Clinical

Anaesthesia in the Armed Forces – A History of the Triservice Apparatus

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The basic design of what was to become the Triservice Apparatus (TSA) was first described in 1968 [1]. It consisted of two Oxford Miniature Vaporisers (OMV) placed in series, leading to an Oxford Inflating Bellows, a length of corrugated tubing, expiratory valve and face mask. Air was used as a carrier gas, but it was noted that a T piece could be attached to the inlet port of one of the vaporisers to allow oxygen enrichment.

Following a review of the anaesthetic equipment available to obstetric flying squad teams, a portable unit was designed that would allow the administration of conventional modern anaesthesia in most emergency situations away from an operating theatre [2]. A one-way draw-over system was considered at the time to be the ‘most versatile and satisfactory solution’ to the problem as it was independent of medical gas cylinders, known concentrations of agents could be delivered, and pollution control was easily affected by ducting from the exit port of the one-way valve.

The Triservice anaesthetic apparatus was formally described by Houghton [3] in 1981. It had two vaporisers which permitted the administration of both halothane for hypnosis and trichloroethylene for analgesia and provided a balanced anaesthetic technique as these agents could be used either individually or together. The apparatus could be employed in a patient breathing spontaneously or undergoing manual ventilation and controlled ventilation was permitted by connecting to a ventilator. Although primarily a military development it was commented in the literature [4] that its principle of design could be extended to civilian practice ‘and it would permit the anaesthetist to carry the tools of his trade in a brief case as does his general practitioner colleague’.

The TSA did not rely on an electricity supply, making it ideal for use in the field or remote locations, and the circuit had the capability to

Fig. 1. The original circuit design taken from reference [1]

Fig. 2. The basic anaesthetic unit mounted on a base plate taken from reference [2]
allow oxygen supplementation.

Importantly for the military the equipment was modular, so that the various components could be used or replaced independently. It was easier to transport and more robust than other equipment available and was very quickly adopted by the Defence Medical Service for use by deploying anaesthetists. At the time it was noted that ‘the striking advantage of the Triservice apparatus is its simplicity’ as ‘there is no unwieldy, pipe strewn Boyle’s machine, the potential for mechanical and gas-pipe connection problems is reduced, and the apparatus is fail-safe. There is no need for rows of gauges, flow meters or an oxygen failure device and during its use reliance on nitrous oxide can be forgotten.’[4] It was commented earlier that ‘occasional anaesthetists’ could be easily taught to give a modern anaesthetic with a draw over type apparatus [2]. This would also be ideal for the military with anaesthetists deploying from an NHS civilian or peacetime setting to battlefield hospital conditions. The transport of heavy oxygen cylinders could be reduced to a minimum and in an emergency there was no danger of hypoxia from failure of the oxygen supply.

Fig. 3. The original TSA taken from reference [25]

One of the key components of the TSA was the Triservice vaporiser that was painted a matt black colour to prevent light reflection in the battlefield. Developed from the OMV, it held a volume of 50ml of volatile anaesthetic agent and, due to its construction of steel, had the potential to be used with any anaesthetic liquid without the risk of corrosion. The 50-ml reservoir was chosen for the Triservice apparatus (as opposed to the original 30ml) because it was found that the smaller OMV reservoir emptied too rapidly and thus required replenishing frequently. A folding stand was constructed of three plates attached to its base that swung out to provide a stable platform. The vaporiser contained ‘forlife’ antifreeze, which was known to solidify at minus 40°C, in the fluid reservoir and this acted not only as a heat store in the base of the vaporizer but also reduced the danger of mechanical distortion when used in colder climates. To favour usage in battlefield conditions, the vaporiser was such that it could be permitted to tilt up to 60° without spilling its contents or altering the delivered concentration. The effects of high or low ambient temperatures on vaporiser output were predicted by reference to the graphs published by Houghton with his initial description [3].

