

The Malawi anaesthetic machine

Experience with a new type of anaesthetic apparatus for developing countries

P. M. FENTON

Summary

One year's experience with a new type of oxygen concentrator and anaesthetic machine, designed for anaesthesia in developing countries, is presented. The apparatus, its performance and problems are described and the author's suggested modifications to improve the original design are outlined. The apparatus, with these changes, represents a significant advance in oxygen availability for hospitals in developing countries as well as improving the anaesthetic capabilities.

Key words

*Equipment; anaesthetic machines, vaporizers.
Oxygen; delivery systems.*

Anaesthetic equipment in developing countries is often old and broken and has connexions that are incompatible with modern 22-mm ISO¹ spare parts and accessories. In addition, equipment either donated by Western countries or else ordered by local misguided individuals may never be used because of incompatibility. The commonest example of this is in the author's experience, the Boyle's machine or ventilator that requires compressed gas or air to operate it where this facility is not available. The 'high tech' store room of useless machines is a familiar and well publicised feature of many Third World hospitals.

The concept has been proposed of an apparatus that can be adapted to give an anaesthetic under all the conditions that may prevail in a developing country, for example, from simple drawover with ether and air, to artificial ventilation with nitrous oxide–oxygen, and added volatile agent.²

In Malawi, Central Africa, in 1986, an anaesthetic machine made by Simonsen and Weel* was introduced which put part of this concept into practice. A domestic-use oxygen concentrator was adapted to supply oxygen and air via a pipeline to a unique combination of continuous flow/drawover anaesthetic machine. A continuous oxygen supply is thus on hand as long as electricity is available to power the concentrator.

This report is based on experience with its use in Southern Malawi between May 1987 and May 1988. The Southern Region of Malawi has seven out of 21 government district hospitals nationwide and two out of

*S & W Medical Technology, Ruxley Corner, Sidcup, Kent DA14 5BL.

three central or general hospitals (loosely defined as centres where specialist care is available). Of the total population of Malawi, 49.6% inhabit the region, therefore theatre operating time would be expected to be above the national average.³ The largest hospital in Malawi, holding some 1000 inpatients, is located in the region.

The region, though lower in altitude than some central and northern areas, is broadly representative of the varying climatic conditions of Malawi as a whole, with minimum temperatures of approximately 10°C in the highlands and maximum temperatures in the range 45–48°C in the lower Shire Valley. Extremes of humidity occur according to the season; however, most operating theatres have some form of air conditioning, operating albeit infrequently.

Thus the performance of this equipment in the region should be applicable to the country as a whole and to other developing countries with hot humid climates.

The Malawi model anaesthetic machine

The apparatus comprises two separate units, the oxygen concentrator and the anaesthetic machine itself with its accessory equipment.

The concentrator, a De Vilbiss DeVo/44, 240 V AC, designed for domestic oxygen therapy has been modified by the addition of two push-release pipeline pressure coupling outlets for oxygen and compressed air. This concentrator works by pumping room air from a compressor through two canisters containing 'Xeolite' which absorbs nitrogen. The canisters are automatically switched alternately so that oxygen is available from one canister while the other

P.M. Fenton, DTM&H, FFARCSI, Anaesthetic Specialist, Queen Elizabeth Central Hospital, P.O. Pox 95, Blantyre, Malawi, Central Africa.

Accepted 4 November 1988.

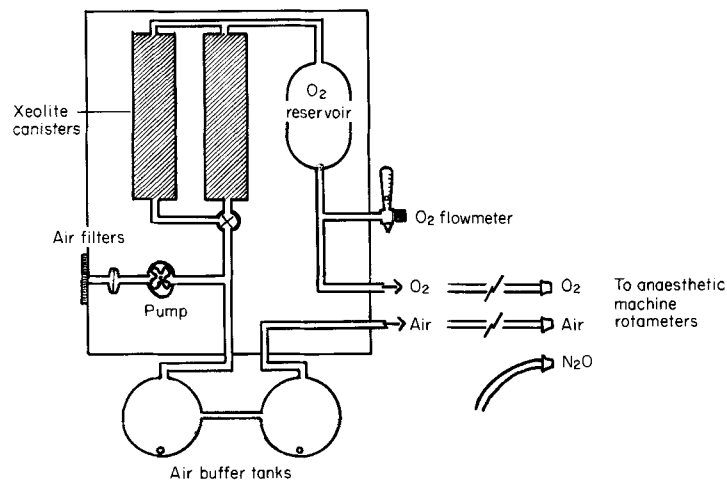


Fig. 1. Schematic diagram of oxygen concentrator.

