Afr. J. Med. med. Sci. (2016) **45**, 31 - 49

Oxygen for children and newborns in non-tertiary hospitals in South-west Nigeria: A needs assessment

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Abstract

Background: Oxygen is important for the treatment of hypoxaemia associated with pneumonia, malaria, and other medical, obstetric, and surgical conditions. Access to oxygen therapy is limited in many of the high mortality settings where it would be of most benefit.

Methods: A needs assessment of 12 non-tertiary hospitals in south-west Nigeria, assessing structural, technical and clinical barriers to the provision of safe and effective oxygen therapy.

Results: Oxygen supply was reported to be a major challenge by hospital directors. All hospitals had some access to oxygen cylinders, which were expensive and frequently ran out. Nine (75%) hospitals used oxygen concentrators, which were limited by inadequate power supply and lack of maintenance capacity. Appropriate oxygen delivery and monitoring devices (nasal prongs, catheters, pulse oximeters) were poorly available, and no hospitals had clinical guidelines pertaining to the use of oxygen for children. Oxygen was expensive to patients (median US$20/day) and to hospitals. Estimated oxygen demand is reported using both a constant mean-based estimate and adjustment for seasonal and other variability.

Conclusions: Making oxygen available to sick children and neonates in Nigerian hospitals will require: improving detection of hypoxaemia through routine use of pulse oximetry; improving access to oxygen through equipment, training, and maintenance structures; and commitment to building hospital and state structures that can sustain and expand oxygen initiatives.

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Keywords: *Oxygen, needs, assessment, children, non- tertiary hospital*

Résumé

Contexte: L'oxygène est important pour le traitement de l'hypoxémie associée à la pneumonie, paludisme et autresconditions médicaux, obstétriques et chirurgicales. L'accès à la thérapie d'oxygène est limité dans la plupart des lieux avec tauxde mortalitéélevés où il serait le plus bénéfique.

Méthodes: Une évaluation des besoins de 12 hôpitaux non tertiaires dans le sud-ouest du Nigeria, évaluant les obstacles structurels, techniques et cliniques à la mise à disposition d'un traitement sûr et efficace de la thérapie d'oxygène.

Résultats: L'approvisionnement en oxygène a été signalé comme étant un défi majeur par les directeurs d'hôpitaux. Tous les hôpitaux avaient un accès à des bouteilles d'oxygène, qui étaient coûteux et fréquemment manquaient en oxygène. Neuf (75%) des hôpitaux utilisaient des concentrateurs d'oxygène, qui ont été limités par l'alimentation inadéquate d'électricité et le manque de capacité d'entretien. Les dispositifs appropriés de livraison et de surveillance d'oxygène (sondes nasales, cathéters, oxymètres de pouls) étaient difficilement accessibles, et pas d'hôpitaux avaient des directives cliniques relatives à l'utilisation d'oxygène pour les enfants. L'oxygène était cher aux patients (médian 20 US $/jour) et aux hôpitaux. L'estimée demanded'oxygène est signalé à la foisà l'aided'une moyenne de base constanted'estimation et ajustement saisonnière et autres variabilités.

Conclusions: Mettrel'oxygène disponible pour les enfants et nouveau-nésmalades dans les hôpitaux nigérians nécessitera à: améliorer la détection de l'hypoxémie par l'utilisation systématique de l'oxymétrie de pouls; améliorer l'accès à l'oxygène à travers l'équipement, la formation et les structures de maintenance; et l'engagement à la construction des structuresd'hôpital etd'état qui peuvent soutenir et étendre les initiatives d'oxygène.

Mots-clés: *Oxygène, besoins, évaluation, enfants, hôpital non tertiaire*

Introduction

Oxygen is an essential medicine that has been saving lives for over 100 years [1]. It is important for the treatment of hypoxaemia associated with pneumonia and other lung diseases, sepsis, malaria, neonatal conditions and other severe illnesses, and is widely used in obstetric, surgical, and anaesthetic care. However, oxygen availability is poor in the low-resource settings that bear the greatest burden of morbidity and mortality globally [1].

Previous studies have shown that relatively inexpensive improvements in oxygen systems can reduce pneumonia case fatality rates among children by up to 35% [2,3]. However, such systems require context-specific planning, technical expertise, and sustained attention to training and supervision [2].

