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Oxygen supplies for hospitals in Papua New Guinea: a comparison of the feasibility and cost-effectiveness of methods for different settings

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SUMMARY

Oxygen therapy is essential in all wards, emergency departments and operating theatres of hospitals at all levels, and oxygen is life-saving. In Papua New Guinea (PNG), an effective oxygen system that improved the detection and treatment of hypoxaemia in provincial and district hospitals reduced death rates from pneumonia in children by as much as 35%. The methods for providing oxygen in PNG are reviewed. A busy provincial hospital will use on average about 38,000 l of oxygen each day. Over 2 years the cost of this amount of oxygen being provided by cylinders (at least K555,000) or an oxygen generator (about K1 million) is significantly more than the cost of setting up and maintaining a comprehensive system of bedside oxygen concentrators (K223,000). A district hospital will use 17,000 l per day. The full costs of this over 2 years are K33,000 if supplied by bedside concentrators, or K333,000 plus transport costs if the oxygen source is cylinders. In provincial and district hospitals bedside oxygen concentrators will be the most cost-effective, simple and reliable sources of oxygen. In large hospitals where there are existing oxygen pipelines, or in newly designed hospitals, an oxygen generator will be effective but currently much more expensive than bedside concentrators that provide the same volume of oxygen generation. There are options for oxygen concentrator use in hospitals and health centres that do not have reliable power. These include battery storage of power or solar power. While these considerably add to the establishment cost when changing from cylinders to concentrators, a battery-powered system should repay its capital costs in less than one year, though this has not yet been proven in the field. Bedside oxygen concentrators are currently the 'best-buy' in supplying oxygen in most hospitals in PNG, where cylinder oxygen is the largest single item in their drug budget. Oxygen concentrators should not be seen as an expensive intervention that has to rely on donor support, but as a cost-saving intervention for all hospitals.

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Introduction

Oxygen is essential for the care of many seriously ill patients with respiratory and non-respiratory conditions. It is required in all wards, emergency departments and operating theatres of hospitals at all levels. For decades, in Papua New Guinea (PNG), as in many developing countries, oxygen supplies have proved expensive and unreliable because of geographical remoteness, poor road conditions, logistics of transport, and the monopoly of supply through a private company. Oxygen, purchased in cylinders, is the single largest drug expense by the government health sector in PNG. In recent years, potentially more reliable options for supplying oxygen " oxygen concentrators and oxygen generators " have been trialled, and the resultant improvements in the detection and management of hypoxaemia have reduced mortality from childhood pneumonia by up to 35% (1,2). It is essential that choices made about oxygen systems are informed by the best available evidence on reliability, cost-effectiveness and safety. Fortunately there is direct evidence from PNG over the last decade that can guide these choices.

This review estimates the oxygen requirements in a typical regional hospital in the highlands. Outside of Port Moresby General Hospital, these hospitals have the highest oxygen requirements in the country. The costs of different methods of providing oxygen in these settings are estimated. In light of the findings of estimated oxygen use and costs, the factors determining the choice of oxygen supplies for different hospitals are discussed.

Current methods of supplying oxygen

Oxygen cylinders

Cylinders filled with oxygen are purchased centrally by the National Department of Health (NDoH) from BOC, a private gas company, and can be collected from Area Medical Stores by staff from hospitals, health centres and provincial health authorities. The cylinders remain the property of BOC, so rent on the cylinder is also charged. The transport costs are met by the hospital, and this can exceed the cost of the gas if vehicle hire is required. There are thus three costs attached to the use of oxygen from cylinders: the cost of the gas, rent for the cylinder and the cost of cylinder transport.

A large G-size cylinder holds about 7000 litres of oxygen at a filling pressure of 13000 kPa (130 bar). Pressure regulators and flow-meters are needed to deliver oxygen from cylinders to patients.

Oxygen concentrators

Oxygen concentrators are small machines which can deliver either 5 or 10 l/min of gas with 85%-95% oxygen concentration continuously. When used together with a multiple flow-meter device, depending on the flow rates and delivery means used, they can deliver individually controlled flows to up to 5 children or 1-4 adults at the same time. The 5 l/min concentrator generates the equivalent of 1 G-size cylinder (7000 litres) in 24 hours. Oxygen concentrators need continuous 240 V, 50 Hz electrical power, which in most provincial hospitals comes primarily from a mains supply. Weekly changing of the coarse-particle filter is the only maintenance needed on a regular basis, and this can be done by nursing staff. Internal maintenance is required eventually, but some manufacturers guarantee a maintenance-free 5-year period. In PNG all internal repairs have been provided by specially trained NDoH engineers. There are now close to 50 concentrators in use at 17 provincial and district hospitals in a program which started in 2005.

