Field anaesthesia and critical care equipment used by the British Military

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Abstract

This article provides a description and discussion of the key equipment used by the British Defence Medical Services (DMS) to provide anaesthesia and critical care in the field. There is a need to balance equipment clinical capability against its suitability for use in the field. By necessity, military anaesthesia and critical care equipment should be robust, portable, compact, easy to use, easy to maintain and clean, and require minimal consumables.

Keywords Anaesthesia; critical care; equipment and supplies; field

Royal College of Anaesthetists CPD Matrix: 1A03, 1D02, 2G03, 3A14, 3I00

Learning objectives

After reading this article, you should be able to:

- describe the draw-over anaesthetic equipment used by the UK Defence Medical Services
- describe other field anaesthesia and oxygen delivery options
- describe field ventilators used by the UK Defence Medical Services

Introduction

Clinicians within the Defence Medical Services (DMS) are required to have multiple abilities alongside their clinic role, including an understanding of team individual roles and skills, consideration of logistics with procurement and the British military clinical care structure,[1] and command of the team. However, to provide optimal clinical care and improve patient outcomes in a fluctuant, challenging, low-resource field environment the clinician also requires resources that are 'fit-for-purpose'. The aim of this article is to describe the British military anaesthetic and critical care field equipment.

Military anaesthetic equipment

Providing equipment that is 'fit-for-purpose' in a variety of settings is virtually impossible and there is often a requirement for different capabilities to use different equipment. This creates training and skill maintenance burdens for military anaesthetists and intensivists. However, there are basic characteristics that all field equipment should have; robust, safe, accurate, easy to use, portable, compact, battery-operated, minimal consumables and easy to maintain/clean.

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General anaesthesia equipment

Draw-over vaporizers: Within the traditional classification, the draw-over vaporizer is one type of vaporizing system where its mechanism is helpfully described by its name; the patient's respiratory effort, or ventilator, 'draws' gas over the surface of the volatile leading to volatile uptake into the gas flow and providing general anaesthesia. The inherent safety of this vaporizer system relies on the depth of anaesthesia influencing the patient's respiratory effort, with a reduction in respiratory effort at increased anaesthesia depth leading to a reduction in volatile delivery. This safety mechanism is bypassed with the use of a mechanical ventilator and so further monitoring is mandatory. Due to the lack of a 'CE mark' the use of the draw-over vaporizer is unfamiliar to most UK anaesthetists. However, for the military environment it has specific advantages: light, portable, robust, simple construction, ability to use different volatiles as they are not calibrated and do not have non-interchangeable fill connectors, does not require power or a pressurized gas source, can be used with mechanical ventilation, has an element of inherent safety and can be used in-circuit while spontaneous ventilating due to its low resistance. The 'Oxford Miniature Vaporizer' (OMV) is used as part of the triservice anaesthetic apparatus (TSAA), seen in Figure 1. Problems with the OMV include poor stability due to mobile feet with a risk of decanting volatile directly into the circuit while in use, and the small 50 ml volatile chamber requiring vigilance to avoid unintentional awareness without end-tidal monitoring. Also, the system requires high gas flows, has limited temperature compensation resulting in a decrease in saturated vapour pressure with cooling although this can be offset by increasing the output percentage, and the output of the OMV varies with atmospheric pressure.

Triservice anaesthetic apparatus: Designed by Brigadier Houghton in the 1980s as a portable anaesthetic delivery system for airborne operations, the TSAA has been proven to be versatile and robust in a variety of environments experienced by the DMS. Over time there have been multiple adaptations but the fundamental components remain the same; vaporizer, ambient air ± supplementary oxygen, a self-inflating bag, a non-return valve and tubing. The current military arrangement for adult patients is demonstrated in Figure 1, with adaptations possible to allow use in paediatric patients >10 kg.[3] The TSAA incorporates two OMVs to provide stability and reduce the risk of awareness, and the non-return valve can be connected to scavenging or a PEEP valve. In terms of supplementary oxygen, this can be supplied from a low- or high-pressure source and the inspired oxygen concentration estimated using the oxygen flow and minute

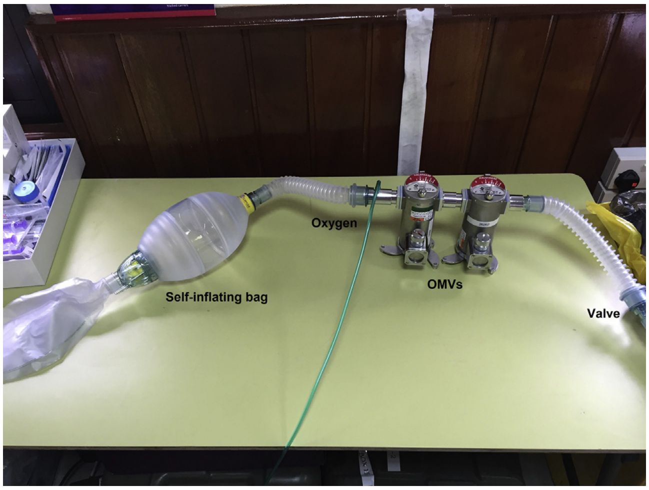

Figure 1 Triservice anaesthetic apparatus.

