

The Triservice Anaesthetic Apparatus: A Review

RS Frazer¹, DJ Birt²

¹Consultant in Anaesthesia, SO1 Clinical, HQ 2 Med Bde, Strensall, York; ²Consultant in Anaesthesia, MDHU Derriford, Derriford Hospital, Plymouth.

Abstract

The Triservice Anaesthetic Apparatus was designed around 30 years ago as a robust and highly portable anaesthesia delivery system for medical support to airborne operations and it has been the core anaesthesia system for the Defence Medical Services since then. Over this period there have been a number of equipment changes but issues remain which are in part mitigated by recent training developments. This article reviews these changes and developments and considers the future of this equipment.

Introduction

The Triservice Anaesthetic Apparatus (TSAA) was designed by Brigadier Ivan Houghton to improve the provision of surgical services to 23 Parachute Field Ambulance and was first described in *Anaesthesia* in 1981 [1]. It was designed to be robust, portable and minimally dependent on resources. Over the years it has been modified and although it has been replaced by a conventional anaesthetic machine at the UK deployed R3 facility in Camp Bastion, it remains in service as the Defence Medical Services (DMS) core anaesthetic equipment for contingent Operations. This article describes the history of the TSAA, its components and philosophy of use. We will highlight developments and issues over the years.

Draw-over Anaesthesia

The delivery of anaesthesia in austere environments, including military operations depends on equipment with a minimal requirement for resources and infrastructure. For example, compressed gas cylinders are heavy, cumbersome and dangerous to move and, although a modern field surgical team would not have to exist without electricity, anaesthetic equipment that can continue to function during an interruption in supply is clearly an advantage. Table 1 lists suggested characteristics of anaesthetic equipment for use in austere environments. Regional and total intravenous anaesthesia also meet a number of these requirements but draw-over techniques maintain their popularity amongst the increasing competition.

- Minimal reliance on compressed gases and electrical supplies
- Robust
- Compact and portable
- Simple to operate
- Able to withstand climatic extremes
- Easily maintained and serviced
- Economical in use
- Versatile in the use of volatile agents
- Versatile with regard to patient age/size

Table 1. Anaesthetic system requirements for austere environments

Corresponding author: Lt Col RS Frazer, SO1 Clinical, HQ 2 Med Bde, Strensall, York. YO32 5SW.
Tel: 01904 442611 Fax: 01904 442689
Email: scottfrazer@doctors.net.uk

In its simplest form draw-over anaesthesia requires a suitable vaporiser and a one-way or non-return patient valve. In contrast to conventional anaesthetic machines which pass gases under pressure through flow meters and a vaporiser, draw-over systems rely on atmospheric air, usually enriched by oxygen, as the main carrier gas. During draw-over anaesthesia the patient's respiratory effort moves air through the vaporiser in proportion to their minute ventilation. This requires a very low resistance system and the ability to maintain vapour output despite wide variations in flow.

The TSAA

There are still a number of draw-over vaporisers available for use. Examples include the Epstein-Macintosh-Oxford (EMO), the Ohmeda Portable Anaesthesia Complete (PAC) and the Oxford Miniature Vaporiser (OMV, Penlon, Oxford, UK). Despite the overwhelming numerical superiority of plenum vaporisers worldwide, developments in drawover vaporiser design continue [2].



Figure 1: The OMV50

The TSAA is designed around a modified OMV50. This has a capacity of 50mls of volatile agent, three fold-out "feet" and an interchangeable concentration indicator scale (Figure 1). Although some drawover vaporisers are temperature compensated, the OMV50 is described as thermally buffered. Changes in vapour output with temperature are smoothed by the mass of metal in the vaporiser and the presence of "Forlife" antifreeze in the base. As originally described two OMVs were used in series, one delivering halothane and the other trichloroethylene (TCE). This combined

the analgesic properties of TCE with the anaesthetic properties of halothane. Reversible calibrated indicator scales were fitted for these 2 agents. Subsequently scales became available for Isoflurane and this has been the agent of choice in later years.

