
The Glostavent: evolution of an anaesthetic machine for developing countries

R. M. BERINGER*, R. J. ELTRINGHAM†

Department of Anaesthesia, Gloucestershire Royal Hospital, Gloucestershire, United Kingdom

SUMMARY
The sophisticated anaesthetic machines designed for use in modern hospitals are not appropriate for many parts of the developing world, as they are reliant on regular servicing by skilled engineers and an uninterrupted supply of electricity and compressed gases, which are not always available. The Glostavent has been designed specifically to meet the challenges faced by anaesthetists working in these countries. It is robust, simple to use, economical, easy to service and will continue to run during an interruption of the supply of oxygen or electricity. Feedback from widespread use throughout the developing world over the last 10 years has led to significant improvements to the original design. This article describes the basic components of the original version and the modifications which have been introduced as a result of practical experience in the developing world.

Key Words: anaesthetic machine, Glostavent

The Glostavent was first introduced in 1997, initially under the name of Oxyvent¹, as a basic anaesthetic machine designed for use in difficult situations. Over the subsequent decade it has been used in many countries, both as an anaesthetic machine in the operating room² and as a ventilator in recovery and intensive care units³,⁴. It is now being used in more than 20 countries including Ghana, Nigeria, Mozambique, Malawi, Zambia, Ukraine and Vietnam and is widely recognised as making an important contribution to safe anaesthesia in these areas⁵.

The experience gained from thousands of hours of use in the field, together with the practical suggestions received from users in the developing world, have allowed many improvements to be incorporated into a new version of the Glostavent (Figure 1). This article describes the core components of the original Glostavent and the subsequent modifications designed to improve its performance.

* B.Med.Sci., B.M.B.S., F.R.C.A., Fellow, Department of Anaesthesia, Royal Children's Hospital, Melbourne, Victoria, Australia.
† M.B.Ch.B., F.R.C.A., Consultant Anaesthetist.

Address for reprints: Dr R. M. Beringer, U 312, 99 Nott Street, Port Melbourne, Melbourne, Vic. 3207.

Accepted for publication on January 14, 2008.


*Figure 1: The Glostavent.*
THE BASIC COMPONENTS OF THE GLOSTAVE NT

The basis of the machine remains essentially unchanged from the original Oxyvent and consists of the same three major components mounted onto a workstation. These are a drawover system, a gas driven ventilator and an oxygen concentrator.

The drawover system

This system allows inhalational anaesthesia to be administered in the absence of a compressed gas supply. Many forms of drawover equipment have been described\(^6\), the features essential to all being a breathing circuit and vaporiser with a sufficiently low resistance to allow spontaneous respiration, a non-rebreathing valve to prevent exhaled gases from re-entering the system and a bellows or self-inflating bag with a unidirectional valve to allow positive pressure ventilation. Supplementary oxygen may be added into a reservoir upstream from the vaporiser.

Drawover anaesthesia is not recommended for small children breathing spontaneously because of the relatively high resistance of the circuit\(^7\). For use in children weighing less than 10 kg, the breathing system can be converted to a continuous flow system simply by occluding the open end of the reservoir tube and providing a supply of oxygen from the oxygen concentrator or cylinder. A standard paediatric circuit (Mapleson F) replaces the non rebreathing valve (Figure 2).

The gas driven ventilator

The Manley Multivent ventilator is a mechanical version of the Oxford inflating bellows. It has proved simple, robust and easy to service under a variety of testing conditions\(^8,9\).

The ventilator is driven either by compressed air from the oxygen concentrator or by oxygen from a cylinder or central supply. The compressed gas acts on a linear thruster, which raises a weighted arm attached to the top of the bellows, thus entraining the inspiratory gas mixture. Once the pre-determined tidal volume has been reached, the weighted arm compresses the bellows and the anaesthetic gas mixture is delivered to the patient. The inspiratory pressure, tidal volume and respiratory rate may be easily adjusted. It is very economical as the volume of driving gas required is equal to only one-sixth of the minute volume delivered to the patient. Furthermore, when oxygen is used as the driving gas, it is subsequently returned to the breathing circuit to supplement the FiO\(_2\). In other words, the same oxygen is used twice. An internal rechargeable battery allows the ventilator to continue to function for a further 100 hours following an interruption in the supply of electricity. This battery is guaranteed by the manufacturer for five years, but in practice usually lasts much longer.