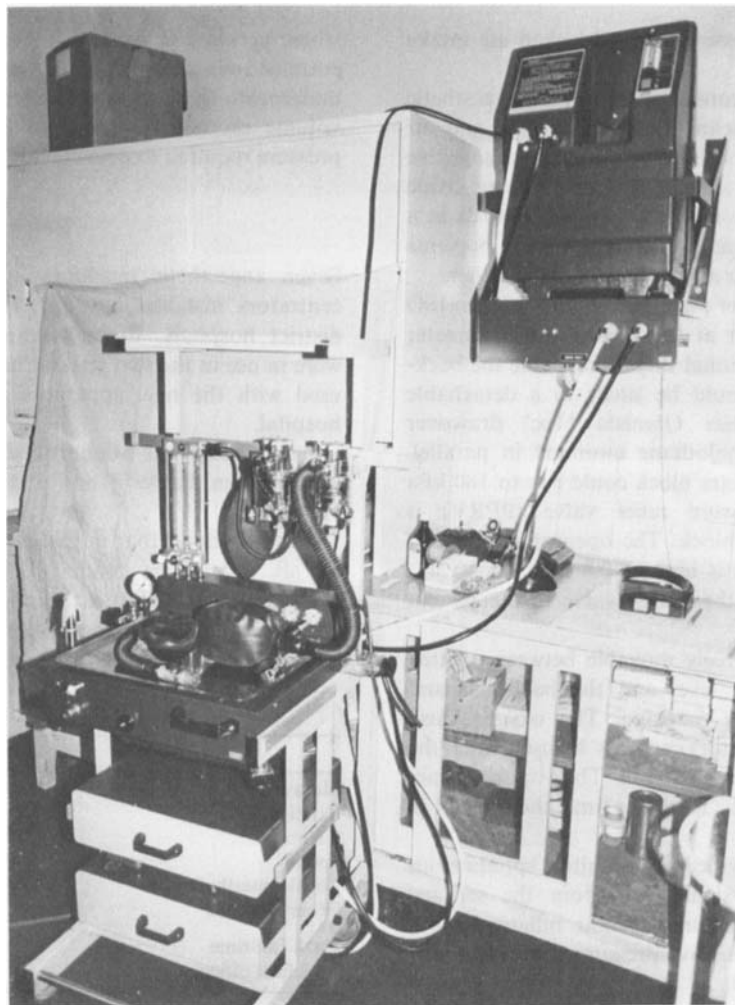


Fig. 2. The concentrator and anaesthetic machine.

is regenerated. The principle is common to most oxygen concentrators and is described elsewhere.⁴

The compressor not only pumps air to the Xeolite canisters but also supplies compressed air to the air outlet and thence to two pressurised buffer tanks. These serve to smooth over changes in air pipeline pressure which would otherwise occur during the canister switching process, and act as traps for condensed water vapour which can be drained at their bases. These tanks are integral with and form the base of a wall-mounted bracket that supports the

concentrator unit proper, placed some 2 m from the ground (Fig. 1).

The original outlet for oxygen, a simple nipple with a flowmeter control up to 5 litres/minute, is retained as a separate oxygen source. This can be used for neonatal resuscitation and for ward connexions when the concentrator is lifted from its bracket, after disconnexion of the pipelines, and wheeled to where it is needed.

The compressor pump in the concentrator can generate a pressure of 180 kPa and is fitted with three alarms: for

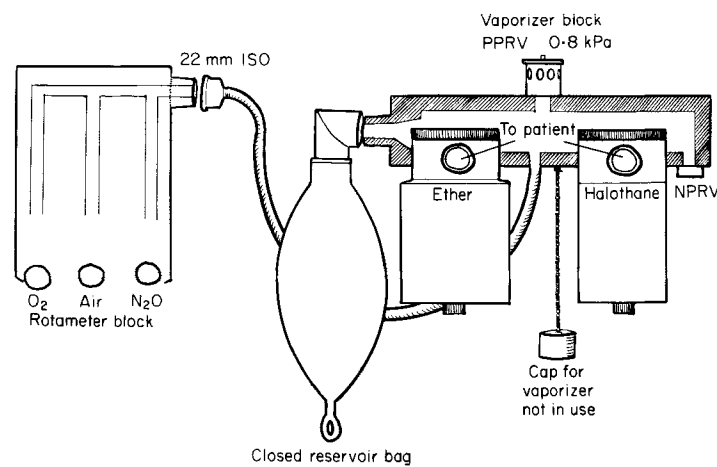


Fig. 3. Arrangement of Rotameters and vaporizers.

overpressure and underpressure and a blocked air intake filter.