Circuit

The other key component of any drawover anaesthesia circuit is the one-way patient valve. Although a number of options are available, Brig Houghton chose a Laerdal valve which was part of a set including a Self-inflating Bag (SIB), which provided the means for manual ventilation. The system is still in existence today as the Resuscitator® (Laerdal Medical Ltd, Orpington, UK). In order to appropriately extend the circuit, corrugated silicone rubber tubing is used (Figure 2). Silicone rubber was originally specified because it was autoclavable, but it makes for a heavy system by modern standards. It should be noted at this stage that all of the connections in the circuit have cagemount (23.1mm) fittings (although the OMV50 can be supplied with 22mm fittings if required).



Figure 2: A common configuration for spontaneous respiration. For clarity the monitoring set-up is not shown.

Although a number of variations are possible, the most common arrangement for spontaneous respiration is described here (Figure 2). From the patient end, the one-way valve is connected to the SIB by a length of corrugated cage-mount tubing, the SIB is connected to the OMV50s by another length of tubing and upstream of the OMVs is a T-piece to allow the connection of supplementary oxygen followed by another length of corrugated tubing to act as a reservoir.

Additional Components

The ventilator

For mechanical ventilation, the original circuit simply replaced the SIB with an in-line ventilator such as the Penlon Oxford or the Cape TC 50. Following the Gulf war the PneuPac® CompACTM ventilator (Smiths Medical, Ashford, Kent, U.K.) was designed and replaced the TC50. It is a robust, relatively compact, time cycled, volume preset flow generator with an I:E ratio of 1:1.8 and can deliver minute volumes between 6 and 14 litres per minute at rates of 10 to 30 breaths per minute. It can be powered by its internal air compressor using mains voltage, a vehicle supply or the internal battery. It is possible to deliver

oxygen enrichment to a port at the rear of the machine when the delivered FiO_2 can be calculated using a nomogram attached to the side of the ventilator. It can also be driven from an external compressed oxygen supply (e.g. in the Emergency Department) when it can provide an inspired oxygen fraction of 0.45, if switched to "airmix", or 1.0 on "no airmix". This is the only way to deliver 100% oxygen with the CompACTM 200.



Figure 3: A common configuration for mechanical ventilation

When used with the TSAA the Sanders T-piece is kept in circuit to supply oxygen rather than the options above. The ventilator is used to provide a gas piston from the distal end of the circuit which is described colloquially as the "pushover" arrangement. The output from drawover vaporisers and for the OMV is similar in both arrangements [3]. As shown in Figure 3, the SIB must be removed from the circuit during mechanical ventilation due to its compliance and the tendency for the system to predispose to "breath stacking". This latter situation is due to a pressurised bolus of air being held between the one-way patient valve and the valve in the rear of the SIB: although ventilation occurs in inspiration, expiration is not possible. A detailed description of the operation of the CompACTM 200 is beyond the scope of this article but may be found in the article by Roberts et al [4].

DeVillbis Oxygen Concentrator

Although the circuit can be supplied from an oxygen cylinder, in recent years it has been more usual to take this supply from an oxygen concentrator. Oxygen concentrators commonly use the properties of zeolite. The granules selectively absorb nitrogen from air under pressure, leaving a higher concentration of oxygen in the remaining gas, the zeolite is regenerated later in the process. The DeVillbis concentrator (DeVillbis, Somerset, Pennsylvania) has a maximum output of 5 litres/ minute producing an oxygen concentration of up to 95%. The device is simple to use the only controls being an on/off switch and a flow knob for the rotameter. There are warning lights for oxygen concentration and an audible alarm if the oxygen output is less than 75%. At normal minute volumes, inspired oxygen concentrations of up to 80% are achievable with the concentrator at maximum flow.

Monitoring

Although a luxury in the developing world, modern monitoring is an absolute requirement for DMS anaesthetists. The current monitor is the Datex-GE S5 Compact (GE Healthcare, Chalfont

St Giles, UK). It allows advanced monitoring of anaesthetic gas mixtures and has improved the safety of the TSAA more than any other recent development.