volume. Though not essential, the British military also carry a field ventilator, the ComPAC 200®, to provide mechanical ventilation (see below). With the TSAA arrangement in Figure 1 it provides a low resistance non-rebreathe system, which protects against bacterial infection and high carbon dioxide concentrations while allowing spontaneous ventilation. However, the TSAA does not incorporate end-tidal monitoring and so additional equipment is necessary. *Frazer and Birt's* article[3] provides further detailed information about this practical, low-resistance, portable, non-rebreathe system.

Diamedica Glostavent® Portable DPA02: Despite the success of the modified TSAA in field anaesthesia, the new DPA02 system is currently being introduced into military service to retire the TSAA. The DPA02 components are similar to the TSAA but the system has additional benefits including its portable, shockproof and weatherproof case which also provides stability when the system is assembled, ease of assembly, improved vaporizer, and CE marking. Figure 2 shows the DPA02 arrangement utilized by the DMS which enables the use of the ComPAC 200® as well as spontaneous ventilation.

Total intravenous anaesthesia (TIVA) is a valid alternative to volatile anaesthesia in the field environment.[4] It can be provided simply through IV boluses of a single agent, via use of microchip-controlled pumps or by titrating response to agents injected into a fluid bag. In addition to the generic advantages of TIVA over volatile anaesthetics, in the field environment this technique is also easy to administer, can require minimal equipment and can be continuous through each step of patient clinical care. However, there is a lack of familiarity, risk of awareness and if using pumps the models were not designed for the trauma patient and require a power source.

Drager Fabius® Tiro: Brought into service with the enduring Operation HERRICK, the Drager Fabius® Tiro is affectionately named 'anaesthetic machine heavy'. Recognizable to most anaesthetists, this theatre anaesthetic machine with ventilator and sevoflurane vaporizer is compact, workstation mounted, easy to assemble, has an internal battery and permits gaseous

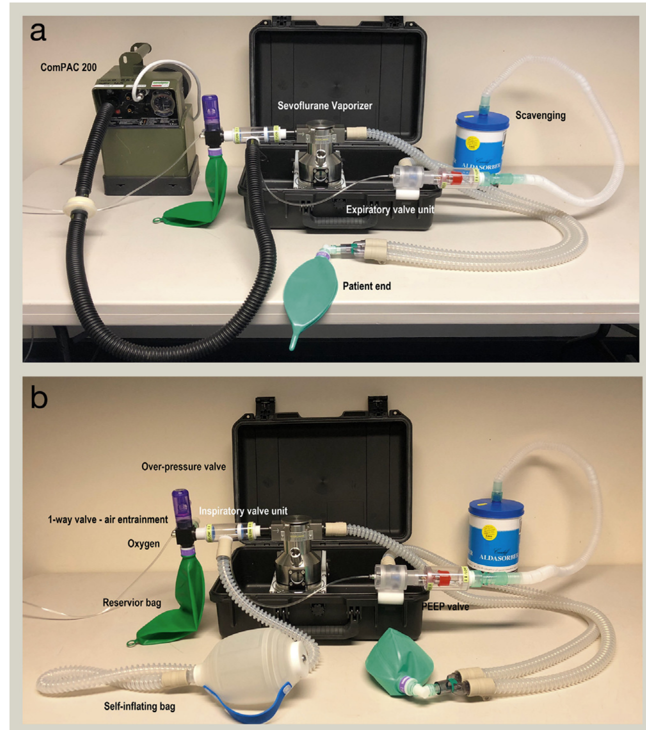

Figure 2 a Mechanical ventilation and **b** Spontaneous ventilation: Diamedica Glostavent® Portable DPA02.

inductions, unlike the TSAA. In addition, the Fabius® Tiro is more efficient than the TSAA when using a circle circuit with low-flow anaesthesia, and the vaporizer has a large capacity. However, significant disadvantages are that is requires cylinder oxygen and is not suitable for mobile, flexible operations.

Mechanical ventilation

The DMS currently have three mechanical ventilators for use in different field environments, although some will be replaced to improve capability in near future. An important feature of all mechanical ventilators used in this environment is the ability to use ambient air rather than pressurized cylinders, reducing risk and weight considerations.