The concentrator is connected to the anaesthetic machine by 5–6 m of pipeline hose for oxygen and air (Fig. 2). The machine has push-release noninterchangeable connectors at the rear for oxygen, air and nitrous oxide and these three gases are controlled by flowmeters as in a conventional Boyle's machine. A safety switch prevents simultaneous selection of air and nitrous oxide together.

A low pressure soft rubber pipe leads from a 22-mm ISO standard conical connector at the top of the Rotameter block, (where, in a conventional Boyle's machine the back-bar mounted vaporizer would be sited) to a detachable vaporizer block which has Ohmeda 'Tec' drawover vaporizers for ether and halothane mounted in parallel. The pressure in the Rotameter block could rise to 180 kPa therefore a positive pressure relief valve (PPRV) is provided on the vaporizer block. The opening pressure of this PPRV (nonadjustable) is high at 0.8 kPa. This valve also prevents jamming of the Ambu valve in the patient system.

The vaporizer block is freely movable between a fitted swivel mount at table-top level and the back bar and can be removed from the machine. The oxygen flush (oxygen from the concentrator) can only be used when the vaporizers are mounted on the swivel. The vaporizers are in parallel so only one can be used at a time: the one not in use is capped off (Fig. 3).

A reservoir bag is provided to monitor spontaneous breathing. The patient system leads from the selected vaporizer to an Ambu bag and Ambu inflating (non-rebreathing) valve so that positive pressure ventilation may be given as required (Fig. 4).

This arrangement of vaporizer, self-inflating bag and inflating valve is the same as other drawover systems such as the EMO or Triservice apparatus. The closed reservoir bag on the vaporizer block replaces the conventional open-ended oxygen reservoir tube of the EMO or Triservice drawover systems: if the fresh gas flow from the Rotameter block exceeds the patient's requirements the bag fills and when full, the excess vents via the PPRV.

The pressure in the patient system will increase to 0.8 kPa in the event of a pause in breathing by the patient or during any other outflow obstruction at the inflating valve. This contrasts sharply with conventional drawover systems

where pressure in the system is always atmospheric. Air is entrained via a small negative pressure relief valve situated underneath the vaporizer block should the patient's minute volume exceed the fresh gas flow. The subatmospheric pressure required to operate this valve is not stated.

Results

Seven anaesthetic machines and 14 wall-mounted concentrators installed by May 1987 were in use in seven district hospitals. Eight machines and 16 concentrators were in use in the two referral hospitals. Nitrous oxide was used with the new apparatus only in the larger central hospital.

Anaesthesia was administered with the new apparatus as shown in Tables 1 and 2 during one year from May 1987.

Table 1 shows that in the district hospitals, only 43.5% of all procedures made use of this new apparatus, compared with 94% in the one central hospital studied. The reason for this lies in the poor level of training in general anaesthetic techniques in the districts.

Table 1. Methods of anaesthesia.

	Central hospital	District hospital
Malawi model	8640	1655
Existing machine	35	?
Ketamine	240	470
Spinal	41	261
Local anaesthetic	241	1120
Other methods	—	About 300
Staff: full-time clinical officers	6	None

The 99 major paediatric cases in Table 2 comprised mainly laparotomies for tumour, bowel obstruction and peritonitis but also included surgery to the spine, chest and heart and cranial surgery. These cases all benefited from the use of a T-piece paediatric system which necessitated the modifications described below.

General anaesthetics were administered on 258 occasions in district hospitals to children under 5 years of age. Approximately 35 used the supplied neonatal resuscitator (paedivalve and Ambu bag) and over 180 cases were performed using ketamine.