In Nigeria, the leading causes of child mortality are malaria (21%), acute respiratory infections (15%), and neonatal causes (at least 27%; comprising prematurity 12%, birth asphyxia 10%, and sepsis 5%) [4], which together account for three-quarters of admissions to a tertiary hospital [5]. Hypoxaemia is common in these conditions, affecting up to half of children with acute respiratory infection, 30% with malaria, and 41% with neonatal conditions – and is a strong predictor for mortality [5,6].

Despite the inclusion of oxygen on the Nigerian Essential Medicines List [7] and growing demand for oxygen solutions in many hospitals, little is known about the oxygen needs or capacities in non-tertiary hospitals in Nigeria.

This study evaluates the current capacity of non-tertiary hospitals in south-west Nigeria to safely and effectively provide oxygen to sick children and newborns, estimates oxygen needs, and describes potential options to improve oxygen supply (Study ID: BMGF OPP1123577).

Materials and methods

We conducted a cross-sectional evaluation of hospitals using a health needs assessment framework [8] to identify and describe capacity and issues in providing oxygen to children and newborns in hospitals. This study was done in preparation for a multi-centre field trial evaluating the introduction of a comprehensive oxygen system (including pulse oximeters, oxygen concentrators, and solar power).

We assessed all health facilities in Oyo state for inclusion according to the following criteria: they had to be either government or mission run secondary health facilities, and admit at least 150 children per year. After we could not identify a sufficient number of hospitals in Oyo state alone, we selected additional hospitals in 3 other states (Ondo, Ogun, Osun) using the same criteria. This therefore provided a representative sample of major secondary health facilities in south-west Nigeria.

We developed a Facility Assessment Form (see Appendix), based on WHO facility assessment tools used in oxygen assessments in Papua New Guinea [2,9,10] and the Gambia [11]. Our assessment covered a broad range of structural, technical and clinical barriers to the provision of safe and effective oxygen therapy we had identified from the literature [2,10,12]. These included issues relating to power supply, financing, human resources (technical and clinical), maintenance structures, medical education and clinical guidelines, essential medical and laboratory supplies, and types of oxygen equipment (including oxygen concentrators, oxygen cylinders, and pulse oximeters).

We used semi-structured interviews with key individuals at each hospital and detailed field visits by clinicians and technicians to obtain data. Key individuals interviewed included hospital directors, chief paediatric medical officers, chief nursing officers, medical records officers, maintenance technicians, laboratory technicians, and other administrative officers.On completion of the facility visit and interviews, the complete data for each hospital were collated and returned to the Medical Director for correction and confirmation of accuracy. Follow up visits and phone calls were made when necessary.

Admission and case-mix data were obtained for the period 1 January 2014 to 30 June 2015. This was obtained from the admission books on each ward by a trained nurse data collector then cross-checked against records in the hospital medical records department to ensure complete capture.

We calculated daily mean oxygen requirements using local hospital admission data and estimated hypoxaemia prevalence (20% neonates, 10% children), mean oxygen duration (3 days) and flow rates (1L/min neonate, 2L/min child) using extrapolated local [5,13] and international [14] data. Case mix assumptions were: 30% malaria, 20% ALRI, 25% neonatal and 10% sepsis [5, 13].

Actual oxygen demand is influenced by seasonal variability (higher in peak season),day-to-day variability in admissions and case-mix (higher with particular conditions and severity of illness), and variability in inter-patient oxygen requirement (including both flow-rate and duration of treatment)[15]. This temporal variability in oxygen demand is expected to be higher in small hospitals than in larger hospitals [15].Using previous mathematical modelling we estimated that providing capacity for 3 times the mean oxygen demand would cover actual oxygen demand approximately 80% of the time during the peak season (and >95% outside the peak season) [15].

Tabulation and graphing of results were done using Excel (Microsoft), and statistical analysis performed using Stata version 15 (Statacorp).