Field anaesthesia: Mechanical ventilation for field anaesthesia is currently provided by the ComPAC 200® ventilator, which has been in service since the Falklands conflict but has proven to function in most other environments. This field ventilator 'looks military' with its green robust housing but also, alongside the option of using the internal battery, its size and shape make it relatively portable and easy to clean. It is quick to assemble as it has limited additional components, has an S10 respirator filter for CBRN environments, and uniquely it can run off internal and external power sources as well as pressurized gas.

The ComPAC 200® provides simple intermittent positive pressure ventilation (IPPV) by acting as a minute volume divider, having set the respiratory rate and minute volume, and has an analogue pressure gauge. The FiO_2 can only be set at 0.45 or 1.0, but unless pressurized gas is used the FiO_2 is calculated using a grid and the input oxygen flow. To provide general anaesthesia the ComPAC 200® can be connected into the TSAA, preceding the OMV, where it safely acts as a gas flow ‘pushover’. Manufacturer recommendations include mechanical ventilation in patients >20 kg, which poses issues when presented with young children as in recent conflicts. However, easy, effective adaptations allow mechanical ventilation in patients <10 kg by using the minimum minute volume (4 l/min) and maximum respiratory rate (30) with a leak in the circuit via an uncuffed endotracheal tube or adjustable pressure limiting valve.[2] The tidal volume achieved is dictated by the volume of leak and lung compliance. Quirks of this ventilator are that the tilted upper housing, which protects the control panel, also reduces visualization, the alarms are inbuilt and simple (disconnection, overpressure, low battery life or gas supply), and a FiO_2 1.0 is not achievable without pressurized oxygen. Hence, despite being a simple, robust, reliable ventilator the ComPAC 200® is only suitable for theatre anaesthesia, and perhaps some transfer situations, as it does not have the ability to provide spontaneous or the more intricate ventilation modes ventilation, or range of FiO_2 settings, required for critical care.

Field critical care: CareFusion’s VELA® ventilator is the current choice for mechanical ventilation in the field critical care environment as it can provide more complex ventilation modes, including non-invasive, for both adult and paediatric (>10 kg) patients. Additional features key to its role are that it can run on low- and high-pressure oxygen sources, the alarm settings are adjustable, it has a mobile custom trolley, is touchscreen, can be used with humidification and is able to support a nebulizer when using a high-pressure gas source.

Patient transfer: The British military patient retrieval teams, Medical Emergency Response Team (MERT) and Critical Care Air Support Team (CCAST), utilize the CareFusion LTV® 1000 for mechanical ventilation of patients (>5 kg) during transfer. Unlike the ComPAC 200® it provides IPPV or volume-controlled ventilation and can support some advanced mechanical ventilation modes including mandatory and supported spontaneous ventilation. Key features as a transfer ventilator are its relatively small size and weight, robustness, internal battery, ability to use a low- or high-pressure oxygen source and success at passing British military air-safety testing. In some operational environments the LTV® has been used in the critical care environment; however, the LTV® 1000 does have noteworthy disadvantages that need to be appreciated by the military clinician. PEEP is external to the LTV® on the expiratory limb of the patient circuit, the electronic menu can be confusing, alarms are quiet, the internal battery degrades requiring the use of additional external batteries, the oxygen flush will not operate on a low-pressure oxygen source and the air filters can be displaced easily.

Oxygen supply

Oxygen concentrator: oxygen concentrators are the main source of medical oxygen for deployed hospital care (DHC). In this environment they have numerous advantages over cylinders; cheap, less dangerous, easier and safer to store and transport, simple to use, and can humidify gas flow. However, they also have the disadvantages of requiring mains power, are not as portable, cannot provide FiO_2 1.0, can be noisy, and require consumables.

The production of a high oxygen concentration patient gas flow occurs via compression of ambient air which is then passed through a zeolite molecular sieve that selectively absorbs nitrogen. To ensure a continuous enriched patient gas flow, the concentrator utilizes a ‘pressure swing absorption cycle’ with two cylinders of zeolite operating alternatively. The enriched gas is then returned to atmospheric pressure in a reservoir and flows to the patient or ventilator via connection hosing.[5] The zeolite sieve is regenerated by ‘bleeding off’ the absorbed nitrogen then flushing it with the enriched gas at the end of the column’s cycle, or by applying negative pressure to the column.[5] Since ambient air is composed of a mixture of gases and the zeolite selectively absorbs nitrogen, the resultant gas flow can only contain up to 96% oxygen. The final FiO_2 delivered to a patient will also depend on the delivery system, with a closed circuit and ventilator providing near that expected of a specific gas flow; however, it is advisable to use inspired oxygen monitoring. Currently the British military use the DeVilbiss oxygen concentrator that can provide a FiO_2 0.93 using continuous gas flows of 5 l/min; however, there are more capable units available. Recently a portable military oxygen concentrator has been developed for the frontline, and it is hoped that this could be used as a solution for supplying medical oxygen in the developing world.