The oxygen concentrator and air compressor

This electrically powered device extracts oxygen from atmospheric air. The air is first compressed

---

**Figure 2**: Diagram demonstrating the conversion of the breathing system from drawover to continuous flow mode for use with small children by the occlusion of the open-ended reservoir tube and the addition of a paediatric breathing circuit.
to 140 kPa and then passed through a chamber containing zeolite that traps nitrogen and produces a continuous supply of over 90% oxygen. The compressed air is cycled alternately between two columns allowing the zeolite to reactivate. The only servicing required is periodic cleaning of filters. The zeolite granules do not require changing.

The standard domestic oxygen concentrator described above has been adapted for use with the Glostavent in order to produce a supply of compressed air to drive the ventilator in addition to the oxygen for the patient to breathe. If the supply of electricity is interrupted and the concentrator ceases to function, then oxygen from the reserve cylinder can be used both to drive the ventilator and supplement the FiO\textsubscript{2} if necessary.

**LIMITATIONS OF THE ORIGINAL DESIGN**

Feedback on the performance of the Glostavent over the last 10 years has generally been extremely favourable\textsuperscript{2-4}, its simplicity, reliability, ease of maintenance and economy being particularly popular features. However, regular users of the Glostavent in unfavourable environments have identified some areas for improvement of the original version and have asked the manufacturer to make appropriate modifications to meet the needs of the developing world.

The main areas of concern are listed below, followed by the resulting improvements in design.

**Electricity supply**

**Problem:** Variations of voltage occur in many countries. When they are extreme this may result in the oxygen concentrator ceasing to work without warning.

**Response:** An Uninterruptible Power Supply unit has been incorporated into the Glostavent. It enables the concentrator to continue working normally despite extreme voltage fluctuations of as much as 30%. In the event of greater fluctuations, or a total failure of power supply, the Uninterruptible Power Supply has battery backup lasting five minutes. This is accompanied by an audible warning.

**Problem:** In the event of a complete supply failure of electricity, the ventilator immediately stops working unless the reserve oxygen cylinder is turned on to provide the driving gas. This requires intervention on the part of the anaesthetist.

**Response:** A changeover valve has been placed within the ventilator drive circuit. If the power fails and the concentrator stops working, the valve automatically switches so that the ventilator is driven by the reserve oxygen cylinder. The ventilator then continues to function without interruption.

**The oxygen concentrator**

**Problem:** The maximum output of 5 l/min is insufficient for adequate pre-oxygenation or for continuous flow anaesthesia in adults or large children.

**Response:** A more powerful concentrator has been introduced with an increased oxygen output of 8 l/min.

**Problem:** Continuous flow anaesthesia over prolonged periods using over 90% oxygen from the concentrator may result in absorption atelectasis or lung damage from oxygen toxicity\textsuperscript{10}.

**Response:** The oxygen concentrator has been modified to produce an additional outflow of compressed air with a maximum flow of 8 l/min. This

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{ventilator_set_up}
\caption{Photos showing the ventilator set up with (a) adult and (b) paediatric bellows.}
\end{figure}
allows alteration of the FiO₂ and has the additional benefit of allowing a total gas flow of 16 l/min, sufficient for the use of any breathing circuit.

**The ventilator**

**Problem**: The tidal volume control is not sensitive enough for accurate ventilation of young children.

**Response**: An additional set of bellows is now available for paediatric use. These have a smaller diameter (9 cm as opposed to 13 cm) but are otherwise identical and easily interchangeable (Figure 3).

**Problem**: Manual ventilation via the weighted arm above the bellows is cumbersome and inconvenient unless the ventilator is very close to the patient.

**Response**: A semi-rigid self inflating bag has been introduced into the inspiratory tubing situated 50 cm from the patient’s airway. This enables effective manual ventilation by the anaesthetist and is sufficiently rigid to have a negligible effect on the tidal volume delivered by the ventilator (Figure 4).

**The OMV vaporiser**

**Problem**: The chamber holds only 50 ml and requires frequent refilling.

**Response**: A new vaporiser has been designed with a capacity of 150 ml.

**Problem**: The lever mechanism has a tendency to stick and requires frequent servicing.

**Response**: The new design is simpler with a greater shuttle aperture, which has much less tendency to stick.

![Figure 4: Photo showing the semi-rigid self inflating bag that can be used for manual positive pressure ventilation.](image)

![Figure 5: Schematic diagram showing the original circuit and the modified design.](image)
The drawover breathing system

Problem: Pre-oxygenation is inefficient due to a combination of factors: the inadequate outflow of oxygen produced by the concentrator; entrainment of air through the open-ended reservoir tube; and the inadequate volume of the reservoir.

