

EXPERIENCE WITH THE GLOSTAVENT ANAESTHETIC MACHINE

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In many parts of the world, anaesthetists have to work in difficult or isolated situations where medical supplies are erratic and servicing facilities are poor or non-existent. Most modern anaesthetic machines, however, are not designed to be used in these conditions, as they require high levels of maintenance and servicing by trained engineers and are dependent on continuous supplies of compressed gases and electricity. Consequently, when conditions are unfavorable, they are liable to malfunction or even fail completely.

An anaesthetist working in such difficult conditions requires an anaesthetic machine which has been specifically designed to overcome these problems. It should therefore be reliable, easy to understand and operate, economical to run, require minimal servicing which can be carried out locally, and be versatile, so that the same machine can be used in all patients both as an anaesthetic machine in the operating room and as a ventilator in a recovery room or I.C.U. Most important of all, it must continue to function if either the electricity or oxygen supplies fail, situations that are all too common in parts of the developing world and that have been responsible for many tragedies.

The Glostavent anaesthetic machine has been designed to fulfill these requirements precisely.

In the development of the Glostavent, four separate components have been incorporated, each of which has, in its own right, already proved valuable in difficult environments. These are the draw-over anaesthesia system, the oxygen concentrator, the Manley Multivent ventilator, and the air compressor.

1. The Draw-Over Anaesthesia System

Atmospheric air is used as the carrier gas, which is drawn over a low resistance vaporiser, in this case, the Oxford Miniature Vaporiser (O.M.V.), either by the negative pressure created during inspiration in spontaneously breathing patients, or by the action of bellows when breathing is controlled. **IT CAN THEREFORE BE COMPLETELY INDEPENDENT OF THE SUPPLY OF COMPRESSED GASES.** Oxygen from a cylinder or a concentrator can be added upstream of the vaporiser, to increase the inspired oxygen concentration.

2. Oxygen Concentrator

This is an electrically powered device which produces a continuous supply of oxygen from atmospheric air, by first compressing the air and then directing it through canisters containing zeolite granules where the nitrogen is absorbed and the residual oxygen delivered to the patient. The zeolite granules are continually being re-activated and do not require changing.

3. Manley Multivent Ventilator

This is a pneumatically driven version of the Oxford inflating bellows. It can be driven either by compressed air or oxygen and only requires a volume of driving gas equal to 1/10 of the patient's minute volume. When oxygen is used for driving the ventilator, it is automatically collected and returned to the breathing circuit. In other words the same oxygen is used twice, first to drive the ventilator and then for the patient to breathe. The bellows of the Multivent can also be operated manually.

4. Air Compressor

This is an integral part of the oxygen concentrator, which has been modified to allow some of the compressed air generated by the concentrator to be diverted for use as driving gas for the ventilator, so that the concentrator provides both the driving gas for the ventilator and oxygen for the patient. In the design of the Glostavent, the four components are mounted on a single trolley, together with 2 reserve oxygen cylinders (figures 1 & 2). It was initially described under its original name of Oxyvent¹ and subsequently as the Glostavent².