Fig. 4. The Triservice vaporiser taken from reference [3]

The TSA circuit worked so that gases that were to be inspired by the patient were either drawn or blown over through the top ports of the vaporiser with a tubular slide determining the proportion of gas actually passing through the vaporizing chamber. The concentration of volatile could be altered by the anaesthetist moving a pointer registering against an engraved scale marked in degrees. The adaptability of this set up was such that there
was a reversible scale over the temperature ranges of 20-30°C calibrated for halothane (0-4.5%) on one side and trichloroethylene (0-1.5%) on the other on a spring clip. There was of course a risk of filling the vaporiser with the wrong agent, but it was noted a ‘pin-indexed system for filling would be inappropriate as it would destroy the versatility of the vaporiser’ [3] which was crucial for flexible usage in the battlefield.

Manual ventilation was achievable by the use of a transparent green polyvinyl chloride ‘Resusci Folding Bag Mark 2’ (Laerdal) which had already been approved by the National Research Council for cardiopulmonary resuscitation. This was thought to have a ‘good feel’ and allowed differences in pulmonary compliance and pressure to be assessed easily. It was accompanied by two transparent contoured face masks with inflatable face pads for adult and child. The construction of this module allowed easy storage with the valve housing and conical connectors being made of a hard green plastic and the actual valve flaps of a silicone rubber. The option of adding an oxygen adaptor to the rear of the bag was also discussed by Houghton. This allowed oxygen to be administered to a maximum of 35% and if a 0.75-m extension tube was attached as a reservoir then up to 65% oxygen could be administered. The oxygen adaptor could be unscrewed and replaced by an ‘antigas respirator canister’ so that the apparatus could be used in a nuclear or chemically contaminated environment. The Oxford Ventilator (Penlon), a volume-cycled flow-generator, was also modified for use with the TSA. This was particularly useful as it had the potential to be powered by a pneumatic motor using non-respired compressed gas. Military engineers could adapt the compressor used to blow up tyres on army trucks to power the ventilator. It could also run on compressed gases from cylinders or from a pipeline. Other factors in favour of the Oxford Ventilator were that it could be used with both adults and children and was detachable and autoclavable [4]. The electrically driven East Radcliffe Ventilator was also permitted to be used with the TSA.

An initial concept in the design of the TSA was that it had to have the potential to be used in conditions where the supply of oxygen cylinders would be limited. Oxygen supplementation was obviously important for general anaesthesia and as there was no commercially available system on the market, a specially designed module, ‘the Houtonox oxygen flow control device’ was developed from the Novox resuscitator so that oxygen supplies could be preserved by having low flow rates of 1 or 4 litres per minute. This regulator consisted of a single-stage reducing valve combined with a flow regulator with an oxygen pin-index fitting for the inlet. The device was sturdy, accurate, and the flow rates were independent of the position of the regulator. The TSA as a non-rebreathing system minimized bacterial contamination and avoided the problem of disinfection of a circle system.

The first documented usage of the TSA by the military under field conditions was with a Field Surgical Team (FST) in the Dhofar province of Oman [5]. Knight and Houghton had also used the equipment in a modern, well equipped hospital in Northern Ireland prior to use in the field. They described the TSA as a very versatile piece of equipment that allowed ‘the administration of oxygen by face mask and endotracheal tube (with and without controlled ventilation, by hand or with a ventilator), the administration of preoperative analgesia for intra-operative analgesia and anaesthesia and postoperative analgesia, and its use in casualty evacuation’. Knight and Houghton each employed slightly different techniques. One preferred thiopentone as an
induction agent and then moderate hyperventilation with halothane or trichloroethylene and tubocurarine when needed. The other used Althesin for induction, pancuronium as the non-depolarising muscle relaxant with manual ventilation in an air-oxygen mixture. Supplemental intravenous fentanyl or phenoperidine was used to minimise the concentration of trichloroethylene administered. [5]