Oxygen generators

This name has recently been given to large oxygen concentrators that are designed to supply the oxygen requirements of an entire hospital. They come in various sizes, with capacities to produce oxygen equivalent to 2-100 cylinders per day. They use the same principle as the small bedside concentrators. They often require a new building to house them. The product gas can be fed into a hospital gas pipeline, or used to fill cylinders which can be stored and then transferred to the wards and operating theatres. Oxygen generators need reliable mains electricity. Power must be continuous if oxygen is fed into pipelines. Where supplies of power are intermittent, generators can be used to fill oxygen cylinders which can be used at times of power interruption.

Oxygen generators are individually constructed to agreed specifications for each

hospital; they are one-off products, as compared to the mass-produced bedside concentrators. Training for engineering staff on maintenance of these machines is essential to maintain continuity of supply.

An oxygen generator with a capacity of almost 60,000 litres (just over eight 7000 l cylinders) of oxygen per day has been running in Goroka General Hospital since September 2009.

Methods

Estimating oxygen requirements

We estimated the patient needs for oxygen in each ward per day in a busy provincial/ regional hospital and district hospital. In the highlands, around 50% of children hospitalized with severe pneumonia will require oxygen (3), at a starting flow rate of around 2 litres per minute (4). The average duration a child with severe pneumonia requires oxygen exceeds 2 days (5). Hypoxaemia also occurs in children with serious non-respiratory illnesses, and the prevalence of hypoxaemia in these critical conditions has been previously estimated at 30% (6). In addition, around 40% of sick neonates will be hypoxaemic at admission (6). Daily case loads for pneumonia, non-pneumonia and neonatal illnesses were derived by taking the average number of admissions in 3 highlands hospitals (Mt Hagen, Mendi and Kundiawa) between September 2006 and September 2007 (1).

Estimates of oxygen demands for adult wards, emergency departments and theatres in provincial hospitals were based on clinical experience of case loads and oxygen use in these settings in several provincial hospitals. We estimated daily oxygen needs in a district hospital based on average estimated case load.

Estimating cost

We did a cost comparison between the three methods (cylinders, concentrators and large generators) of providing the estimated daily oxygen usage of a large provincial or regional hospital. To do this, direct costs were sought from the manufacturers for concentrators (Airsep, USA) and cylinders (BOC, PNG), from the records of cylinder usage by one provincial hospital (Mt Hagen General Hospital), and from the usage of the generator installed in another provincial hospital (Goroka General Hospital). Indirect costs, including installation and training costs, were estimated based on the programs for implementation of bedside oxygen concentrators in hospitals in PNG (1) and from the installation of the large oxygen generator in Goroka. Transport costs for oxygen cylinders could not be reliably estimated as these vary significantly according to remoteness, availability and modes of transport to the oxygen plant. However, transport adds considerably to the overall cost of providing oxygen in cylinders, and the estimate proposed here for cylinders is therefore lower than the actual cost. In the bedside oxygen concentrator model it was assumed that 9 concentrators would be needed for a large provincial hospital (2 in the children's ward, 1 in the adult medical ward, 1 in the adult surgical ward, 1 in the emergency department, 1 in the special care nursery, 1 in the surgical recovery area/ intensive care unit and 2 spare), since it would be logistically important to provide oxygen in all patient care areas where hypoxic patients may be managed.

A similar cost estimate was done for district hospitals. Given the sharing of patient care areas between patient groups in these facilities, it was assumed that 3 concentrators would be sufficient: 1 with 5 l/min capacity, 1 with 10 l/min capacity and 1 spare.

Results

Oxygen requirements for a large provincial or regional hospital on an average day are shown in Table 1. The estimated total number of litres required per day " about 38,000 litres " is equivalent to 5 large 7000-litre oxygen cylinders per day.

The estimated costs of supplying in excess of 38,000 litres per day over two years are outlined in Table 2. Oxygen cylinders cost about K555,000, bedside concentrators cost about K223,000 and an oxygen generator costs K1 million over two years. The annual recurring costs (excluding the initial outlay and one-off building costs) of using a generator amount to K210,000, and this is similar to the cost of setting up and maintaining a system of bedside concentrators for the provision of oxygen on all the wards and the running of an anaesthetic machine and ventilator.