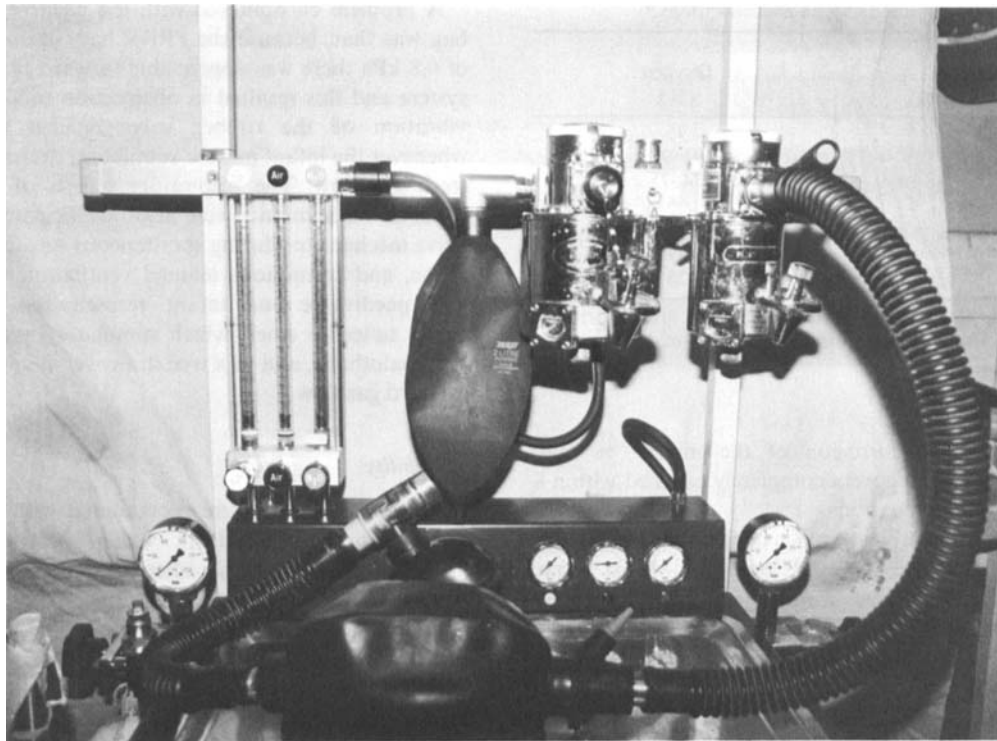


Fig. 4. The vaporizer block and patient system.

Table 2. Classification of operations.

	Central hospital	District hospital	
Laparotomy	295		
Major head, neck, spine	219	88	
Thorax	8	All major operations	} 575*
Major paediatric	99		
Minor paediatric	Included in 'others'		
Hysterectomy	93	8	
Caesarean section	1261	462	
Minor gynaecological	3042	Included in 'others'	
Eye	490	60	
All others	3690	2399	
Totals	9197	3850	

* Excluding laparotomies and Caesarean section but including hernia, hydrocoele, etc. classified as 'major' in district hospitals.

Thirty-seven percent of 615 adult major cases were deemed by the anaesthetist to require ventilation by a mechanical ventilator which needed the modifications described. All except 16 Caesarean sections were anaesthetised with the apparatus in the manufacturer's intended mode, using spontaneous ventilation with ether through the Ambu bag. The 16 exceptions were severe pre-eclamptics who received mechanical ventilation, as above. Additionally, three patients were ventilated for respiratory failure postoperatively (two) or for Guillain-Barré syndrome (one). Approximately 40% oxygen was given from the concentrator which was used to power a Manley ventilator.

One physician anaesthetist (the author) and six fulltime clinical officer anaesthetists gave anaesthetics in the central hospital. Anaesthesia was given by a variety of clinical officers and medical assistants in the districts, some with 6 months' training but most had no formal training in anaesthesia.

The concentrator requires electricity to function and

interruptions to the supply are a frequent event in most rural areas. However, in practice it was found that lack of electric light and autoclaving facilities are more limiting for surgery than failure of the oxygen supply. In the districts, where ether was the only volatile agent in use, air is acceptable for most cases. Emergency oxygen cylinders were not available, though pin-index yokes were fitted to the machines for oxygen and nitrous oxide.

Theatre oxygen consumption from existing 'bull-nose' cylinders was cut virtually to zero and overall oxygen consumption (including wards) for district hospitals was reduced to between a quarter and a half of previous levels. Overall, oxygen consumption for central hospitals was reduced by about a half. The reasons for the continued use of cylinder oxygen included: insufficient concentrators for patients who required oxygen on the wards and reluctance on the part of untrained hospital staff to lift the heavy concentrator down from its high bracket (so placed for electrical safety).

Problems

Water condensation was considerable in the air-buffer tanks and the presence of water in the air Rotameter sometimes made it inoperable during wet weather, despite regular twice-daily drainage from the base of the tanks. Water did not cause such a problem in the oxygen pipeline and Rotameter because it is absorbed by the zeolite granules in the concentrator.