Cylinders: Oxygen cylinders are less commonly used in field anaesthesia and critical care. However they are essential for air transfer due to the change in atmospheric pressure and subsequent partial pressure of oxygen at altitude. In this environment the oxygen concentrator is not practicable as it cannot produce the high FiO_2 required for critical care patients, especially with the increased FiO_2 requirements at altitude, can only provide low gas flows which reduce the functionality of the LTV®, and it is also relatively cumbersome. Hence, MERT and CCAST both carry UK standard oxygen cylinders.

Analgesia equipment

Pain medicine is an expanding sub-speciality in military anaesthesia with its importance highlighted by the traumatic injuries experienced in recent conflicts. Providing adequate effective analgesia for patients is a desire from ‘point-of-injury’ to rehabilitation.

Regional anaesthesia: Routine use of regional anaesthesia for trauma patients in the field setting is a positive recent development after acquisition of suitable equipment, allaying fears of a ‘dirty environment’ and lack of evidence for worse patient outcomes such as compartment syndrome.[6] With the injury patterns seen in the Iraqi conflict, particularly lower limb amputations secondary to improvized explosive devices, there was a desire to explore the regular use of regional anaesthesia as it is relatively cheap, can improve patient outcomes including reduction of chronic pain,[7] and prevents systemic side effects of analgesic medications. Procurement of a field ultrasound machine, the Sonosite MicroMaxx, and consumables has permitted more routine peripheral nerve blockade and regional anaesthesia. However, an additional challenge to providing continuous regional anaesthesia via perineural catheter has been the pump. Two potential options exist for the field environment, firstly the elastomeric pump that works on the principle of providing a constant flow through a uniform catheter, with the driving force produced by the elastic distension of the local anaesthetic (LA) reservoir. Pump selection is determined by the required infusion rate and size of the reservoir. This system is cheap, portable, simple and once attached does not require further input. However, the reservoir cannot be refilled which can increase costs, the system does not provide the accuracy required for neuroaxial anaesthesia, and may become inaccurate with environmental changes. These factors are pertinent in the field environment where chest injuries are common, and temperature and altitude can vary particularly during air transfer. The second option uses a microprocessor to drive the LA flow, working in a similar way to the electronic volumetric pumps in the NHS. These devices are relatively small but require battery power, hence, are not as accessible in all environments though they do deliver more accurate LA volumes and so can be used for neuroaxial blockade.

Patient controlled analgesia (PCA): Systemic analgesia can be provided via opioid PCA which can be continued inflight during repatriation. This is provided via the B. Braun Space® PCA pump which is small, easy to use, compact, includes patient safety features as well as anti-tamper devices, and can be battery or mains powered. Specifically, the PCA pump has a selectable morphine programme that can be modified to pre-determined limits. B. Braun have standardized the Space® collection, permitting pumps to be stacked as a module and operating menus to be similar, increasing capability and reducing training for the DMS who use other pumps from the collection.

Fluids warmers and infusers

Anaesthetists are familiar with the 'trauma lethal triad', incorporating acidosis, coagulopathy and hypothermia, that leads to worsening haemorrhage and increased mortality.[8] To minimize these and provide rapid 'haemostatic resuscitation' in major trauma the British military have moved to using the Belmont® Rapid Infuser RI-2 after previously using the Level 1 H-1200. This system produces heat via electromagnetic induction coils, can infuse fluid up to 1000 ml/min or via bolus, is easy and quick to set-up, has air alarms and an interactive interface that sums infusion volumes. However, the Belmont® can only be used in DHC as it requires mains power, and the consumables are expensive.

Operating table

The Lojer Field Operating Table, known as the 'Lightweight Operating Table' (LWOT), is utilized in UK military Role 2/3 as defined in NATO doctrine. The LWOT incorporates an Inditherm Mattress for patient warming and has a maximum safe working load of 150 kg. Trendelenburg and reverse Trendelenburg can be achieved with a patient in-situ, plus supine, lateral and lithotomy positions are possible. Table height can be adjusted between 680 and 900 mm on initial set-up.

Broselow® bag

Recent conflicts presented a high proportion of paediatric patients to predominantly 'adult military clinicians' and so to assist in an emergency the British military adopted the Broselow® bag. This bag uses a colour-coded 'Broselow® Tape' to measure patient length and directs the clinician to the corresponding colour-coded module containing appropriate emergency equipment and drug dose information. However, the tape and bag were developed using a US population, with evidence of inaccuracy in other populations,[9] and other techniques considering body habitus show more accuracy.[10] In addition, replacement of used equipment is only through purchase of a whole new module. Therefore, Broselow® bags have been withdrawn from DMS with development of a replacement ongoing. ◆

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