Response: The production of oxygen from the concentrator has been increased as described above. Furthermore, the reservoir has been modified by a number of additions designed to increase performance: a one-way valve at the open end of the reservoir tube; a two litre distensible bag to increase the volume of the reservoir; and a 5 cmH₂O safety valve to prevent pressure build up within the reservoir (Figure 5).

Problem: There is no reservoir bag to allow observation of depth and frequency of ventilation.

Response: The distensible bag included as part of the new reservoir is ideal for this purpose (Figure 5).

Problem: The drawover mode is unsuitable for small children breathing spontaneously because of resistance within the circuit, but conversion to continuous flow mode requires intervention on the part of the anaesthetist (Figure 2).

Response: The one-way air entrainment valve allows the same circuit to be used for either drawover or continuous flow anaesthesia without the need for any intervention by the anaesthetist. This is because the content of the reservoir tube depends on a balance between the supplementary gas flow entering the reservoir and the patient’s minute volume leaving the reservoir (Figure 6). If the supplementary gas flow is less than the minute volume, the pressure in the reservoir falls and air is drawn in through the one-way valve (2). In this situation the circuit acts as a drawover system. If on the other hand the supplementary gas flow is increased until it exceeds the patient’s minute volume, the pressure within the reservoir rises to the pressure determined by the safety valve (1) and the circuit acts as a continuous flow system. This relationship is demonstrated by the degree of distension of the reservoir bag, which collapses if atmospheric air is being entrained. This is represented graphically in Figure 7.

Positive pressure within the reservoir is particularly useful for overcoming resistance when anaesthetising small children. It also minimises air entrainment if a high FiO₂ is required together with hyperventilation, such as in pre-oxygenation or when flushing the circuit.

**Figure 6:** Schematic diagram showing how the content of the reservoir tube is dependent upon the balance between supplementary gas flow and patient’s minute volume.
In addition to the modifications of the original Glostavent listed above, other additional features have been requested:

- An active scavenging system—an electrically driven scavenging tube has been built into the frame of the Glostavent. It is totally silent and generates a negative pressure of less than 0.5 mmH\textsubscript{2}O.
- Suction apparatus—a standard foot-operated suction system is now also available.

**DISCUSSION**

In many parts of the developing world the provision of a safe and reliable anaesthetic service is an extremely challenging undertaking. Anaesthetists working in disadvantaged locations encounter problems on a regular basis that seldom, if ever, confront those working in more advanced and prosperous countries. For example, they may be without electricity for prolonged periods, the supply of oxygen may fail and soda-lime is scarce or nonexistent. Furthermore, those working in isolated hospitals seldom receive visits from service engineers, so maintenance and repair is entirely dependent on skills that can be provided locally.

In these circumstances the provision of ‘high-tech’ anaesthetic machines and electronic monitors dependent on modern computer technology is clearly inappropriate. At the first fault, they cannot usually be repaired locally and are often consigned to the graveyards of anaesthetic apparatus that currently litter the developing world\textsuperscript{12}.

Anaesthetists working in these areas are only too familiar with this scenario whereby inappropriate donations of high-tech anaesthetic machines suddenly appear and are expected to provide instant solutions. The concept of training, after-sales service, support facilities and customer satisfaction rarely feature. So it is not surprising to hear of these donations referred to locally as ‘poisoned gifts’ or ‘aid and goodbye’.

Unfortunately, those anaesthetists who have the necessary experience of local conditions are seldom consulted when new anaesthetic equipment is being designed or when resources to improve anaesthesia services are being allocated. As a result the cycle of failure, disappointment and disillusion amidst appalling waste continues unabated.

The evolution of the Glostavent differs from that of the ultra-sophisticated anaesthetic machines which tend to dominate trade exhibitions throughout the world. The Glostavent is the result of close collaboration over many years with anaesthetists experienced in providing anaesthesia in the face of deprivation. When consulted, they were not only able to identify the unique problems they faced, but also provided the ideas which enabled the problems to be overcome.

Experience with the Glostavent has shown it to be safe, robust, reliable, efficient and versatile when used in the operating theatre or intensive care unit.

In response to suggestions from anaesthetic practitioners working in some of the most hostile environments in the world, many improvements have been incorporated into the new machine to enable them to overcome the unique difficulties they face.

**POTENTIAL CONFLICT OF INTEREST**

Dr Eltringham has been involved as an adviser throughout the development of the Glostavent, although neither author has benefited financially from the project.

**ACKNOWLEDGEMENTS**

The authors wish to acknowledge the advice and help received from Mr Richard Tulley, chief engineer of Diamedica, in redesigning the Glostavent and in the preparation of this paper, as well as the numerous anaesthetists, clinical officers and nurses in the developing world who have shared their experiences with us.
REFERENCES