Emergency casualty cases were assumed to have a full stomach and therefore following a period of 3 to 5 minutes pre-oxygenation and intravenous induction they were intubated ‘to protect the lungs from gastric contents. Most were then ventilated mechanically. Satisfactory surgical anaesthesia was achieved in 3 to 5 minutes by slowly increasing the concentration of the volatile agent following induction with a maximum of 4.5% halothane being used. Providing there were no involuntary movements or pupil reactions to incision the halothane was maintained at 0.5-1% or the trichloroethylene at between 0.5-0.75% for controlled respiration and 1-2% halothane for spontaneous respiration. It was also noted that intravenous analgesic supplementation with fentanyl (0.05-0.1 mg) or phenoperidine (0.5-2 mg) could allow the trichloroethylene to be reduced to 0.25-0.5%. The TSA was able to operate for about 4 hours before the 50ml vaporiser reservoir required refilling, and with a flow of 1 litre per minute a small 300 litre oxygen cylinder was able to last up to 5 hours [5]. They noted that compared with controlled ventilation, for a casualty breathing spontaneously, a higher concentration of volatile agent was required in the initial period leading to stable anaesthesia. Compared with the original OMV the output of the Triservice vaporiser had been adapted to increase the maximum delivered trichloroethylene from 1% to 1.5% and from 3% to 4.5% for halothane. As experience progressed it was concluded that the use of halothane or trichloroethylene alone was not satisfactory for spontaneous respiration but a combination of the two produced an acceptable level of anaesthesia more smoothly and more rapidly. For maintenance of anaesthesia during controlled ventilation, either volatile agent alone proved suitable. A rapid recovery could also be achieved with the TSA and this was particularly important in a military setting as theatre or nursing personnel were freed up to undertake other duties. It allowed a greater throughput of cases in theatre at times of increased casualties.

In April 1982, Argentina invaded and took control of the Falkland Islands. The response of the Conservative government was to deploy a taskforce to reclaim the islands. Following their return to the UK, both Royal Navy [6] and British Army [7] anaesthetists published their experiences, particularly of how the TSA was employed and any problems they had encountered. About 800 general anaesthetics were performed over the whole campaign and 637 of these were by naval anaesthetists. The hospital ship SS UGANDA was a merchant cruise liner adapted in Gibraltar ‘en route’ to the Falkland Islands. There were two anaesthetists onboard who had two model M Boyle’s machines, three Pneupac ventilators, two Penlon Oxford ventilators with air compressors and four TSAs at their disposal. The two aircraft carriers, HMS HERMES and HMS INVINCIBLE had theatre facilities available onboard. Onboard HMS HERMES, 16 general anaesthetics were performed, for battle casualties following the Exocet attacks on HMS SHEFFIELD and HMS GLAMORGAN. General anaesthetics were given to 26 patients onboard HMS INVINCIBLE. These were initially for Argentinian sailors, from the trawler Narwal, with shrapnel wounds. Fortunately there was never such a shortage of gases that TSA usage became mandatory. One Royal Naval surgical team disembarked with 3 Commando Brigade at San Carlos and together with the Army Field Surgical Team set up the field hospital at Ajax Bay. It was no surprise that anaesthesia ashore was carried out under particularly difficult and often hazardous conditions, but the medical officers involved concluded that the TSA was very valuable as it was compact and, as it was easy to transport, dispensed with the requirement for bulky anaesthetic equipment.

During the Falklands campaign, the TSA...
was used for the first time under low ambient temperatures. It was also first occasion on which the TSA had been used for prolonged periods under battle conditions. In his original description of the TSA, Houghton showed that the output of the TSA varied with temperature and produced graphs to indicate that at low temperature the output fell. The ambient temperature on the hospital ship SS UBANDA was about 18°C, but as expected it was far colder in the Ajax Bay Field Hospital where the ambient temperature was nearer 13°C. Anaesthetists found it necessary to turn up both halothane and trichloroethylene control settings after about 20 minutes in order to maintain the required level of anaesthesia.