The Ohmeda 'Tec' drawover ether vaporizer has a smaller capacity and poorer thermocompensation compared to an EMO so that when high flows are used during induction of anaesthesia the indicated 15% ether decreases to 10–11%, and induction of robust patients requires repeated doses of suxamethonium to be given before an adequate level of etherisation is achieved.

All the Ohmeda 'Tec' drawover halothane vaporizers

Table 3. Expected oxygen concentrations.*

Flow from 'O ₂ ' Rotameter (litres/minute)	Oxygen (%)
2	95
4	91-92
5	74-75
6	65
8	50
10	47
15	28

95% oxygen at a flow of 2 litres/minute achieved after 'warm up' of 7-10 minutes from switching on or from flow of 15 litres/minute.

* From S & W technical data.

suffered from severe corrosion of the milled '% Hal' selection wheel and some were completely jammed within a few months in humid locations.

The use of an Ambu bag in place of the Oxford inflating bellows (OIB) produced mixed opinions. Most users preferred the OIB which has a more restful hand position that is important when prolonged hand ventilation may be required. The OIB can deliver a greater minute volume than the Ambu bag, and the air flow resistance is greater through the Ambu bag during spontaneous ventilation (the author measured subatmospheric pressures of 0.2-0.3 kPa during quiet breathing through the Ambu bag compared with no recordable pressure drop across the OIB).

Air flow resistance was made even greater when the concentrator was not working (as might happen during electricity failure) and inspired air had then to be drawn through the negative pressure relief valve. However, these were minor problems; the apparatus was well liked generally and considered an attractive new piece of equipment, robust in construction, and suitable for district hospital use though, as mentioned below, it was elaborate.

For central hospitals, however, the inability to change from drawover to continuous flow to meet the needs of different clinical situations proved a major flaw: satisfactory anaesthesia for the surgical workload shown in Table 2 requires more than drawover techniques and an Ambu bag.

The use of nitrous oxide with the oxygen-enriched air from the oxygen concentrator soon gave rise to several problems. Unless the oxygen flow was limited strictly to 2 litres/minute (including oxygen direct from the nipple outlet) there is a likelihood of hypoxia when nitrous oxide is used, since the oxygen concentration falls off rapidly when the flow from the concentrator exceeds 2-3 litres (Table 3).

Medical assistants and clinical officers familiar with cylinder oxygen supplies were confused by the effects of flow and oxygen concentration. High oxygen concentrations are unnecessary with ether anaesthesia and it was found to be the only safe anaesthetic technique for Caesarean section using this apparatus.

About 15 litres/minute flow is provided when the oxygen flush button is operated and for the first few seconds the oxygen content is high, while the small reserve in the zeolite canisters and internal oxygen reservoir is drained. Thereafter, however, oxygen concentration can decrease to values as low as 28%. There is no indication to the user of the oxygen concentration that is being administered to the patient.

A problem encountered with the paedivale and Ambu bag was that, because the PPRV had an opening pressure of 0.8 kPa there was appreciable forward flow through the system and this resulted in obstruction to expiration, with vibration of the rubber valve against the exit port whenever the infant minute ventilation decreased below the fresh gas flow. The respiratory efforts of neonates and small or weak infants were also insufficient to operate the valve mechanisms during spontaneous breathing with halothane, and continuous manual ventilation was necessary. The paedivale and infant resuscitation bag may be better suited to ether, which stimulates ventilation, rather than halothane, and to a true drawover system without any forward gas flow.

Reliability

No major problems were encountered with any of the 30 concentrators installed in either central or district hospitals. One machine blew an internal fuse due to voltage surge. Oxygen delivery checked 8 months after operation by the manufacturers was satisfactory (in accord with the values in Table 3). A further check after one year, showed one machine was not able to produce higher than 80% oxygen and this was ascribed to a dirty internal air filter which required returning the apparatus for service.

Many machines were used all day long, 5 days a week, and also at other times for emergencies. The anaesthetic machine itself also proved well constructed and reliable, though it had few moving parts to go wrong.

Discussion

It is only necessary in the district hospitals to have the unmodified concentrator (without pipelines, connexions, buffer tanks or Rotameters) and, using the simple oxygen outlet nipple, supply oxygen at up to 5 litres flow/minute to a conventional T-piece reservoir and drawover ether vaporizer mounted on the basic anaesthetic machine. The necessary drillings could be provided and blanked off so that conversion to upgrade the machine could easily be carried out, should the need arise later.