Oxygen requirements for a small provincial

TABLE 1

OXYGEN REQUIREMENTS FOR AN AVERAGE DAY IN A REGIONAL HOSPITAL IN THE HIGHLANDS

Hospital admissions/procedures	Average number of daily admissions	Average number hypoxaemic	Flow rate (l/minute)	Oxygen requirements (l/day)
Children with pneumonia or bronchiolitis	2.2	1.1	2	3,168
Children with pneumonia admitted the previous day, still hypoxaemic	1	1	1	1,440
Non-pneumonia admissions	3	1	1	1,440
Neonates with respiratory distress	2-3	1	1	1,440
A moderately busy surgical list requiring an anaesthetic machine to run 6 hours, assuming only one theatre is running	-	4 surgical operations (other procedures may not require oxygen)	10	3,600
Adults with COPD, pneumonia or heart failure in the emergency department and medical wards	-	3	4	17,280
Emergency adult trauma patients in surgical ward	-	1	6	8,640
Out of hours obstetric emergency requiring 2 hours of anaesthetic machine	-	1 surgical operation	10	1,200
Total				**38,208**

COPD = chronic obstructive pulmonary disease

hospital or a district hospital are shown in Table 3, and costs over 2 years are outlined in Table 4. The estimated cost of supplying around 17,000 litres of oxygen per day over 2 years using cylinders is K333,000 plus transport costs and for bedside oxygen concentrators is K33,000.

Discussion

More than 38,000 litres of oxygen are needed on an average day for new admissions in a busy provincial hospital, and more than 17,000 litres a day in a district hospital. This estimate of overall needs may be conservative, as some patients will require more than one day of oxygen therapy. We have factored in that children with severe pneumonia will require on average 2 days of oxygen therapy, but this is also likely to apply to adults with chronic lung or heart disease and to neonates with respiratory disease. While in resource-poor settings the necessity of oxygen has been recognized in

TABLE 2

ALTERNATIVE MODELS FOR REGIONAL HOSPITALS: COSTS OF PRODUCING ABOUT 38,000 LITRES PER DAY FOR 2 YEARS

	Cost per unit (kina)	Total cost for 2 years (kina)
Oxygen cylinders (5 x 7000 l cylinders = 35,000 l)		
Gas cost for one 7000 l cylinder (G-size)	140	511,000
Transport costs[a]	Depends on hospital requirements, location, vehicle hire rate	
Deposit for cylinders (x 45)[b]	800	36,000
Rent for 1 cylinder per year (x 45)[b]	96	8,640
Total for cylinders		**K555,640**
Oxygen generator system (capable of producing about 60,000 l per day)		
Oxygen generator with 10 cylinders (including delivery)	565,000	565,000
Building costs	120,000	120,000
Existing manifold servicing and repair of leaks in gas pipeline	70,000	70,000
Electricity for 2 years (kW hours) 28kW x 24 x 0.65 x 365 x 2 x K0.75 (per kW hour)	65% usage[c] of 28 kW per day, at a cost of 0.75K per kW hour[d]	239,148
Additional cylinder purchase (x 17)[e]	700	11,900
Maintenance costs (estimated)	25,000 per year	50,000
Total for oxygen generator system		**K1,056,048**
Bedside oxygen concentrators producing approximately 64,000 litres per day (plus 2 spare concentrators)[f]		
Airsep Elite (5 l/min) (x 3 + 1 spare)[f]	1,490	5,960
Airsep Intensity (10 l/min) (x 4 + 1 spare)[f]	3,388	16,940
Flow-metre devices (x 8)	1,220	9.760
Concentrator, anaesthetic machine and ventilator x 2 (US$20,000 each)	54,200	108,400
Delivery costs	15,000	15,000

	Cost per unit (kina)	Total cost for 2 years (kina)
Indirect costs: installation, training, supervisory visits and maintenance	10,000	20,000
Electricity costs[f] Elite: 3 x 350 W = 1050 W 1.05kW x 24 x 365 x 2 x 0.75K/kW hour	13,797	
Intensity: 4 x 590 W = 236W 2.36kW x 24 x 365 x 2 x 0.75K/kW hour	31,010	
Anaesthetic machines: 1 x 590 W = 590 W 0.59kW x 8 365 x 2 x 0.75K/kW hour[g]	2,584	47,391
Total for bedside oxygen concentrators		**K223,451**

