ANAESTHETIC EQUIPMENT FOR A DEVELOPING COUNTRY

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SUMMARY
A development aid project to Malawi is described. This involved the development of a suitable anaesthetic machine for use in under-developed countries and the selection of a suitable oxygen concentrator to provide it with air and oxygen. All government hospitals were provided with anaesthetic equipment and personnel were trained to keep it regularly serviced. Follow up testing of reliability was undertaken. The cost benefit to the country amounted to £234084 (sterling) per year. This is the first instance of widespread use of standardized anaesthetic equipment which includes oxygen concentrators.

KEY WORDS
Equipment: anaesthetic machine, oxygen concentrator, vaporizers.

As one of the low income countries in Africa, Malawi shares many anaesthetic problems with other developing countries, including transport difficulties and insufficient staff training. One of the authors (J.P.) worked in Malawi from April 1982 to June 1989, as project manager for Danida (Danish Industrial Development Agency). Upon arrival, he found that each hospital had different anaesthetic equipment, of varying makes and countries of origin. The only common characteristic was that they were all dependent on continuous gas flows. Some district hospitals also had an EMO vaporizer [1], but often it could not be used, either because the concentration control had jammed, or the thermocompensator valve had failed. All the anaesthetic equipment had been given to the Malawi Government as gifts from other governments or missions. Some newly donated anaesthetic machines were already obsolete when they arrived in the country, so spare parts would be unobtainable in the future.

The anaesthetic equipment had rarely if ever been serviced [2] during the previous 5–10 years. The reasons included lack of spare parts, lack of tools to repair equipment and insufficient technicians trained to service the equipment.

The Medical Technical Unit had a service centre–store house of 8 m². Five technicians, all trained abroad, had the responsibility of servicing all the medical equipment in the 23 Government hospitals throughout the country. When they ordered spare parts, it took 12–18 months from the day they identified the need to the time the spare parts arrived in the country.

The provision of oxygen for the different districts hospitals was another major problem. When a district hospital sent staff to collect oxygen cylinders from the only company supplying gas, they were frequently not allowed the necessary number of cylinders. Often, the hospital lacked transport to collect cylinders. Many district hospitals bought fewer cylinders than needed because of their limited budget (one 48-ft³ (1.36 m³) oxygen cylinder costs £3.73 (sterling)). The oxygen cylinders often leaked.

The anaesthetic staff at district hospitals had only undergone a 2–6 week training programme. When they were transferred from one district hospital to another, they had to start working with a different anaesthetic machine; this was especially difficult for those with limited theoretical knowledge. Visiting surgeons or gynaecologists frequently transferred more complicated patients back to a central hospital and many patients, who
could have undergone surgery at a district hospital, were transferred also because of the lack of safe anaesthetic services at district level.

**History of the Development Aid Project**

Aware of the problems, one of the authors (J.P.) wrote a report to the Malawi Ministry of Health in September 1982 [personal correspondence with Ministry of Health, Malawi 15.9.82], and suggested the purchase of anaesthetic equipment which complied with International Standards Organisation (ISO) recommendations, combined with an oxygen concentrator [3].

The development of the Malawi anaesthetic equipment, specially designed for a developing country, was commenced in 1985 by the second author (M.N.) The aims in developing the new anaesthetic apparatus were ease of use, versatility and ease of servicing.

The design principles were that all units should be similar and incorporate the ISO standards, so that the units could be serviced anywhere in the country with the same procedure.

We tried to determine if an oxygen concentrator could deliver the necessary amount of oxygen and atmospheric air to a specially designed anaesthetic apparatus. After testing, it was decided that the DeVilbis oxygen concentrator model DeVo/44 (DeVilbis, Somerset, PA 15501-0635 U.S.A.) satisfied our requirements. Oxygen concentrators have been used for many years, and have been described in several articles [4–6], but not used on a large scale and in combination with an anaesthetic machine. In order to avoid fluctuation in oxygen flow, a buffer tank was incorporated in the system, at the outlet of the concentrator (fig. 1).

It is desirable to have atmospheric air available for use in the anaesthetic apparatus. Air for the anaesthetic gas system is taken, therefore, from
Fig. 2. Oxygen concentrator connected to the Malawi anaesthetic apparatus with pipelines for oxygen and atmospheric air.

