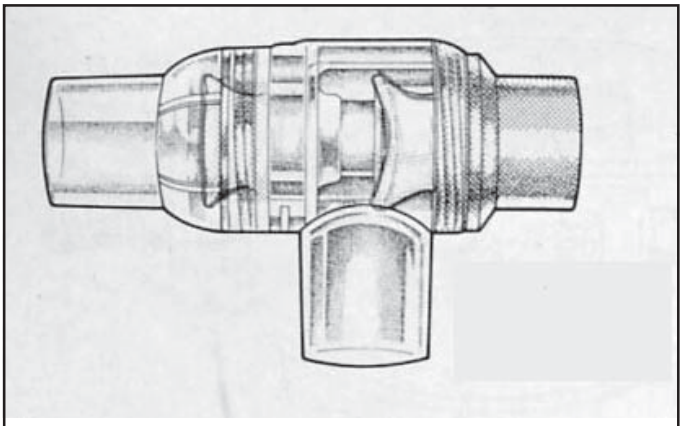

Figure 5. AMBU E1 anaesthesia valve

The tap on the side of the OIB is intended for connection to supplemental oxygen when using the bellows for resuscitation purposes. During anaesthesia, however, it is preferable to leave this closed and supply oxygen upstream of the vaporiser. Adding oxygen at the bellows dilutes the anaesthetic vapour.

To operate the bellows to assist ventilation the recommended manoeuvre is a rocking motion, rather than direct up and down. This creates less fatigue over time, and produces less variability in tidal volume. The movement of the bellows during IPPV is characterised by three phases: down, up, pause.

Laerdal, Ambu or other self inflating bags are considered together as there is little practical difference between them. Their valves are used to create the one-way flow in the circuit, and are attached to the patient's airway to minimise rebreathing. The bag can be separated from the valve by a length of 22mm anaesthetic tubing to allow it to sit better. The inflow side of the bag needs to be arranged so that all gas is drawn through the vaporiser, and no air entrainment is allowed, which would dilute the anaesthetic and potentially lead to awareness. Spontaneous ventilation does not cause a movement of the bag unless there is a fault in the draw over circuit causing a resistance upstream. To observe gas flow in the circuit, tape a fine feather or piece of paper at the inflow end of the whole system.

One Way Valves

The non-rebreathing valve (usually an Ambu valve or Laerdal valve) should be placed as close to the patient's airway as possible to minimise the apparatus dead-space. Both valves can be scavenged. A Heidbrink valve, or similar spring loaded blow-off valve, (which is not one-way) can be used downstream of an Oxford Inflating Bellows during spontaneous respiration, providing both OIB valves are functional. The magnet should not be used to disable the valve in this instance.

Connecting tubing

The connecting tubing of a draw over circuit is standard 22mm tubing. Antistatic tubing is required for ether, otherwise lightweight plastic tubing is more convenient.

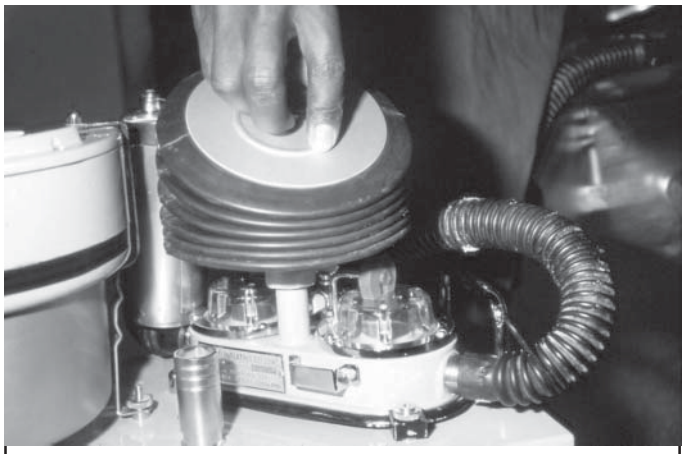

Figure 6: Magnet in place on the Oxford Inflating bellows

Conducting A Draw-Over Anaesthetic

Intravenous induction

This is performed as normal and the airway maintained in an appropriate fashion. Face masks, endotracheal tubes and laryngeal mask airways are all suitable for drawover anaesthesia.

Inhalational induction

During an inhalational (gaseous) induction a seal is required between the face and the mask, or gas will not be drawn through the vaporiser. When this occurs the patient will breathe room air around the mask and remain conscious!

In adult anaesthesia it is relatively easy to coax a mask on the face and still keep the patient calm and cooperative. A benzodiazepine and/or opioid premedication will assist with this in anxious patients, and markedly improves the tolerance to pungent volatile agents such as ether or isoflurane. Problems may arise with elderly, edentulous patients in whom masks may not fit well, or males with heavy beards in whom the seal is hard to maintain. Filling the beard with lubricant jelly does help, but makes the mask very slippery. A defibrillator pad or transparent sticky plastic dressing with a hole cut in it fulfils the same need and is easier to hold.

In paediatric use the problem is two-fold. The child may be uncooperative so that maintaining a mask seal is difficult (and sometimes psychologically traumatic). Small children (<15kg / 3 years) may not generate sufficient tidal volumes to draw vapour into the circuit through the one-way valves, so even the cooperative ones may be slow to induce!

One solution is to enlist an assistant to operate the bellows (or self-inflating bag) to prime the circuit and bring vapour up to the mask. Continued operation of the bellows will create flow through the circuit and keep the supply of vapour coming, and the induction can be done as if using a plenum anaesthetic system. The mask seal will not be as important.