[a] Note that cylinder transport costs are not included as they vary widely between hospitals, but should be taken into consideration when evaluating the economics of using oxygen cylinders: estimates range from K50,000 upwards per year depending on the location of the hospital and the frequency of trips to the depot

[b] The cost estimate budgets for cylinder deposits and rental are for 45 oxygen cylinders where these are used as the main source of oxygen, which allows for 5 cylinders in use at any one time, 5 full in reserve and 35 either full or available for refilling

[c] Electricity use can be reduced by running the generator intermittently to fill oxygen cylinders where oxygen can be stored; we therefore budgeted for 65% usage per day, required to produce 39,000 litres per day

[d] Electricity costs assume 24-hour operation of the concentrators at K0.75/kWhr

[e] The generator can be used to fill oxygen cylinders, which allows power to be used intermittently rather than continuously, and excess cylinders can supply surrounding small hospitals or health centres/clinics

[f] Oxygen output of bedside concentrators exceeds demand, but this number is needed to supply all patient care areas of the hospital and have 2 spare in case of malfunction; the electricity costing for bedside concentrators assumes that 7 concentrators are working 24 hours a day, which is unlikely, and therefore the overall cost is likely to be lower; a similar relationship holds between the theoretical and realistic daily oxygen outputs

[g] Electricity costs for anaesthetic machines assume 1 machine working 8 hours each day of the year

anaesthetics and increasingly in the management of childhood pneumonia, it is equally important in many conditions for all age groups (7). Hospital oxygen demands therefore need to take into account the routine requirements of adult and paediatric wards as well as scheduled and emergency surgery. Oxygen needs will fluctuate depending on seasonal changes in the incidence of acute respiratory infections, disease outbreaks, emergencies and surgical activity, and the use of equipment with a high oxygen requirement such as ventilators.

Oxygen cylinders have been used for decades to deliver oxygen to the least accessible locations. They require hardly any maintenance and minimal pre-existing infrastructure, and are universally acceptable by health workers. However, the estimates produced in this paper, along with previous studies (8), confirm that this option is very expensive. Previous studies in PNG show that using cylinders is unreliable and leads to unavailability of oxygen on 20% of occasions (3). The estimate that we have made on the 2-yearly cost of oxygen cylinders (K555,000) is conservative as we have not included transport costs, which will be particularly high in locations remote from the manufacturing plant, and especially where vehicle hire is needed. Though no estimates are available of the overall cost of transport of cylinders to hospitals, even without that the PNG Health Department spends more money on cylinder oxygen than any other drug.

The estimate we made of the costs of bedside oxygen concentrators is comprehensive: it includes a number of machines in excess of the oxygen requirements of a provincial hospital because of the need to have oxygen in multiple patient care areas and a spare concentrator in case of malfunction, and includes the costs of training and maintenance. In district hospitals, fewer oxygen concentrators are needed as the numbers of patient care areas and

TABLE 3

ESTIMATED DAILY OXYGEN REQUIREMENTS FOR A DISTRICT HOSPITAL

Hospital admissions/procedures	Average number of daily admissions	Average number hypoxaemic	Flow rate (l/minute)	Oxygen requirements (l/day)
Children with pneumonia	2	1	2	2,880
Non-pneumonia admissions	2	1	1	1,440
Neonates with respiratory distress	2	1	1	1,440
Surgical procedures under ketamine taking 1 hour each, including recovery	-	2 surgical operations	4	480
Adults with COPD, pneumonia or heart failure in medical wards	-	1	4	5,760
Emergency adult trauma patients in surgical ward needing oxygen for first 12 hours	-	1	6	4,320
Out of hours obstetric emergency requiring 2 hours of anaesthetic	-	1 surgical operation	10	1,200
Total				**17,520**

COPD = chronic obstructive pulmonary disease

patients treated are fewer than in provincial or regional hospitals. Therefore, only 3 concentrators are needed, including one spare, making it possible to set up an oxygen concentrator system in a district hospital for around K33,000.