‘Control settings of up to 2.5% halothane and 1% trichloroethylene in air were often needed during spontaneous respiration anaesthesia in order to counter tachycardia, tachypnoea, limb movements and sweating’ [8]. Naval anaesthetists, Bull and Tighe reported that ‘it became common practice to cuddle the vaporisers under our clothing to supply additional heat with apparent good effect. It became evident that such additional heat was required to maintain a satisfactory level of anaesthesia’. [8]

Correspondence in Anaesthesia after the war [9] discussed that temperature compensation had been thought about when concept of the TSA was in its infancy as it would certainly have been possible to design a vaporiser that incorporated it. In view of the increasing complexity and difficulties in servicing, maintenance and calibration, this idea was rejected early on. With no temperature compensation available, this meant that the OMV could continue to be used for all available volatile agents provided that the detachable scale was changed.

Two British Army anaesthetists, Jowitt and Knight, described their experiences with TSA as part of the Parachute Field Surgical Team in the Falklands [7]. They concluded that the TSA had ‘functioned adequately at all times and required minimal maintenance’. Both anaesthetists employed different techniques for induction of anaesthesia; however maintenance of inhalational anaesthesia was via the TSA vaporizers. A total of 113 cases were undertaken (43 ventilated and 70 breathing spontaneously). Manual compression of the self inflating Laerdal bag was employed to ventilate the lungs with the adequacy of ventilation being determined by observing chest wall movement. Ventilation was performed by another member of the field surgical team to allow the anaesthetist to be free to perform other tasks. Although safe and effective, assistants reported that the bag squeezing was very tiring. At the end of the war, both anaesthetists proposed that the green Laerdal bag should be replaced with the new silicone version ‘to provide a more sensitive ‘feel’ for manual ventilation’. [7]

The steady throughput of cases was maintained as anaesthetists become more skilled with TSA in wartime situations. They were able to time more precisely the speed with which patients awoke from anaesthesia. It was noted that on shutting off the OMVs the average time to respond to command was less than 5 minutes [7]. Some users noted that there was a lightening of anaesthesia after 10–15 minutes which could have been explained by the induction agents eventually wearing off. Another problem reported was that occasionally, during spontaneous respiration, the Laerdal valve did not close properly and resulted in air dilution of the volatile agents. There were no recorded cases of awareness despite obvious signs of light anaesthesia. This was thought to be a consequence of the amnesic properties of trichloroethylene. [8]

By 1987 other volatile agents such as enflurane and isoflurane were starting to be used in modern clinical practice. It was considered that Halothane was no longer the ideal agent to use as the hypnotic component of a balanced anaesthetic technique [10]. Halothane had been shown to be more dysrhythmogenic than enflurane or isoflurane in the presence of endogenous or exogenous catecholamine - which would be high in acutely traumatized soldiers. The risk of halothane hepatitis was also a real issue as battle casualties often need repeated surgery for initial debridement of their wounds and then for subsequent delayed closure. Repeat exposure to halothane, with the risk of liver
dysfunction ensured that studies of the newer agents with the TSA were performed. Kocan [10] concluded that enflurane and isoflurane were acceptable alternatives to Halothane and that satisfactory anaesthesia was achieved in all the cases observed. It was also noted that in view of the shorter recovery time and the enormous cost differences, enflurane was preferable to isoflurane [10], although as enflurane had a higher MAC it would be unable to be administered as a single agent at sufficient concentration from one OMV. Others too, [11] were aware of the current feeling about liver damage due to repeated halothane anaesthetics and commented that ‘it would be preferable if this were not used in the first instance where repeated procedures would be necessary’. It was also apparent in 1988 that the manufacture of trichloroethylene had been threatened in the past and that the future production could not be guaranteed. Wise words commented that the battle field was not the place for anaesthetists to be learning how to use a new anaesthetic agent as many were becoming unfamilar with trichloroethylene.