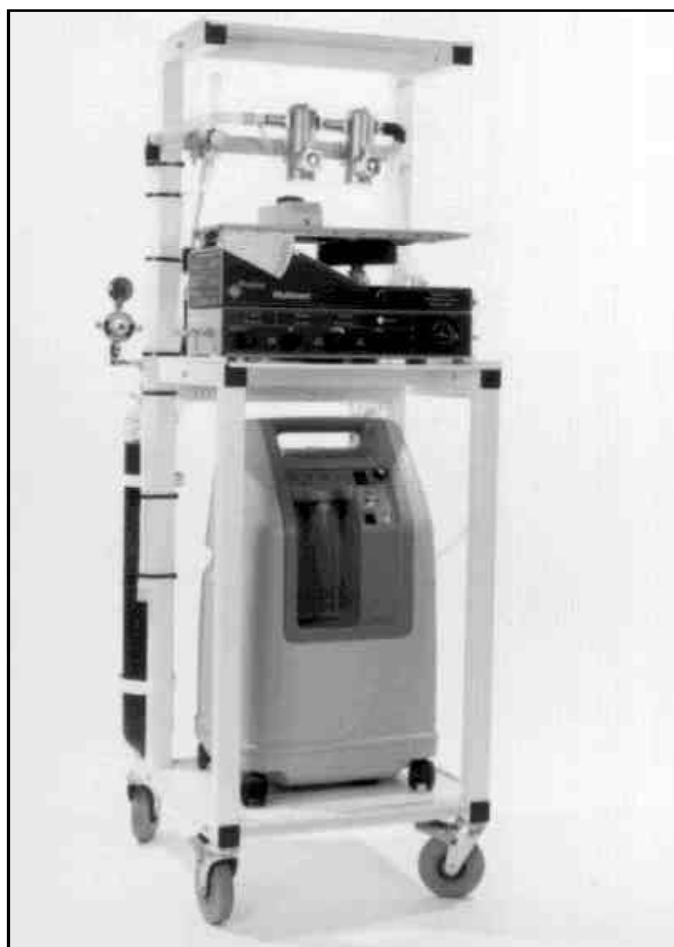


Figure 1: The Glostavent

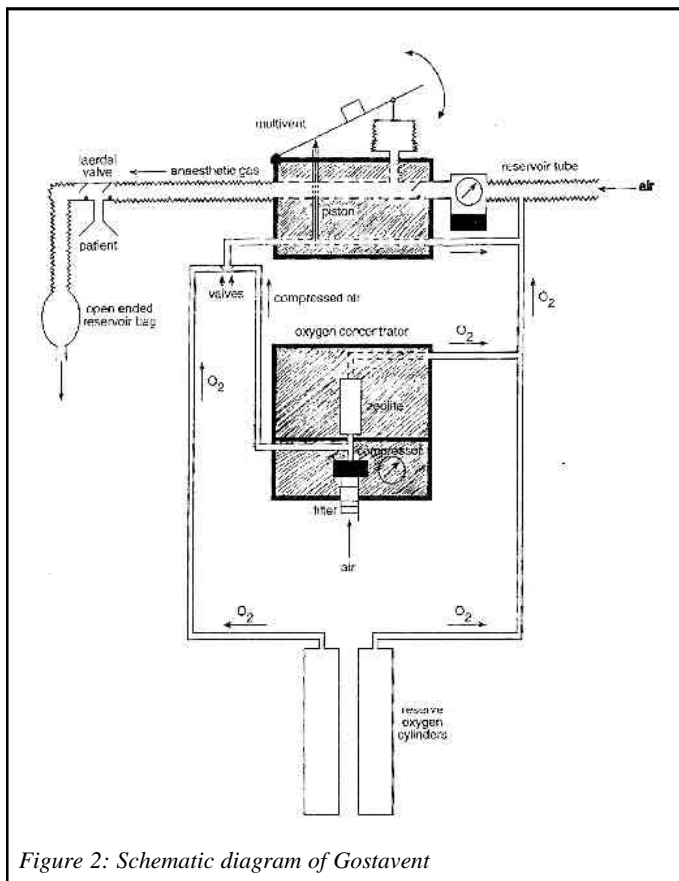


Figure 2: Schematic diagram of Gostavent

Although it has now been in regular use in several hospitals throughout the world for the past 6 years^{3 & 4} delivering anaesthesia safely to thousands of patients, few reports of its use have so far been published⁵, and a full description of its operation illustrating its many advantages is not available.

Its potential as a safe, reliable and cost effective anaesthetic machine has been recognised by the Association of Anaesthetists of Great Britain & Ireland, the World Federation of Societies of Anaesthesiology and the Department for International Development, all of whom have contributed to its development.

However, anaesthetists practicing in difficult situations or in isolation need to be confident that it will perform predictably and reliably in their own environments, so that it can be used safely when monitoring facilities are limited or totally absent.

To illustrate this, the records of patients whose anaesthetic had been administered using the Gostavent in a district general hospital with full monitoring were scrutinised. A standard anaesthetic technique was used so that the performance of the Gostavent under various conditions could be analysed and recommendations made for its operation in adverse situations.

Anaesthetic Technique

After a period of pre-oxygenation, anaesthesia was induced intravenously with propofol 2.5mg kg⁻¹.

If intubation was indicated, this was achieved following vecuronium 0.1mg kg⁻¹ or rocuronium 0.6mg kg⁻¹. In patients not requiring intubation, a laryngeal mask airway (LMA) or facemask was used.

A draw over technique with an inhalational agent in an air/oxygen mixture supplemented by opiates was used in all adult patients. In children under 25kg, the Gostavent was adapted for continuous flow use. (see below)

Either isoflurane or halothane was administered via the O.M.V., to give expired concentrations of 1-1.3 times the Minimum Alveolar Concentration. Opiate supplements (fentanyl 0.3mcg kg⁻¹ or morphine 0.03mg kg⁻¹) were administered intravenously at 15 minute intervals in ventilated patients. In patients breathing spontaneously this rate of administration was adjusted as necessary to maintain a respiratory rate between 10-20 breaths per minute. In patients receiving I.P.P.V. the ventilator was set to deliver a tidal volume of 5ml/kg at a rate of 10 breaths per minute. Supplementary oxygen from either the oxygen concentrator or a cylinder was delivered into the side arm of the reservoir tube at flow rates ranging from 0.5 to 5 litres per minute in order to maintain the Sa O₂ above 95%.