Bedside concentrators are significantly cheaper than both cylinders and generators. However, they do require a continuous power source, which is limiting in remote health facilities. They also require regular maintenance by the health workers using them (cleaning of external pore filter) and periodic checks every 12 months by a technician or engineer. It is necessary to have a skilled engineer who can provide timely repairs if faults occur. If these services are not in place, a health facility may be without oxygen until repairs can be completed. A back-up oxygen cylinder should be available in all health facilities using concentrators to cope with faults that occur from time to time, while repairs are being done, and to cope with power interruptions. The use of concentrators needs well-functioning systems for communication between health facility and biomedical support. Oxygen concentrators are now being used in 17 provincial hospitals in PNG, and there is good experience in what is required to sustain them.

One disadvantage of oxygen concentrators is that the maximum pressure generated (140 kPa) is not sufficient to run standard anaesthesia equipment, which typically requires 400 kPa. This problem can be overcome by using anaesthesia machines which have been specifically designed to be used with an oxygen concentrator (see www.diamedica.com). The model we have proposed also includes anaesthesia

TABLE 4

ALTERNATIVE MODELS FOR A DISTRICT HOSPITAL OR SMALL PROVINCIAL HOSPITAL: COSTS OF PRODUCING ABOUT 17,000 LITRES PER DAY FOR 2 YEARS

	Cost per unit (kina)	Total cost for 2 years (kina)
Oxygen cylinders (3 x 7000 l cylinders = 21,000 l)		
Gas cost for one 7000 l cylinder (G-size)	140	306,600
Transport costs[a]	Depends on hospital requirements, location, vehicle hire rate	
Deposit for cylinders (x 27)[b]	800	21,600
Rent for 1 cylinder per year (x 27)[b]	96	5,184
Total for cylinders		**K333,384**
Bedside oxygen concentrators producing approximately 21,000 litres per day (plus 1 spare concentrator)[c]		
Airsep Elite (5 l/minute) (x 1 + 1 spare)[c]	1,490	2,980
Airsep Intensity (10 l/minute) (x 1)[c]	3,388	3,388
Flow-meter devices (x 3)	1,220	3,660
Delivery costs	7,500	7,500
Indirect costs: installation, training, supervisory visits and maintenance	2,000	4,000
Electrtity costs Elite: 1 x 350 W 0.35kW x 24 x 365 x 2 x 0.75K/kW hour[d]	4,599	
Intensity: 1 x 590W 0.59kW x 24 x 365 x 2 x 0.75K/kW hour[d]	7,753	12,352
Total for bedside oxygen concentrators		**K33,880**

[a] Note that cylinder transport costs are not included as they vary widely between hospitals, but should be taken into consideration when evaluating the economics of using oxygen cylinders

[b] The cost estimate budgets for cylinder deposit and rental are for 27 oxygen cylinders where these are used as the main source of oxygen, which assumes that refilling cylinders would occur once every week or two and allows for 3 cylinders in use at any one time, 3 full and ready for use and 21 available for refilling

[c] Oxygen output is 5 l/min x 60 x 24 x 1 = 7,200 (Elite) and 10 l/min x 60 x 24 x 1 = 14,400 (Intensity), total per day = 21,600 l

[d] Electricity costs assume 24-hour operation of the concentrators at K0.75/kWhr

equipment for surgery independent of cylinder oxygen, a cost that may not be necessary in all hospitals. The top of the range machine costs about US$20,000 and a simpler version without a ventilator costs about US$10,000. A busy provincial hospital will have 2 operating rooms, so the costs for 2 top of the range anaesthetic machines have been included in the oxygen concentrator model. This amounts to about 50% of the total cost of supplying oxygen using concentrators. Smaller hospitals where only minor surgery is done would not need this equipment, making oxygen concentrator systems even cheaper in district hospitals. If an anaesthetic machine is needed in district hospitals the additional cost is US$10,000 (K27,000).

The bedside oxygen concentrators currently used in PNG were all purchased from the same manufacturer and have proved reliable in tropical conditions. They are made in very large numbers (total unit numbers exceed one million), which leads to low unit cost, and they receive good product support from the manufacturer. Expertise in bedside oxygen concentrator maintenance and repair and provision of spare parts are needed in each of the four regions of the country. Currently such expertise is not sufficiently spread throughout the provinces where concentrators are used. Work is required on all concentrators at intervals of about 10,000 hours of use (more than a year of continuous use). Measures need to be in place to carry out this essential maintenance locally at minimal cost.