Common Modifications and Clinical Strategies

Alternative Reservoir

Unlike a conventional anaesthetic circuit there is little visible indication of respiration when using the TSAA. The final upstream piece of corrugated tubing acts purely as a reservoir but does not give any indication of spontaneous breathing. The Laerdal resuscitator 2.6L collapsible reservoir bag can be attached in its place to act as a crude respiratory monitor. It includes protective valves to allow entrainment and to protect against overpressure [5]. Figure 4 illustrates this setup.



Figure 4: Use of the reservoir bag to indicate spontaneous respiration. Note also the alternative oxygen supply arrangement.

The Revised Laerdal Resuscitator

A recent change in the design of the Laerdal resuscitator has made the new model incompatible with the original TSAA configuration. Assembly with the new model requires the “pushover” arrangement with the SIB and its reservoir bag connected to the distal (upstream) end of the OMVs (Figure 5)



Figure 5: Laerdal Resuscitator®: the new version is on the right

Paediatric Modification

The non-return valve offers little resistance and TSAA has been found to be safe in its original configuration for children of 10 kg and over [6]. For smaller children, the OMVs can be converted into a crude continuous flow anaesthetic machine for use with a Mapleson F system. To provide an overpressure blow-off valve, an APL valve can be attached via a short length of corrugated tubing to the upstream end of the T-piece. Oxygen and other gases are introduced into the system via the T-piece to fill the Jackson-Rees bag and allow spontaneous breathing or hand ventilation. This is illustrated in Figure 6 and described in more detail in the recent article by Ralph et al [7].

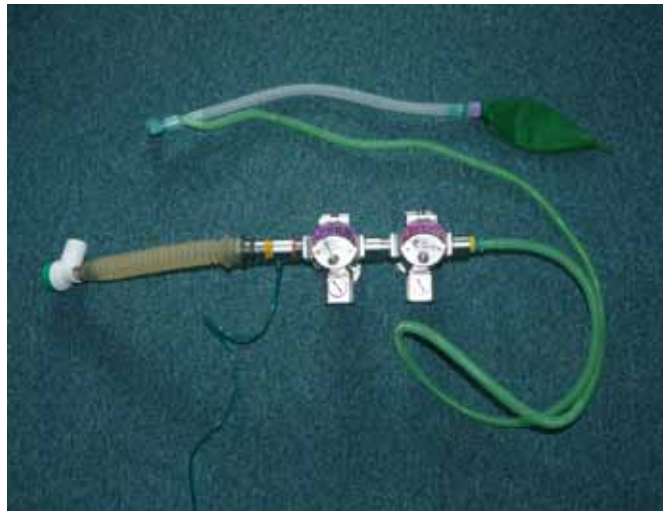


Figure 6: Setup for paediatric anaesthesia using an APL valve

Preoxygenation

Preoxygenation is normally undertaken with a supply from an oxygen cylinder in addition to the concentrator due to the limited flow from the latter device. This can be achieved by connecting the SIB to the cylinder and the T-piece to the concentrator. A disadvantage with this approach is that inadvertently leaving the cylinder supply on results in significant dilution of volatile agent and therefore awareness is likely. This is only the case where the SIB is in circuit so it should not be seen during established mechanical ventilation. A popular alternative is to connect both oxygen sources to a 3 way connector (typically a Luerlok 3-way tap) which is joined to the T-piece. As both supplies are upstream of the OMs, dilution of volatile agent is not seen.

In preparation for induction, preoxygenation is achieved with both oxygen sources feeding into the circuit and the SIB connected. Anaesthesia is induced in the usual fashion and hand ventilation may be started using the SIB. For maintenance, the SIB is removed, the cylinder supply switched off, the ventilator tubing connected and mechanical ventilation begun. An alternative approach for RSI only is to preoxygenate and induce/intubate with the Bag-valve-mask separate from the rest of the circuit which avoids the potential to leave the SIB in circuit during IPPV as well as the potential for dilution of volatile agent if the cylinder supply is left running.