It should be noted that the flowmeter on the concentrator may be used if the concentrator is used alone.

The Malawi Anaesthetic Trolley

The apparatus is based on the design of the traditional anaesthetic trolley. Pin index yokes are placed on the side panels, one for the oxygen cylinder on the left and one for a nitrous oxide cylinder on the right. Both take cylinders up to Size E (64 x 102 mm).

The yokes are connected to reducing valves, with a machine pressure of 300 kPa (3 bar), and thence to non-return valves. The rear panel of the trolley unit is equipped with non-interchangeable connections for flexible pipelines for oxygen, atmospheric air and nitrous oxide. The internal gas tubing of the unit has non-return valves at the connection points for the oxygen and nitrous oxide pipelines to prevent gas escape when using cylinders but not pipelines.

On the front plate of the apparatus, there is an oxygen flush valve for oxygen supply direct to the patient system, and a selector switch between nitrous oxide and atmospheric air. This prevents accidental hypoxia which would arise if nitrous oxide and atmospheric air were added simultaneously.

The flowmeter unit is equipped with three antistatic flowmeters. Those for oxygen and nitrous oxide are calibrated from 0.2 to 12 litre min$^{-1}$, while that for atmospheric air is calibrated from 0.2 to 15 litre min$^{-1}$.

The gases leave from the left side of the flowmeter bank and pass by flexible tubing to a swing console, which is mounted at the front on the left side, and fitted with two PAC drawover vaporizers (Cyprane, Ohmeda, New Devonshire House, Scott St West, Cheshire BD21 2NN, U.K.) for ether and halothane. The console is sited here as it is convenient for the breathing system in relation to the patient, and it is easy to use the vaporizers, as these may be placed close to the anaesthetist. The vaporizer console swings around an upright pole which keeps the vaporizers in a vertical position.

Gas enters the vaporizer on the left of the console close to the reservoir bag near a pressure limiting valve. If the input flow exceeds the patient's minute volume, excess gas escapes through this valve. This pressure limiting valve opens at 1 kPa and so it is not possible to use the reservoir bag for artificial ventilation and it also
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prevents production of a positive pressure at the inlet of the vaporizer which would cause a vapour concentration greater than that set. If the supply of fresh gases through the flowmeter is inadequate, the patient inspires room air through a low pressure valve which opens at 0.03 kPa.

If desired, the vaporizer console may be dismounted easily and attached to a wall rail system by two claws positioned at the rear. The ISO recommendation that it should not be possible to connect two vaporizers in series is followed in that it is only possible to attach the patient breathing system to one vaporizer at any time; a blank socket is available to seal off the vaporizer not in use. Ether and halothane vaporizers were chosen, as these two anaesthetic agents are most commonly available in district hospitals. A trichloroethylene vaporizer is not incorporated because medical production of this agent has been discontinued in many countries.

**Patient system**

The corrugated tubes are fitted with metal ISO 22-mm connectors (gas flowing out of the male taper). This prevents missconnection. A self-inflating bag (Ambu International, Søndre Ringvej 49, DK-2600 Glostrup/Copenhagen, Denmark), is used for ventilation with the Ambu E non-rebreathing valve. This has a resistance less than 0.1 kPa at a flow of 10 litre min$^{-1}$ during inspiration and expiration, and a resistance of less than 0.2 kPa during inspiration and 0.25 kPa during expiration at a flow of 40 litre min$^{-1}$.

For paediatric use, the Ambu Paedivalve is used with a resistance of less than 0.05 kPa during inspiration, and less than 0.1 kPa during expiration at a flow of 5 litre min$^{-1}$. At a flow of 15 litre min$^{-1}$ the resistance is less than 0.25 kPa during inspiration and less than 0.04 kPa during expiration.

The patient system is connected as shown in figure 3. By combining the anaesthetic equipment as shown, the following variations exist in gas supply to the vaporizer system:

(a) Oxygen rich gas from the oxygen concentrator via the oxygen rotameter.
(b) Oxygen rich gas from the concentrator mixed with air from the oxygen concentrator.
(c) Oxygen from a central supply via the oxygen flowmeter.
(d) Oxygen from a large cylinder via the oxygen flowmeter.
(e) Oxygen from a D or E cylinder on the unit via the oxygen flowmeter.
(f) Oxygen as in (c), (d) and (e) mixed with air from the concentrator via the air flowmeter.
(g) Nitrous oxide from central supply, large cylinder or from a D or E cylinder on the unit,
via nitrous oxide flowmeter mixed with oxygen as specified in (a), (c), (d) and (e).