The experience with large oxygen generators in PNG is so far positive, but limited to one centre (Goroka Hospital). Oxygen generators have some advantages over bedside concentrators: they can generate sufficient pressure (400 kPa) to run conventional anaesthetic machines, and by filling transportable cylinders there is the potential for producing enough oxygen to supply surrounding rural hospitals and smaller clinics if oxygen generation exceeds hospital usage. However, this excess is likely to be less than predicted, especially if there is leakage from pipelines, and it is currently unclear whether the Goroka generator will produce enough oxygen to meet the oxygen needs of all health facilities in the Eastern Highlands Province.

Compared to bedside oxygen concentrators, a generator requires a very large initial outlay: more than 4 times the cost of establishing a comprehensive oxygen system to all hospital clinical areas based on bedside oxygen concentrators. Oxygen generators require significant technical expertise and infrastructure, and malfunctions will result in shortage throughout the whole hospital if there is no back-up available. Bedside concentrators, being portable, allow the use of a concentrator from another ward or a spare, while repairs are done. If generators are supplying oxygen to patient care areas through gas pipelines wastage of oxygen can occur if there are leakages in gas piping systems (9).

When compared to the high cost of cylinder oxygen from a private supplier, the initial capital cost of the oxygen generator system at Goroka General Hospital should eventually be recovered, for the provision of an equivalent amount of oxygen. However, infrastructure and ongoing costs " a new building to house the generator, repair and maintenance of gas pipelines and manifold, and the capital cost of cylinders if the system is used to refill cylinders " substantially add to the initial capital costs of the generator, and mean that the total cost would take more than 3 years to be recovered. The oxygen generator in Goroka needs to be monitored for performance, maintenance requirements and costs for the first 5 years to evaluate if it is a successful prototype for similar hospitals.

Considerations when choosing oxygen systems in different hospitals

Three types of hospital situations will be considered:

- Hospitals with pre-existing medical gas pipelines and mains electricity
- Hospitals and health centres with 24-hour mains electricity but no pre-existing pipeline system
- Hospitals and health centres with limited or no mains electricity.

Large hospitals with pre-existing medical gas pipelines

Port Moresby General Hospital and some provincial hospitals in PNG have existing gas pipelines, but many of these are in need of maintenance. These hospitals generally have adequate electricity supplies from mains

power, with an electricity generator as a back-up supply. Although this is often assumed, when considering the use of oxygen concentrators or generators the electricity supply should be checked and upgraded as needed.

In addition to cost, a major consideration in choosing a method for supplying oxygen in these hospitals is the condition of the pre-existing gas pipelines: whether they would deliver gas from an oxygen generator, or a bank of cylinders connected to a manifold, effectively, safely and without substantial leakage. Several questions regarding pipelines which arise from consideration of the relevant International Standards Organization (ISO) Standards for medical gas pipeline systems (10) are listed in Table 5. If pipelines are in poor condition, oxygen generators can be used to fill oxygen cylinders, which are transported to areas of patient care when needed, though, given the large oxygen requirements of provincial hospitals, this exercise is time-consuming and labour-intensive.

Repair or replacement of copper pipelines should be carried out by specialist subcontractors, and is an expensive exercise. Once a pipeline has been upgraded and is ready for testing to the specified requirements, a third party expert assessor should certify that the system complies with the specification and the safety aspects of the relevant ISO Standards.

The more widespread adoption of pipelines and oxygen generators into PNG hospitals will require either the development of specialist engineers qualified in this complex field, or the use of specialist subcontractors with its attendant costs. If repair, replacement or maintenance of gas pipelines is considered too costly or complex in an individual institution, or the set-up costs of a generator are unaffordable, use of bedside oxygen concentrators in all hospital clinical areas where oxygen is required will cost less than a quarter of the cost of an oxygen generator, and currently is the preferred option.

Hospitals and health centres with 24-hour mains electricity but no pre-existing pipeline system

This situation applies to most provincial hospitals and many district hospitals in PNG, where there is a combination of mains electricity with a back-up generator delivering 240 V, 50 Hz AC with adequate wiring throughout the hospital. In these hospitals, the use of bedside oxygen concentrators (5 l or 10 l per minute) in designated high-dependency areas within wards (Figure 1) will be far cheaper than installing an oxygen generator and a piped system, or buying oxygen in cylinders (Table 2).

Most provincial hospitals employ engineers who are capable of extending the electrical wiring system if required at low cost, and such engineers have installed the short, plastic-tubing systems used to deliver oxygen from oxygen concentrators to several beds in a high-dependency area, in compliance with ISO 8359 (12).