Volatile Agents and Gas Induction

Although isoflurane is normally used in the OMV50, as it is a “universal” vaporiser a number of anaesthetists have looked at the possibility of using sevoflurane. Liu & Dhara tested the vaporiser on a flow-bench and suggested that the output should

be suitable [8]. Brook and Perndt subsequently used sevoflurane clinically and stated that it was possible to perform an inhalation induction with two vaporisers [9] but the modern penchant for gas induction with sevoflurane has been difficult to satisfy with the TSAA. The OMV was designed when the relatively potent halothane was the volatile agent of choice and maximum outputs are limited when 4 MAC of sevoflurane is the target. Results are conflicting but the original TSAA does not appear to lend itself to this technique [10]. Sevoflurane has been used in the Universal PAC [11] and more recently Diamedica (Diamedica (UK) Ltd, Bratton Fleming, Devon, England) has developed a sevoflurane vaporiser which for the first time appears to produce a sufficient output for inhalational induction using a single vaporiser in a drawover system [2].

Common Pitfalls

The TSAA is not without its problems and has many critics. It is generally agreed that there is still a need for a portable drawover anaesthetic system to be available to the UK military [12] but the original TSAA is overdue for replacement. It has a number of particular problems:

Disconnections and practical hazards

Unfamiliarity, heavy tubing and complex procedures for changing configurations all contribute to the hazards of using the TSAA. It is a useful system for insertion and mobile operations but should not be the first choice equipment for an enduring mission. This was highlighted in January 2009 when a Patient Safety Incident report was submitted from Op HERRICK to PJHQ regarding the TSAA. The concerns identified included the potential for disconnection due to the number of connections in the circuit and the lack of familiarity amongst multi-national personnel.

Scavenging

Active scavenging is rarely available in the field so volatile agents are usually scavenged by activated charcoal in the form of a Cardiff Aldasorber (Shirley Aldred & Co Ltd, Derbyshire, U.K.). This adds to the hardware at the patient end as a scavenging connection must be made to the outlet of the non-return valve.

Consumption of Volatile Agent

Recycling of volatile agents cannot be achieved with the TSAA so consumption is high. Furthermore, as the capacity of the OMV is low refilling of vaporisers during anaesthesia is a common event. The presence of two vaporisers allows maintenance of anaesthesia but care must be taken to avoid disruption of the system, spillage and boluses of volatile to be delivered inadvertently.

Dead Space

Although it has improved safety, the addition of patient monitoring, spirometry, scavenging and heat and moisture exchange have increased the length of the TSAA beyond the non-return valve by a significant amount. This increases dead space and the potential for disconnections. That said, such additions would be needed on any modern anaesthetic system.

Training

Training on the TSAA has been difficult since the demise of the military hospitals and the reluctance of NHS Trusts to use equipment which is unconventional. Although it is possible to view the equipment at the pre-deployment Hospital Exercise

(HOSPEX), because of fidelity limitations it is not the ideal location to simulate an anaesthetic with the equipment. In view of these shortcomings a high fidelity simulation course has been developed. The requirement to actually give an anaesthetic to a mannequin which would be monitored by the equipment that is deployed meant that only the physiologically modelled mannequin, METI HPS® was suitable and a contract has been established with the Cheshire and Merseyside Simulation Centre to deliver the training.

On the one-day course the team is initially introduced to the TSAA and to the capabilities of the simulator as familiarisation is also important for effective non-technical skills. Subsequently four scenarios are run with one or more anaesthetists and an ODP. Each scenario has been designed with input from military Subject Matter Experts and the civilian simulation staff to combine realistic medical and equipment related problems and to explore the team dynamics in critical problem solving.

Allied Approaches to Drawover Anaesthesia

US forces have also used a draw-over apparatus for light scales of effort. Their system has been based around the Ohmeda Universal PAC. This vaporiser has some differences from the OMV, the main one being that it is temperature compensated. At present US forces still make use of it but are actively seeking a replacement because manufacture of the PAC has ceased.