The following modifications were carried out by the author at the principal central hospital on machines under his direct supervision. The modifications enable the apparatus to be used in all the four modes described by Ezi-Ashi² by a simple switching of connexions which takes a few seconds.

The vaporizer block has to be mounted on the back bar, and thus the oxygen flush facility is lost. This is a safety feature (see above).

Modification for use with a Blease-Manley ventilator. The ventilator supply hose (22 mm female) is connected directly to the Rotameter block so that air, oxygen or nitrous oxide operates the ventilator. The inspiratory outlet of the Manley ('to patient') passes to the selected vaporizer, and thence to the patient (a double-length Manley patient system is needed). The expiratory limb is connected in the usual way. This constitutes a low pressure (patient airway pressure) 'pushover' technique through a drawover vaporizer and consequently vapour concentrations would be expected to be higher than indicated. In practice, with halothane a setting of '0.5%' gives satisfactory results and greater than '1%' is not allowed when using the ventilator

mode for fear of overdose. Measurements of the vapour concentrations under these conditions were not made because the necessary apparatus was not available. The PPRV is immobilised.

Modification for use with a T-piece paediatric system. The vaporizer block is connected directly to the Rotameter block by a special female–female connector consisting of two catheter mounts joined back to back. Continuous flow now passes through the selected vaporizer and the paediatric system is connected in the usual way.

The vaporizer block supply hose, now hanging loose, is simply capped onto the vaporizer not in use, which closes the two remaining routes for gas to escape in one manoeuvre.

The PPRV is also immobilised on this modification. Positive pressure relief, which is essential when the drawover mode is used to avoid continuous flow leading to a jammed valve (and consequent risk of pulmonary barotrauma) is achieved reliably, and at lower pressure than 0.8 kPa. It is accomplished by cutting a hole in the bottom of the reservoir bag, to make it into an open-ended reservoir limb.

Extra vaporizer. A drawover vaporizer for trichloroethylene was fitted in series with the halothane vaporizer. The 'Goldman' vaporizer, used since it was readily available in sufficient numbers, worked well when filled with trichloroethylene. This modification enabled the machine to be used as a Triservice apparatus.

To ensure against hypoxic gas mixtures. Rotameters should be labelled 'oxygen-enriched air' and an oxygen analyser built into the equipment.

Conclusions

The availability of oxygen, especially to outlying hospitals, was greatly improved by the concentrators, and the cost of oxygen to the health budget was reduced to between a half and quarter of the cost of cylinder oxygen.

The use of a domestic oxygen concentrator with a combined continuous flow and drawover anaesthetic

machine is an innovation of great promise for Third World anaesthesia and there will undoubtedly be further developments. The Simonsen and Weel apparatus for Malawi was given much greater versatility by the use of modifications outlined above and they are essential if service in a central hospital is envisaged and the full potential of the concept is to be realised.

The use of nitrous oxide in combination with the oxygen from an oxygen concentrator is potentially hazardous. Serious and prolonged hypoxia is likely to occur (and did occur) in the very setting for which this apparatus is designed: hospitals in developing countries where poorly trained personnel are giving anaesthesia and where previous experience has been with Boyle's machines. Nevertheless after familiarisation with the apparatus the quality of the anaesthetic service in Southern Malawi, particularly at the central hospital, has been considerably improved since the introduction of the Malawi model anaesthetic machine and reliability of the concentrators is so far remarkable.

Acknowledgments

The author acknowledges the generosity of the Danish International Aid Agency (DANIDA) through which this apparatus was given to Malawi.

I thank Dr I. Wilson, UTH., Lusaka, Zambia for his advice and encouragement in the preparation of this paper and my wife, Joan Fenton, for typing the manuscript.

References

1. ISO 5356/I Conical connectors for Breathing Systems. International Standards Organisation, Geneva.
2. EZI-ASHI TI, PAPWORTH DP and NUNN JF. Inhalational anaesthesia in developing countries Part I. The problems and a proposed solution. *Anaesthesia* 1983; **38**: 729–35.
3. *National Atlas of Malawi*. Population density. Malawi Government National Statistical Office 1977: 66.
4. EZI-ASHI TI, PAPWORTH DP, NUNN JF. Inhalational anaesthesia in developing countries Part II. Review of existing apparatus. *Anaesthesia* 1983; **38**: 736–41.