Results

We conducted identification and screening of hospitals in cooperation with the State Hospital Management Board (Figure 1). The Oyo State Hospital Management Board provided a list of 432 government, private, and mission secondary health facilities, of which 24 active hospitals were screened in initially. We identified an additional 8 government and mission hospitals from Ogun, Osun and Ondo states giving a total of 32 hospitals for determination of eligibility. Twelve hospitals met the inclusion criteria and were included in our study, providing representation of medium-sized hospitals that admit children in South-West Nigeria. A multidisciplinary team of paediatricians and engineers/technicians visited all the included hospitals to conduct facility assessments between May and June 2015.

Admission and case-mix data

Table 1 describes the key characteristics of each hospital. The median annual paediatric admissions was 767 (range 185-3431),of which 25% (range 3-59%) were neonatal admissions. Reported numbers of paediatric beds predicted actual admissions with large variation, with an average of 34.6 (95% CI 4.4-64.7) admissions per bed annually. Seasonal variation affected admissions substantially, with weekly admissions between May and July being approximately twice the weekly admissions between November and January. Government hospitals were severely impacted by industrial action, with closures of all such facilities for 30% of days (range 54-163 days) between January 2014 and June 2015. Senior clinicians at multiple sites reported incomplete record keeping (especially for newborn admissions) and incomplete and inaccurate case-mix data.

Most hospitals (11/12) had a dedicated neonatal area and the five largest hospitals had dedicated neonatal nursing staff. All hospitals had nursing coverage 24 hours a day, though staffing numbers varied greatly. Only two hospitals had nurses with paediatric training. Two-thirds of hospitals (8/12) had access to a paediatrician; the remainder had access to a Family Medicine

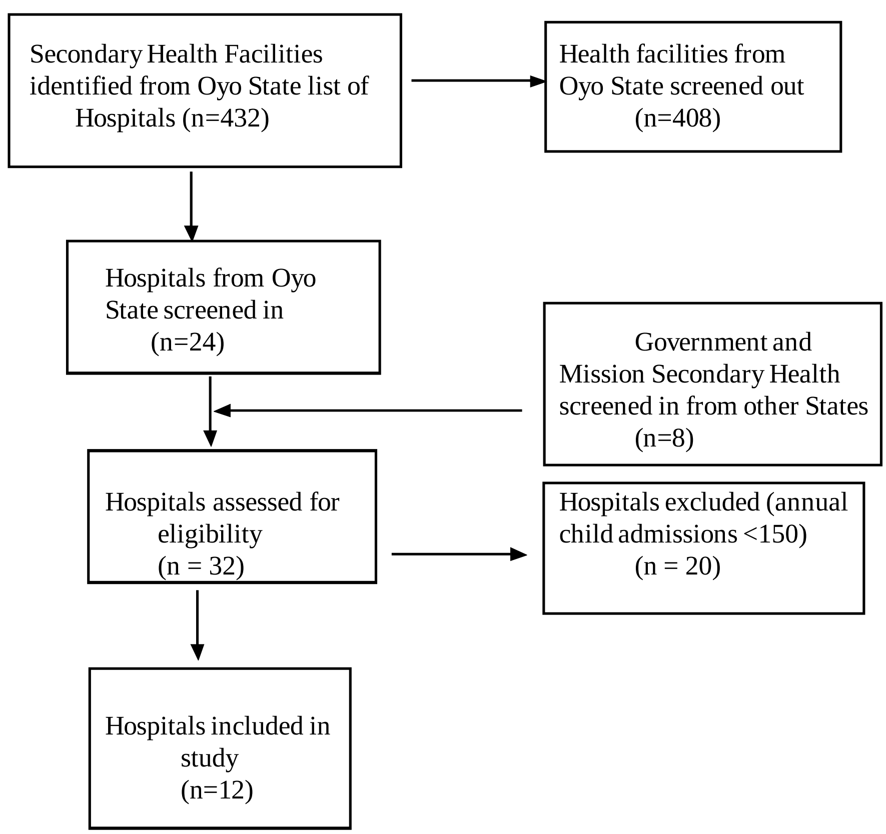


Fig.1: Flow diagram of screening, inclusion and exclusion of hospitals

Table 1: Characteristics of 12 secondary health facilities, estimated oxygen demand, and current oxygen capacity