(h) If compressed gases fail, anaesthesia may be carried out with room air alone, fed through the low pressure valve on the vaporizer console.

Servicing of the equipment

An indispensible part of the project was the establishment of three store house–service centres, one in each region of the country. These are equipped with tools, turning lathes, drilling machines, electronic tools, etc. Three years’ supply of spare parts were supplied with the equipment, in addition to a tool kit for each hospital for minor repairs. Spare parts for another 2 years’ use have been supplied recently.

Two service technicians have been trained in Denmark for 3 months, and six more have received a 4-week training locally.

Field monitoring of the oxygen concentrators

Testing of the Malawi Anaesthetic Equipment in situ began in December 1986 when the first three units were installed at two different hospitals. The remainder (42 anaesthetic machines and 102 oxygen concentrators) arrived in Malawi in March 1987 and the project started at all Government hospitals soon after. By the end of April 1987, all Government hospitals in Malawi used the same anaesthetic equipment.

After installation of the equipment, follow-up visits have been made to every district, central and general hospital twice a year to evaluate the performance of the oxygen concentrators, solve any problems which have arisen and to advise and teach the staff.

A total of 1125 measurements on 75 oxygen concentrators have been made to test their performance at different flows using Datex OT 101 oxygen analysers (Instrumenta Corporation PO Box 357 SF 00101 Helsinki 10, Finland) (table I). Over a period of 26 months, all concentrators have worked according to specification. The concentrators have a build-up time of 10 min before they produce 95% oxygen. After 3 min, they produce a concentration of 68% oxygen.

If the combination of oxygen and air is used, it is now established routine at district hospitals to use a fixed flow of oxygen of 2 litre min⁻¹. The oxygen concentrator produces 95% oxygen at 2 litre min⁻¹ while also providing a flow of air up to 7 litre min⁻¹ (fig. 4). At greater flows of air, the concentration of oxygen decreases significantly.

When concentrated oxygen and nitrous oxide are used together it is a rule that the concentrator oxygen flow should not exceed 4 litre min⁻¹ to prevent hypoxia.

Savings

The majority of district hospitals are now self sufficient for oxygen. The oxygen concentrators have been working for 26 months with a total of 97218 working hours. The calculated average flow to operating theatres and wards is 3.33 litre

<table>
<thead>
<tr>
<th>Flow (litre min⁻¹)</th>
<th>Oxygen concentration (% v/v)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 (n = 450)</td>
<td>95 (0.02)</td>
</tr>
<tr>
<td>4 (n = 450)</td>
<td>92 (0.03)</td>
</tr>
<tr>
<td>6 (n = 225)</td>
<td>65 (0.42)</td>
</tr>
</tbody>
</table>

FIG. 4. Decrease in oxygen concentration both with increase in flow of oxygen with gas (lower line), and with an oxygen-rich gas flow of 2 litre min⁻¹ (upper line).
TABLE II. Savings on the Health budget resulting from the installation of oxygen concentrators at all Government Hospitals in Malawi (average values per month over 26 consecutive months (April 1987–June 1989)). † Calculated average flow of 3.33 litre min⁻¹. £ = pound sterling

<table>
<thead>
<tr>
<th>Hours of operation</th>
<th>General and Central Hospitals</th>
<th>District Hospitals</th>
<th>All Hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen produced by concentrators (litre)†</td>
<td>486912</td>
<td>260139</td>
<td>747051</td>
</tr>
<tr>
<td>Cost of oxygen produced if bought in 48-ft³ cylinders (£)</td>
<td>1387</td>
<td>741</td>
<td>2128</td>
</tr>
<tr>
<td>Cost of electricity at £22 MWh⁻¹ (£)</td>
<td>21</td>
<td>11</td>
<td>32</td>
</tr>
<tr>
<td>Saved from not buying oxygen cylinders (£)</td>
<td>1366</td>
<td>730</td>
<td>2096</td>
</tr>
<tr>
<td>Saved on transport of oxygen cylinders (£)</td>
<td>2451</td>
<td>6884</td>
<td>9335</td>
</tr>
<tr>
<td>Saved on transport of patients (£)</td>
<td>8076</td>
<td>8076</td>
<td></td>
</tr>
<tr>
<td>Total savings per month (£)</td>
<td>3817</td>
<td>15690</td>
<td>19507</td>
</tr>
<tr>
<td>Total savings per year (£)</td>
<td>45804</td>
<td>188280</td>
<td>234084</td>
</tr>
</tbody>
</table>

With a calculated total production of oxygen 19424156 litre.