The patients ranged in age between 1 and 92 years, in weight between 10 and 130kg and the duration of surgery between 10 minutes and 5 hours 30 minutes.

The Gostavent was used in any one of 4 different modes, depending on the type of breathing (spontaneous breathing or I.P.P.V.) and the source of the oxygen(concentrator or cylinder) [Table 1].

Table 1. Grouping of patients according to type of breathing and source of oxygen.

	Type of Breathing	Source of oxygen
Group 1	Spontaneous	Cylinder
Group 2	Spontaneous	Concentrator
Group 3	I.P.P.V	Cylinder
Group 4	I.P.P.V	Concentrator

Ventilation

In spontaneously breathing patients, provided the rate of administration of opiates was adjusted to maintain the respiratory rate between 10-20 breaths per minute, both respiratory depression on the one hand and light anaesthesia on the other could be avoided by using simple clinical observation alone [Table 2]. This is an important factor in situations where capnography is unavailable.

In patients receiving I.P.P.V., the ventilator settings gave levels of FeCO₂ which were satisfactory.

The minute volume was found to be similar in all four groups, although in both groups of spontaneously breathing patients (groups 1 & 2) this was associated with higher respiratory rates and lower tidal volumes and resulted in higher FeCO₂ values than in those receiving I.P.P.V. (groups 3 & 4).

Table 2 . Relationship between Tidal Volume, respiratory minute volume and FECO₂.

	Respiratory rate Breaths/min (Mean ± SD)	Tidal volume VT (ml)	Resp. minute volume (Litres/ min) (Mean ± SD)	FECO ₂ (mmHg) (Mean ± SD)
Group 1	16 ± 4.3	241	3.8 ± 4.9	49.3 ± 7.2
Group 2	15 ± 6	250	3.9 ± 5.1	48.6 ± 7.8
Group 3	10 ± 1	380	3.8 ± 0.9	39.8 ± 5.8
Group 4	10 ± 1	380	3.8 ± 1	39.5 ± 6.3

Oxygenation

No problems with oxygenation occurred in any of the patients. There was a clear relationship between the flow rate of added oxygen and the FiO₂ in all groups (figure 3). When the concentrator was the source of oxygen(groups 2 & 4), FiO₂'s of 75-85% could be achieved with a flow of 5L/Min. However, when using cylinder oxygen (groups 1 & 3) which is not contaminated with nitrogen or inert gases, a corresponding FiO₂ was achieved with much lower flow rates. This is an important factor when cylinders are in short supply and oxygen needs to be conserved.

During I.P.P.V. (groups 3 & 4) the driving gas for the ventilator was either oxygen from the cylinder (group 3), or compressed air from the concentrator (group 4).

When this driving gas was added to the inspired mixture, FiO₂'s were found to be 20% higher in the case of O₂. Indeed, in group 3, FiO₂'s of over 35% were consistently achieved without the need for any supplementary oxygen whatsoever.

An important safety feature of the draw over system is that, in the absence of nitrous oxide, the accidental delivery of a hypoxic mixture is impossible. As the FiO₂ has been shown to be largely predictable for a given flow rate of supplementary oxygen from either concentrator or cylinder, the absence of an oxygen analyser need not preclude the use of the Glostavent. However, its use is recommended in situations where the FiO₂ may be critical, such as sickle cell disease, chronic bronchitis, or in the intensive care unit.

The O.M.V.

The O.M.V. proved entirely satisfactory both for draw over and continuous flow anaesthesia. In most patients, the target concentration of inhalational agents was achieved by using a dialed concentration of 2MAC for 15 minutes followed by 1.5MAC thereafter. Good correlation was seen between the concentration shown on the vaporisor setting and the inspired concentrations for both agents (figs. 4a & 4b).

Despite the absence of a full temperature compensating mechanism in the OMV as is found in more sophisticated

Fig 4 (a). Relationship between Vaporizer Settings and Inspired & Expired concentrations of Halothane (Mean and Standard error).