Adaptation of the drawover system to use with a standard Ayre's T-piece circuit is also possible for the very young. This is done by connecting the T piece to the outlet of the OIB[19,20]. The fresh gas flow is provided by the assistant slowly operating the bellows 6 - 8 times a minute and the T piece is used in the normal fashion. The distal valve should be operational for this system to be used. Paediatric drawover techniques are not detailed in this review.

Maintenance of anaesthesia

Spontaneous ventilation has several advantages, especially when using new or unfamiliar equipment and leaves the anaesthetist's hands free for other tasks. The volatile agent has to be delivered at higher values to compensate for the absence of nitrous oxide. Parenteral opioid analgesics should be provided, again titrated to signs of anaesthetic depth. Alternatively supplementation by regional anaesthesia may be effective.

Neuromuscular blockade requires the patient to be ventilated. This can be done manually, or through the use of a suitable 'draw-over ventilator', such as the Manley Multivent (Penlon UK; figure 7).

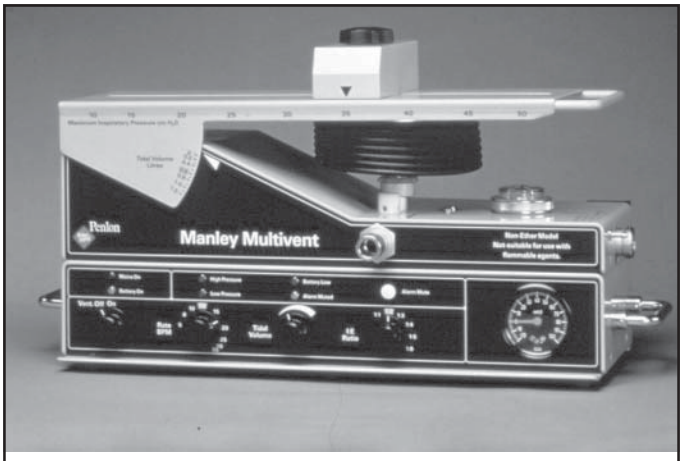

Figure 7: Manley Multivent

Volatile Agents (*See also Update in Anaesthesia No 11 - Volatile Anaesthetic Agents*).

Ether is still available in many parts of the developing world, and where medical supplies are restricted industrial grade ether may be successfully used. Unfortunately it is flammable in air, and explosive in oxygen and can be ignited within a 25cm radius of a source of ether vapour "zone of risk". Provided sensible antistatic precautions are taken to prevent any sources of sparking / ignition within this zone ether may be safely used. During ether anaesthesia diathermy should not be used in the airway, chest or upper abdomen. Ether possesses excellent anaesthetic and analgesic properties. It has a low potency which results in a prolonged inhalational induction with a well described excitement phase. For this reason ether anaesthesia is easiest provided following an intravenous induction. The OMV was originally designed to assist with ether induction by additional use of halothane. It is placed downstream of the EMO, and an OMV setting of 1% greatly speeds induction, taking less than 10 minutes. The halothane can be turned off when the ether concentration reaches 12 -15%.

Halothane (Fluothane) is widely available and relatively inexpensive. It ranks highly as the agent of choice for use in children. Although it slowly degrades some metals in the anaesthetic equipment, and absorbs into rubber components of

the circuit, it is an excellent agent that has been used for nearly 50 years. Halothane contains thymol which coats moving parts in the splitting system, and builds up on wick devices, but can be removed with application of ether - see under OMV.

Trichlorethylene (Trilene) has a relatively low anaesthetic potency but provides good analgesia. In the Triservice apparatus (Penlon) trichlorethylene and halothane were traditionally used in series. It is becoming harder to source, although chemical reagent trichlorethyelene is sometimes available.

Enflurane (Ethrane) is an agent that has rapidly been phased out in many parts of the world after brief popularity in the 1980's. It is still in use where economic factors favour it. It can be used for inhalational induction and maintenance. Its main disadvantage is its propensity to induce epileptiform phenomena, particularly with hypocarbia and in children. Two OMV vaporisers are required to provide adequate concentrations for induction.[21]

Isoflurane (Forane) has the same saturated vapour pressure as halothane, and is thus theoretically suitable for use in any vaporiser designed for halothane.[22] Gaseous induction with isoflurane is impaired by its relative pungency and airway irritative properties. With benzodiazepine and / or opioid premedication, and a gentle approach, this is an easily surmountable problem. Isoflurane has come down in price since its patent expired.

Sevoflurane (Sevorane) has been used in draw-over, but its use is hampered by a need to deliver high percentages which are at the upper limits of simple vaporiser performance capabilities, as well as its high cost. Using additional wicks to maximise output can be helpful, but latent heat of vaporisation rapidly cools the system and lowers performance. Two OMV vaporisers are required to provide adequate concentrations for induction.[22]

Right agent, wrong vaporiser?

Some vaporisers (OMV and TEC) are designed for use with different agents and a variety of scales are provided to allow this. Care should be taken that agents (eg ether, trichlorethylene and halothane) are not mistakenly put in the wrong vaporiser, or the wrong dial used.

Conclusion

Draw-over anaesthesia holds distinct advantages in less affluent hospitals where the advantages over any other form of anaesthetic delivery system are not only economic, but also practical, and the training required to deliver safe anaesthesia is kept to a minimum. During field anaesthesia the added attractions of portability and reliability allows rapid and effective deployment of anaesthesia equipment to the area of need. Field anaesthesia, such as that performed by the military and humanitarian organisations, is greatly simplified by combining draw-over and intravenous techniques. Major surgery is made possible that is undoubtedly life saving. In the first world hospital, exposure of trainees to draw-over techniques results in a deeper understanding of equipment and more skilled anaesthetist.

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