TABLE 5

QUESTIONS OUTLINED IN INTERNATIONAL STANDARDS ORGANIZATION ISO 7396-1:2007 (10), ESSENTIAL IF GENERATORS OR A BANK OF CYLINDERS ARE BEING CONSIDERED AS THE OXYGEN SOURCE

Are the pipelines leaking?
What is the condition of the terminal units (wall outlets) where connections are made?
Are there sufficient shut-off valves?
Does the manifold work and is it usable for the intended higher throughput?
Is there a reserve manifold capable of supplying the pipeline at 100% flow?
Is the pipeline of adequate diameter for the intended flows? If the copper pipe is too small in diameter, larger pipes may be required to be installed.

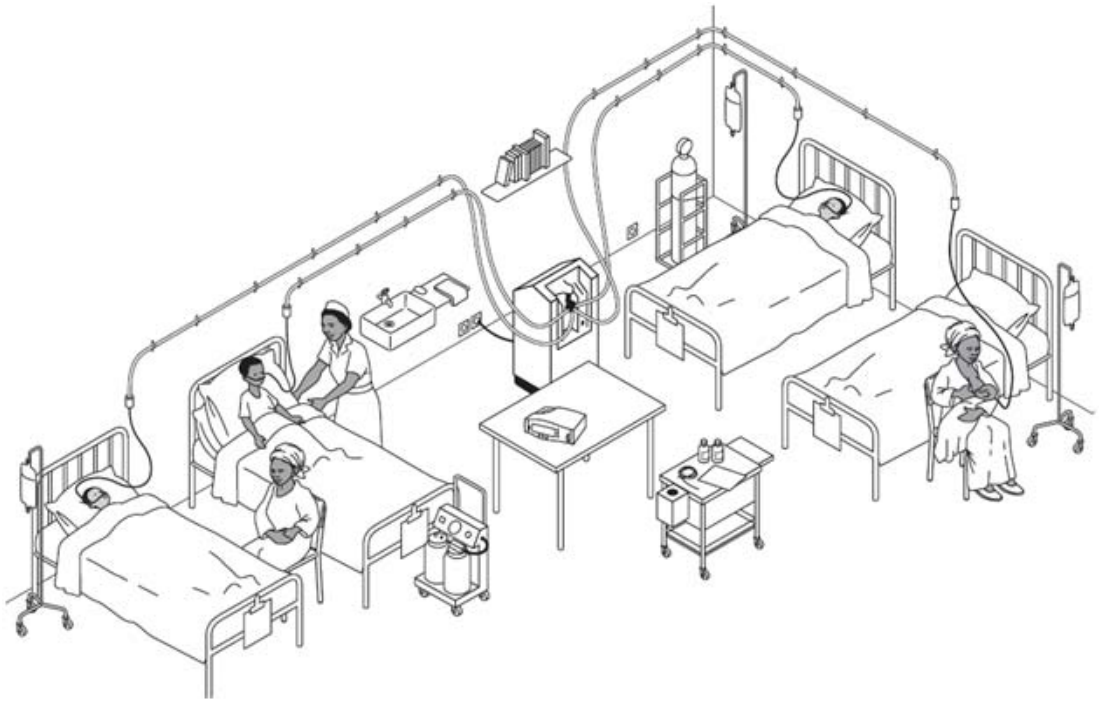

Figure 1. A high-dependency area in a children's ward that is supplied with oxygen by an oxygen concentrator. Figure by David Woodroffe of David Woodroffe Digital Illustration, United Kingdom, reproduced from The Clinical Use of Oxygen (11).

Hospitals and health centres with limited or no mains electricity

For hospitals without a reliable source of 240 V, 50 Hz electrical power the only ways to provide oxygen are (a) the transportation of cylinders, often over large distances, (b) to provide an alternative power source for 24 hours per day, or (c) to use small oxygen generators which can fill cylinders when power is available and provide a reservoir for when power is not available. Currently the third option is only a theoretical possibility and has not been tested in any field setting. Whether it would be feasible depends on the number of hours of power available, whether the power when available is continuous or intermittent, how much power is required to refill cylinders and whether this would exhaust the power needed for other requirements of the hospital. Different options for providing alternative energy sources to run concentrators (b, above) are described below.

Storing power to run oxygen concentrators

For hospitals with between 4 and 23 hours of mains electricity per day it is possible to charge up to eight batteries with DC power at 6 volts per battery and then to use an inverter to provide AC power at 230 V and 50 Hz to drive a single 5 l/min concentrator when the mains power is not available. Such a system should cost between K8000 and K23,000 depending on the number of batteries needed and will be significantly cheaper than currently available solar power systems.