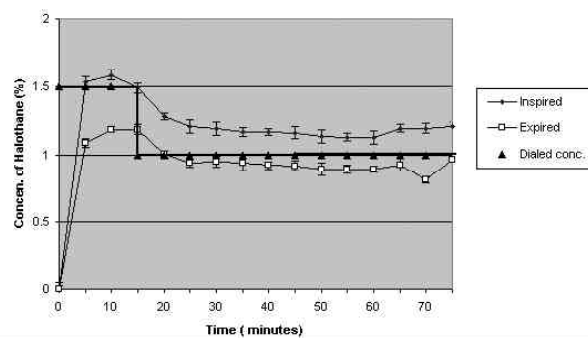


Fig 4 (b). Relationship between Vaporizer Settings and Inspired & Expired concentrations of Isoflurane (Mean and Standard error).

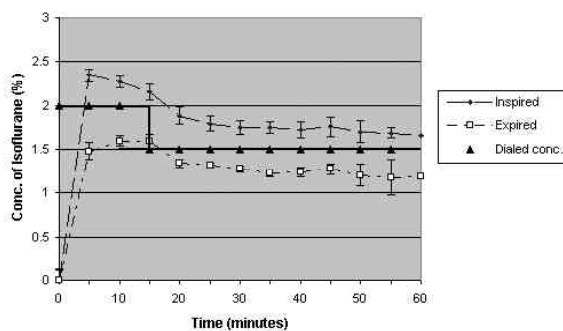
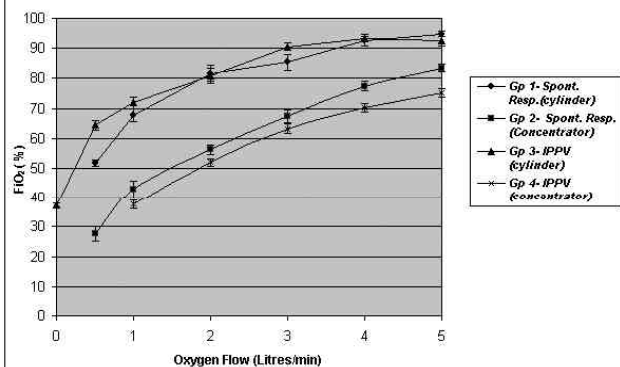


Fig 3 . Relationship between FiO₂ (Mean and Standard Error) and Supplementary Oxygen Flow (L/min).



vaporisers, the fall in output concentration seen as the vaporiser cooled, was small and clinically insignificant. With the concentrations used, the chamber held sufficient volatile agent for approximately 2 hours of anaesthesia for isoflurane and 3 hours with halothane before requiring refilling.

Paediatric Use

The use of the draw over technique is not recommended in small children breathing spontaneously, because of the resistance of the circuit and the deadspace of the valves⁶. For this reason, in children under 25kg, the Glostavent was converted for continuous flow use. This was achieved simply by occluding the open end of the reservoir tube with a bung, in order to allow the gas flow to build up sufficient pressure to pass through the vaporiser. A Mapleson E circuit was then attached to the common gas outlet, as with any standard continuous flow anaesthetic machine and oxygen administered at a flow rate of 4L/Min from either the cylinder of the concentrator. The O.M.V was shown to function equally satisfactorily for continuous flow and draw over anaesthesia, so that no change of vaporiser was required.

Using the Glostavent

An important feature of the Glostavent is its simplicity, enabling first time users to master it quickly and easily. The same circuit is used for both I.P.P.V. and spontaneous respiration. Conversion from one to the other simply involves turning the ventilator off and bypassing the bellows, no other action is necessary. A handle is attached to the bellows to facilitate manual ventilation when this is required.

Under normal circumstances, when electricity is available, it is more convenient as well as more economical, to conserve cylinders of oxygen and to use the concentrator to provide both the oxygen for the patient and, when I.P.P.V. is required, the compressed air to drive the ventilator. In this mode, a flow rate of oxygen of 2 L/Min delivered into the side arm of the reservoir tube raised the FiO_2 to 50-55% in both spontaneously breathing and ventilated patients. This is satisfactory in most cases and can be recommended for routine use. Higher FiO_2 values, in the region of 75% can be obtained by increasing the oxygen flow to a maximum of 5L/Min. If still higher oxygen concentrations are required, oxygen from the reserve cylinders can be added.

In the developing world oxygen cylinders are expensive to purchase and to transport and they should normally be kept in reserve, to be used only if an electricity failure renders the concentrator inoperable or to increase the FiO_2 in an emergency.

When I.P.P.V. is used, the driving gas for the ventilator can either be oxygen from the cylinder (Group 3), or compressed air from the concentrator (Group 4). When the concentrator is in use, any interruption in the supply of electricity triggers an audible alarm. This alerts the anaesthetist that the concentrator has stopped. The reserve oxygen cylinders are then turned on and the anaesthetic can continue without interruption.