If a hospital had bought this quantity of oxygen in 48-ft³ cylinders (£3.874/48 ft³ cylinder), the cost would have been £55328 (sterling). The oxygen concentrators have a power consumption of 0.4 kW. Allowing for the cost of electricity in Malawi, this produces net savings in the 26-month period of £54496; this excludes additional savings on transport.

During his stay in Malawi, one of the authors (J. P.), collected data on the frequency of transport of oxygen cylinders, and of patients transferred because of lack of safe anaesthesia at the district hospitals. Before the introduction of the Malawi Anaesthetic Equipment, the district hospitals collected oxygen cylinders an average of 2.50 times per month per district hospital. After April 1987, oxygen cylinders were collected only 0.21 times per month per hospital. In addition, fewer patients were transferred from the district hospitals to the central hospitals. The central hospitals now receive 1.8 patients fewer per district hospital per month.

Before the project, district hospitals spent £12933 per month on transport of oxygen and patients per month. As a result of the installation of the Malawi Anaesthetic Equipment, the transport expenditure has been reduced to £4127 per month—a total saving of £8806 per month for the 20 district and one general hospitals.

The total savings for the health budget is approximately £19607 per month or £234084 per year (table II), as a result of the countrywide installation of an anaesthetic system, especially designed to suit the needs of a developing country.

**DISCUSSION**

The total budget for this project, including 101 oxygen concentrators, 45 anaesthetic machines, three store and service centres, tools, spares for the next 5 years, training of two technicians in Denmark and six trained in Malawi has been £800000. The £234084 savings on the health budget as a result of the installation of the new anaesthetic equipment at all government hospitals in Malawi amounted to 2.16% of the total health budget of £10817131 for the fiscal year 1987/88 (information from Ministry of Health, Malawi).

Installation of anaesthetic equipment with oxygen concentrators supplying oxygen, both in theatre and various wards (maternity, paediatric and medical wards), could be a financially viable solution to many of the problems which exist in Anaesthetic Departments in any developing country, where the oxygen supply is irregular and costly. Furthermore, mortality rates have decreased significantly at the district hospitals in Malawi, especially in maternity and paediatric wards.

The design of the Malawi Anaesthetic Equipment makes it easy to use with a low pressure ventilator instead of manual ventilation, provided the drawover vaporizer console with its pressure limiting valve is replaced by a pressure vaporizer. A Manley Ventilator has been connected to an oxygen concentrator for almost 1 year at one district hospital. The unit is used on both medical and paediatric wards and is working satisfactorily.

The problems which we anticipated in using oxygen concentrators in a developing country in the tropics included the effects of high relative
humidity during the rainy season and the high content of dust in the air in the dry season. To prevent water getting into the flowmeter of the anaesthetic machine, a small watertrap was added at the bottom of the buffer tank of the oxygen concentrator. The water has to be drained daily and it proved no problem for staff to remember to do this. Corrosion caused by high humidity affected three of the 45 initial vaporizers. These have been replaced and all new vaporizers are treated against corrosion; this has proven effective. The three standard filters at the air intake have proved sufficient to keep dust out of the concentrator.

Since September 1989, one oxygen concentrator has been connected to solar cells at a mission hospital in the bush. Until now this unit has performed satisfactorily. Although it is too early to base further recommendations on experience with this unit, if it continues to function well, it promises new opportunities for third world countries where electricity may be scanty and unreliable. The use of solar power also reduces running costs further.

When embarking upon the task of supplying a developing country with new standarized anaesthetic equipment, future supply of spares and the training of technicians are probably the most important considerations. Equipment around the world worth many millions of pounds is currently not being used because of absence of such simple spare parts as nuts and bolts.

ACKNOWLEDGEMENTS

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REFERENCES