Solar power systems to run oxygen concentrators

Solar power has been used to run concentrators, but there are cost and logistical barriers (13). In general a solar panel will produce an average of 6 hours of DC power at the maximum rated output per day. This power therefore needs to be stored in batteries and connected to an inverter to give the 24-hour AC output needed to run a concentrator. There are known systems which can be purchased to do this.

Unfortunately a capital cost of about US$20,000 for the solar power system is needed to run concentrators costing only around $550 each. However, the solar panels have a long life if not vandalized or stolen (about 25 years) and other components have a life of at least 5 years. Therefore the annual amortisation cost of the complete solar power system is about US$1500 (about K4100). The capital cost then becomes about US$2000 per year for each 5 litre/min concentrator over a life of at least 5 years. The annual cost of an equivalent quantity of oxygen (1 cylinder per day) from cylinders would be about US$18,900 (K140 x 365 divided by 2.71) (see Table 2). There are new building designs which provide extensive areas for solar panels sufficient for driving a 350 watt concentrator for 24 hours a day. Appropriate solar and battery power systems are available from a company which claims to have supplied 70% of the world market for solar refrigerators to WHO specifications (see www.dulas.com).

Intermittent mains or electricity generator power

The same kind of batteries as those used for a solar power system can be used to store power from intermittent mains or an electricity generator and thus can deliver the 24-hour continuous AC power needed by an oxygen concentrator. The battery system costs up to US$8500 depending on the number of hours of mains power available and therefore the number of batteries needed. This system will also produce the equivalent of 1 cylinder per day, with an annual cost of US$18,900, and therefore would repay its cost in less than a year.

Direct current concentrators

Concentrators that can be powered by DC power, thereby removing the need for an inverter when alternative DC power sources are used, are currently made for single-patient use. These portable machines are smaller (maximum of 0.5-1 l/min) and more expensive than the standard 5 or 10 l/min concentrators that have been used in PNG. However, concentrators powered by a DC motor are about 20% more efficient on energy consumption than the normal AC concentrators. There are hopes that a 5 l/min concentrator that runs off DC may be developed in the next few years at a reasonable price.

Pulse oximeters

Pulse oximeters are essential for the accurate detection of hypoxaemia (11,14). Regardless of the source of oxygen used, pulse oximeters should be purchased for all hospitals. Pulse oximeters cost about $1000 (K2700) and reusable sensors cost about $150-200 (K470). Reusable sensors can be expected to last a year if properly used. A provincial hospital needs 4-5 pulse oximeters and a 5-year supply of sensors, adding K23,000 to the cost of any oxygen system over 5 years. A district hospital needs 2 oximeters and a 5-year supply of sensors, adding K10,000 to the cost of an oxygen system over 5 years.

Conclusion

Oxygen supply systems based on bedside oxygen concentrators are currently the 'best-buy' for supplying oxygen in provincial and district hospitals in PNG, being much cheaper than the alternative sources. The choice of method for supplying oxygen needs to take into account pre-existing infrastructure including availability of electricity, and accessibility of technical and engineering expertise. In large hospitals where there are existing oxygen pipelines in good condition, or in newly designed hospitals, a large oxygen generator may be a long-term infrastructure investment, but still much more expensive than bedside concentrators for the same volume of oxygen generation. For a functioning national oxygen concentrator or generator program more biomedical engineering capacity is urgently needed in each region of the country. Further training is needed for the existing engineering staff.

There are some options for oxygen concentrator use in remote health centres that do not have reliable power, including battery storage of mains or solar power. Although these add considerably to the establishment costs when changing from cylinders to concentrators, a battery-powered system should repay its capital costs in less than one year; however, this has not yet been evaluated under field conditions.

The PNG Health Department and hospital chief executive officers (CEOs) should not wait for external agencies or donors to support

oxygen concentrator programs. Changing to oxygen concentrators as the primary source for oxygen should be seen as an urgent, cost-saving intervention for the Health Department and for individual hospitals. Pulse oximeters are an essential part of managing hypoxaemia and should be included in any program of improved oxygen systems.

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COMPETING INTERESTS

The authors declare that they have no contracts, consultancies, shares or other financial interest in any company which manufactures oxygen equipment or other medical devices.

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