When cylinders are in use, conservation of supplies becomes extremely important. As has been clearly shown in groups 1 & 3, satisfactory FiO_2 's were achievable with minimal flows of supplementary oxygen and indeed during I.P.P.V. without the need for any additional oxygen whatsoever.

Further conservation is possible because of the unique design of the Manley Multivent ventilator. With most other gas driven ventilators, the volume of driving gas required is equal to the patient's minute volume^{7 & 8}. The Manley Multivent, however, was specifically designed for economy and the requirement for driving gas reduced to 1/10 of the minute volume⁹. With the minute volume for example set at 4 litres per minute, the driving gas is utilised at a rate of 0.4 litres per minute and an E size oxygen cylinder containing 680 litres should not only be able to drive the ventilator, but also supply the average oxygen requirement for a period of 28 hours. The Glostavent is therefore ideal for situations where cylinder supply is difficult and conservation is important.

Costs

1. Volatile Agents

Although other volatile agents can be used in draw-over anaesthesia, only halothane and isoflurane have so far been reported. Halothane is not only more readily available in the developing world than isoflurane, but is also cheaper and, because of its lower MAC value, can be used in lower concentrations. The mean rate of utilisation of halothane was found to be 16ml/hour and isoflurane 25ml/hour. At respective prices of 6.4p and 19p per ml¹⁰, the cost of the inhalational agents were £1.02 and £4.75 per hour of anaesthesia.

2. Opiates

The mean rate of utilisation of the opiates was: fentanyl 100mcg/hr⁻¹ and morphine 10mg hr⁻¹. The corresponding costs per hour of anaesthesia were 24p and 66p respectively¹¹.

3. Oxygen

The cost of the electricity required to operate the concentrator calculated on present U.K. rates is only 2.5p per hour, regardless of the flow of oxygen produced. In contrast, when using cylinder oxygen, the cost varies in proportion to the flow rate. When using a standard 680L cylinder, (currently priced at approximately £2.00) the cost can vary from 10 pence per hour, at a flow rate of 1/2 Litre per minute, to £1.00 per hour at 5 Litres per minute.

The most economical way of providing anaesthesia with the Glostavent is therefore to use halothane as the volatile agent, with fentanyl supplementation and the concentrator as the source of oxygen. With this combination, general anaesthesia can be maintained for a cost of under £1.50 per hour [Table 3].

Conclusion

The Glostavent is much less expensive than the majority of continuous flow anaesthetic machines in current use and yet offers considerable advantages when used in difficult situations.

These include, not only the low cost of the anaesthesia, but much more importantly, the ability to maintain the delivery of an anaesthetic safely when cylinders of oxygen, nitrous oxide and compressed air and supplies of soda lime may be scarce and the electricity supply unreliable.

Regardless of the conditions in which they work, the aim of anaesthetists all over the world is the same, that is to provide an anaesthetic service which is both effective and safe at all times.

Table 3 . Cost of maintenance of anaesthesia per hour

Halothane 16 ml (6.4 pence/ml)	£ 1.02
Fentanyl 100 mcg (24 pence/ 100 mcg ampoule)	£ 0.24
Electricity to drive the concentrator (per hour)	£ 0.03
Total cost	£ 1.29

To achieve this, considerably greater demands are placed on anaesthetists in the developing world because of the lack of drugs, equipment and facilities than those in wealthy environments with greater resources. In the attempt to make anaesthetic machines ever more foolproof for use when conditions are ideal, the basic problems that still confront the majority of anaesthetists throughout the world are easily forgotten. Modern sophisticated machines, however expensive, cannot be considered good enough for use in the developing world if they cannot be relied on when conditions become unfavorable. Only equipment which has been specifically designed to overcome their problems is adequate. The Glostavent can make a significant contribution towards meeting these requirements and is recommended for use in the developing world.

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Further information is available on www.glostavent.com

Summary

The Glostavent is an anaesthetic machine which has been designed to enable anaesthetists practicing in adverse conditions to overcome the difficulties they are likely to encounter. These include inadequate or non-existent monitoring and servicing facilities and frequent disruption in the supplies of oxygen, nitrous oxide, soda lime or electricity.

An examination of the records of patients who were anaesthetised using the Glostavent with full monitoring, demonstrates its predictability, reliability and economy over a wide range of clinical situations. Suggestions are made for its cost effective operation. It is recommended as an anaesthetic machine capable of providing a safe and reliable anaesthetic in adverse conditions.

Key Words

Equipment - anaesthetic machine
- reliability in adverse situations

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