Isoflurane and the TSA were investigated in more detail during the mid-1980s [12]. Having the physical properties of being nonflammable, not explosive and chemically stable with a low rubber solubility it had the potential to be easily transported and could be used as a single agent. This would lead to the possibility of a single OMV in the TSA circuit. The low biotransformation of isoflurane fulfilled the criteria to allow for repeat anaesthetics on injured personnel and the suggested analgesic properties were also favorable. Induction and recovery were noted to be rapid. Other advantages included a stable cardiovascular system and little respiratory depression [12]. It was also no surprise that induction was complicated by coughing in a service population who were generally heavy smokers [13]. Later, Tighe [14] compared isoflurane as a sole agent with the traditional agents of the TSA, halothane and trichloroethylene. He concluded that isoflurane provided ‘similar conditions of anaesthesia and analgesia, with the added advantages of a lower respiratory rate, more economical use of oxygen and the requirement for only one vaporiser’. Not surprisingly, Yoganathan and Houghton [13] found that both induction and maintenance of anaesthesia were technically more difficult with isoflurane than with halothane when the two agents were compared. The respiratory depression and the pungency of the isoflurane ‘resulted in a slower uptake of the volatile agent’. They were also concerned that a draw-over technique was an expensive way to deliver isoflurane although this was counter argued by Tighe [15] as inconsequential in the military environment ‘when compared to the overall cost of operating a field hospital and the cost of the weapons making anaesthesia necessary’. As military casualties had a very high risk of aspiration, it was considered better to intubate, thus avoiding the slow and complicated gaseous induction experienced with isoflurane.

The next significant military deployment of the TSA was during the 1st Gulf War in 1992. The operating facilities available were now more sophisticated than that previously experienced in the Falklands War with the modern field hospital having ‘an integral generator-driven electricity supply, which should continue to function in all but the most desperate conditions’ [16]. Anaesthetists were also starting to use intravenous anaesthetics for maintenance on a regular basis and it was considered that a conversion from an infusion technique to an inhalational, hand-ventilated anaesthetic would be straightforward. This was considered a minor inconvenience when compared with the catastrophe of loss of theatre lighting, suction, monitoring and automatic ventilation all of which would be lost if the electricity supply failed. The operating theatre complex was an open tented area containing eight field operating tables all of which were equipped with TSA, Ohmeda 9000 syringe infusion pump and a manual sphygmomanometer [17]. There were also two Critikon Dinamap automatic non-invasive blood pressure monitors available and four pulse oximeters. The potential for chemical weapons now played a more
important role and so a further two operating tables were sited in a collective chemical protection area. The attachment of a chemical agent absorption filter at the air intake port of the ventilator was available should the theatre become contaminated. The most commonly used volatile agent during the 1st Gulf War was Halothane and even though trichloroethylene was no longer available in the UK in 1992 it was available from the war mobilization stock. Isoflurane was reserved for use on patients with suspected head injury only.

The TSA was subjected to the opposite temperature extremes that it had experienced in the Falklands conflict as temperatures of between 45-53°C were measured in a Gulf War operating room [18]. The TSA had not initially been designed for this extreme of temperature. Merridrew [18] was aware that the working temperature of volatile agents from OMV in the TSA had only been published with a temperature range of 13°C to 27°C and undertook a hospital based study of isoflurane outputs measured at minus 1 to 55°C using a Datex Capnomac. Not surprisingly the further the temperature rose above about 30°C, the more dangerous the maximum OVM outputs became and various external bypasses were investigated to reduce the excessive isoflurane draw-over output of the OMV.

The Cape TC 50 ventilator was issued to field hospitals to complement the Triservice anaesthetic apparatus and gained popularity among service anaesthetists. For reasons of convenience, ease of assembly and good working ergonomics, some anaesthetists assembled the Triservice apparatus using the TC 50 to push the fresh gas flow (pushover mode) through the OMV. A study by Taylor and Restall [19] looked at this configuration and concluded that there was no difference in the performance of the OMV in the pushover or draw-over mode. In 2000, the production of the TC 50 ventilator ceased as did servicing and sales of spare parts [20]. It became clear that a replacement would become necessary and by 2005 the ComPac 200 ventilator (Pneupac; Smiths Medical, Watford, UK) had become the standard military ventilator issued to all field hospitals [21].