	1	2	3	4	5	6	7	8	9	10	11	12
Hospital Type	State	Mission	Mission	State	State	State	State	State	Mission	Mission	Mission	State
Beds)	13	32	63	36	46	60	48	36	20	14	70	25
(child + neonatal	(9+4)	(20+12)	(38+25)	(26+10)	(22+24)	(44+16)	(20+28)	(16+20)	(15+5)	(12+2)	(40+30	(21+4)
Admissions (annual)	185	507	2343	238	791	849	3431	1945	431	344	2345	744
Child	180	444	1649	231	552	679	1959	1111	292	325	972	683
Neonate	5	63	693	7	239	170	1473	834	139	19	1373	61
Est. O2Demand (L/day)	437	1199	5545	563	1872	2009	8122	4603	1021	814	5550	1761
Child (Mean L/day)	426	1051	3904	546	1307	1607	4636	2329	691	770	2301	1616
Neonate (Mean L/day)	11	148	1641	17	565	402	3486	1974	330	44	3249	145
3X mean (L/day)	1311	3598	16636	1690	5615	6027	24367	13810	3063	2443	16650	5283
Est. O2 Demand (pts/day)	0.2	0.5	2.5	0.2	0.8	0.8	4.0	2.3	0.5	0.3	3.1	0.7
Child (Mean pts/day)	0.1	0.4	1.4	0.2	0.5	0.6	1.6	0.9	0.2	0.3	0.8	0.6
Neonate (Mean pts/day)	0.0	0.1	1.1	0.0	0.4	0.3	2.4	1.4	0.2	0.0	2.3	0.1
3x mean (Pts/day)	0.5	1.4	7.5	0.6	2.5	2.5	12.1	6.9	1.4	0.9	9.2	2.0
Paediatric Staff												
Access to Paediatrician	No[i]	No[i]	Yes[ii]	No[i]	No	Yes	Yes	Yes	Yes	Yes[ii]	Yes[ii]	Yes
Medical	7	4	6	7	12	17	16	11	5	6	4	2
Nursing (paediatric)	11	7	18	26	31	62	26	33 (3)	9 (2)	4	18	16 (2)
Time on strike (%)	30%	Nil	Nil	30%	30%	30%	10%	10%	Nil	Nil	Nil	21%
Power Supply (hr/day)	6-12	6-12	12-18	6-12	6-12	12-18	12-18	6-12	>18	>18	12-18	6-12
Mains (hr/day)	<6	<6	<6	trivial	<6	<6	<6	trivial	6-12	6-12	trivial	trivial
Generators (hr/day)	~7	~7	~7	~8	~7	~7	~16	~12	~12	<6	~18	~7
Power Interruptions	hourly	hourly	hourly	hourly	hourly	hourly	hourly	hourly	>daily	>daily	hourly	hourly
Oxygen Supply												
Oxygen cylinder	Yes[iv]	Yes[iv]	Yes	Yes[iv]	Yes	Yes	Yes[iii]	Yes	Yes[iv]	Yes[iv]	Yes[iv]	Yes[iv]
Oxygen concentrators	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Reliability	V Poor	Poor	Fair	V Poor	Fair	Poor	Poor	Fair	Fair	Poor	Poor	Poor
Oxygen delivery	Poor	Poor	Fair	Poor	Fair	Fair	Poor	Good	Fair	Poor	Good	Good
Re-use nasal prongs	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes
Pulse oximeters	0	0	0	0	0	3	0	0	1	1	0	0
Maintenance capacity & procedures	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Fair

Clinical guidelines, education & review	Poor	Fair	Poor	Poor	Fair	Poor	Good	Fair	Fair	Poor	Fair	Poor
Care Systems												
Clinical records	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Administrative records	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Poor
Medication & supplies	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Infection control	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Neonatal resuscitation	Poor	Poor	Poor	Poor	Poor	Good	Good	Poor	Poor	Poor	Poor	Poor

Notes: (i) Family Medicine Consultant only; (ii) part-time; (iii) piped system connected to large oxygen cylinder; (iv) not available in paediatric areas. Summary indicators of oxygen supply and care systems include composite measures for oxygen supply reliability (presence of oxygen source, access to resupply, quantity to meet need), oxygen delivery devices (nasal prongs/catheter presence, access to resupply, quantity to meet need), clinical records (quality of case note and admission book documentation), administrative records (quality of medical record summary statistics procedures, documentation, and reporting), medication and supplies (checklist of essential items), infection control (availability and visible use of water and soap in clinical areas, reported infection control procedures), neonatal resuscitation (presence of resuscitation bag, neonatal mask, resuscitation table/cot).