The Australian Defence Force use draw-over equipment also and the system they have chosen is also based around the OMV50. This has been developed into a set of equipment such that, although the OMV is not CE marked, the entire setup has been given type approval. It is the Field Anaesthesia Machine (FAM 100) manufactured by Ulco Medical (Marrickville, NSW, Australia) [11].

Conclusion

The TSA was first described in 1981 as the ideal anaesthetic apparatus for airborne and amphibious entry operations. Some equipment changes have been necessary over the years but the original requirement for robust, portable equipment is unchanged. That said, anaesthesia no longer has to depend on volatile agents. Robust, lightweight and accurate intravenous pumps are available with long battery lives for TIVA and this also removes the need for scavenging. Although TIVA is increasing in popularity, especially for repeat procedures, the support for volatile agent based anaesthesia remains strong. Indeed the position of conventional anaesthesia worldwide, especially from drawover apparatus in austere environments is such that new equipment is still being developed.

The DMS is likely to maintain a drawover volatile anaesthesia capability especially for entry operations and this is widely supported by Defence Anaesthetists. This article highlights a number of areas where the TSAA fails to satisfy the expectations of DMS Anaesthetists and in a number of cases causes real concern. The disconnection risks, unfamiliarity and lack of CE marking of the OMV50 are examples. The issue of CE marking is an interesting one as there is no CE standard for drawover vaporisers. It is, however, possible for a set of equipment (including a draw-over vaporiser) to obtain CE certification (e.g. the FAM 100). The above concerns suggest that a replacement is required but many of the original features of the TSAA are still relevant. Any replacement must be compact, lightweight and robust. It is difficult to envisage a modern field surgical unit without electricity, but an anaesthetic

apparatus that is independent of compressed gas supplies would be preferable.

Although the replacement for the TSAA is yet to be identified, options exist and are being examined. In the meantime potential users must be aware of the issues highlighted in this article and ensure that they are appropriately trained in its use before deployment. Instruction from experienced users is available on pre-deployment training courses.

References

1. Houghton I. The Triservice anaesthetic apparatus. *Anaesthesia* 1981; **36**: 1094-1108
2. English WA, Tully R, Muller GD, Eltringham RJJ. The Diamedica Draw-Over Vaporizer: a comparison of a new vaporizer with the Oxford Miniature Vaporizer. *Anaesthesia* 2009; **64**: 84-92
3. Taylor JC, Restall J. Can a drawover vaporiser be a pushover? *Anaesthesia* 1994; **49**: 892-4
4. Roberts MJ, Bell GT, Wong LS. The CompPAC and PortaPAC portable ventilators bench tests and field experience. *J R Army Med Corps* 1999; **145**: 73-7
5. Birt D. A reservoir bag for the Triservice Anaesthetic Apparatus. *Anaesthesia* 2006; **61**, 510-511
6. Bell GT, McEwen JPJ, Beaton SJ, Young D. Comparison of work of breathing using drawover and continuous flow breathing systems in children. *Anaesthesia* 2007; **62**: 359-363
7. Ralph JK, George R, Thompson J. Paediatric Anaesthesia using the Triservice Anaesthetic Apparatus. *J R Army Med Corps* 2010; **156**: 84-86
8. Lui EH, Dhara SS. Sevoflurane output from the Oxford Miniature Vaporizer in drawover mode. *Anaesth Intensive Care* 2000; **28**: 532-6
9. Brook PN, Perndt H. Sevoflurane drawover anaesthesia with two Oxford Miniature Vaporizers in series. *Anaesth Intensive Care* 2001; **29**: 616-8
10. Mellor A, Hicks I. Sevoflurane delivery via the Triservice apparatus. *Anaesthesia* 2005; **60**: 1151
11. Pylman ML, Teiken PJ. Sevoflurane concentration available from the universal drawover vaporizer. *Mil Med* 1997; **162**: 405-6
12. Mercer SJ, Beard DJ. Does the Tri-Service anaesthetic apparatus still have a role in modern conflict? *RCoA Bulletin* 2010; **60**: 18-20