As Sevoflurane had started to enter clinical practice, this new agent was investigated [21] as it was a becoming a favorable agent for use with patients with a compromised airway. Mellor and Hicks performed a study [21] to assess the maximum deliverable concentration of sevoflurane via the TSA. The results also showed that low concentrations of sevoflurane were delivered relative to those that would be expected with other anaesthetic agents in the draw-over mode, but the delivered sevoflurane concentration was higher in the pushover mode. The study concluded ‘that maintaining a sufficiently high concentration of sevoflurane for long enough to achieve deep anaesthesia for intubation would prove very difficult and that adding more OMV would provide little additive effect’. It was disappointing that when two room temperature OMVs with sevoflurane were both turned to maximum output the maximum concentration of sevoflurane achieved was only 4.5% and this fell to 4% within 2 minutes in the draw-over mode. The authors recommended that sevoflurane should not be used for induction of anaesthesia with the TSA [21].

Due to the nature of their injuries, many of the patients in whom the TSA is used in the field will require pre-oxygenation. The way that this was achieved has been the subject of much debate in the literature. As described earlier, the original TSA was supplied with a Houtonox oxygen regulator with two preset flow rates of 1 and 4 litres per minute in an attempt to conserve oxygen. Although Houghton showed that supplementation with 4 litres per minute would raise the inspired FiO2 to 0.6, this was before it had been demonstrated that higher levels of inspired oxygen were required for effective pre-oxygenation. The oxygen cylinder attached to the TSA only delivered at 4 litres per minute to aid oxygen supplementation, using a reservoir tube and T-piece. It was considered that anxious and unpremedicated patients would be likely to
have a higher minute volume when asked to breathe deeply during pre-oxygenation. It was also considered that with an oxygen supplement of only 4 litres per minute and a minute volume of 20 litres per minute the resultant FiO2 would be less than 0.4 [15]. Several methods to improve this have been described, one of which is the positioning of an extra oxygen reservoir at the open end of the reservoir tube. This comprised simply of a 100 x 50 cm plastic bag fitted around a piece of disposable plastic breathing system tubing that could hold about 40 litres of oxygen collected over a 10 minute period. The patient then breathed the contents of the bag through the draw-over apparatus. This was considered to be ‘easy to use, inexpensive and portable’ [22]. Houghton rightly commented [23] that pre-oxygenation studies had demonstrated that ‘three maximal deep-inspirations were as effective as 3–4 min of normal respiration using pure oxygen and that by using a 20-litre bag prefilled with oxygen, effective pre-oxygenation could be achieved using three maximal deep-inspirations, assuming a vital capacity of 6 litres’.

Recent conflicts in Afghanistan and Iraq have seen military surgeons and anaesthetists being required to operate on civilian casualties including children. A recent study [24] reported no significant difference in the work of breathing between the Mapleson F and the TSA and that a lower weight limit of 10 kg could now be recommended in clinical practice.

It is clear that the TSA has been a most valuable servant for the British Military and still has a vital role in providing anaesthesia in remote and dangerous situations. Unfortunately the equipment does not carry a CE mark and so cannot generally be used in civilian practice in the NHS without permission. As a compromise Military Anaesthetists attend simulation training courses and deploy as Specialists Registrars under supervision to learn how the apparatus functions, prior to deploying as a consultant. Future miniaturization of anaesthetic equipment and the increasing usage of newer agents such as desflurane and xenon will all determine the future role of TSA in military deployments.

References


24. Bell GT, McEwen JPJ, Beaton SJ, Young D. *Comparison of work of breathing using drawover and continuous flow anaesthetic breathing systems in children*. Anaesthesia 2007; 62: 359-

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