consultant (n=3) or only junior paediatric doctors (n=1). No hospitals had clinical guidelines relating to hypoxaemia, pneumonia or the use of oxygen – and only one hospital had any clinical guidelines at all. Most hospitals (8/12) held regular staff education and half (6/12) held clinical review (e.g. mortality and morbidity) meetings.

Oxygen supply

All hospitals had some access to oxygen cylinders or oxygen concentrators, however provision of oxygen to children was limited by inadequate power supply, inadequate oxygen equipment, and high cost. Challenges in providing oxygen were recognised by many hospital directors, including one director who described oxygen as "my biggest headache".

Of the nine hospitals that used concentrators, one hospital conducted preventive maintenance and four could attempt onsite repairs. One hospital reported recently discarding 12 concentrators which had been donated approximately 2 years before. No hospitals used 'flowmeter assemblies' or 'flow splitters' to share concentrators between multiple children; one hospital shared oxygen using a dual-outlet concentrator; others did not share at all. Oxygen tubing and nasal prong were reported to be readily available at only two hospitals, and while most hospitals (7/12) reused nasal prongs cleaning methods were poorly defined and variable. Three hospitals had pulse oximeters available in paediatric areas; no hospitals tested all patients routinely on admission.

(Table 2), and oxygen was variably charged per hour, per day, or per admission. For a 3-day admission with severe pneumonia, the overall median charge was estimated to be ₦21,925 (US$110), with oxygen accounting for approximately 36% of this. Only one hospital provided oxygen (and other care) free to children (though special State-sponsored arrangements).

Hospital systems

Power supply was frequently interrupted at all hospitals, and diesel generators were the main source of power during the day. Rationing of power was employed universally, and emergency power outside daytime work hours required the use of small petrol generators. The cost of using petrol generators after hours was often passed on to the patient.One hospital had solar power to supply vaccine fridges; another hospital had a solar power array which was not functional due to faulty design (this was confirmed upon inspection by the assessment team's solar engineer).

All hospitals had good supply of essential medications and supplies, mostly provided through user-pay private-public partnerships. All hospitals had basic washing facilities in each ward area. Only two hospitals had neonatal resuscitation equipment readily available in the delivery room. Most hospitals (9/12) had Xray facilities and all hospitals had access to basic laboratory tests (haematocrit, malaria test).

Table 2: Costs of oxygen to facilities and patients

Item	Median cost (range) Naira	Median cost (range) USD
Oxgyen costs to facility		
Refill H-type oxygen cylinder	₦10,000 (7,510-11,000)	$50.25 (37.74-55.28)
Annual cylinder refill cost	₦756,000 (96,850-2,280,000)	$3,799 (484-11,400)
Costs to patient		
3-day admission for pneumonia	₦21,925 (0-60,500)	110.18 (0-304.02)
-Admission/Bed Fee	₦825 (0-7,500)	$$4.12 (0-37.70)
-Medication/Supplies	₦11,400 (0-21,980)	$57.29 (0-110.45)
-Oxygen (2 days)	₦7,800 (0-48,000)	$39.20 (0-241.21)

Note: June 31 2015 exchange rate $1 USD: ₦199 Naira.

Cylinder oxygen was expensive (table 2), costing hospitals between ₦96,000 to 2.2 million (US$484 to 11,400) per year in refill costs alone. Transport costs were not recorded but would have been substantial as most hospitals received supply from BOC in Lagos (approximately a 3 to 6-hour drive each way). Costs to patients were substantial

Estimated oxygen demand

The constant mean-based estimated oxygen demand ranged from 437 to 8,122 Litres per day (median 1,816L/day). This is equivalent to between 0.1 and 4.0 patients being on oxygen every day throughout the year (median 0.7 patients/day). Neonates accounted for 36% of the estimated total demand.

Table 3: Limitations to the provision of safe and effective oxygen therapy to children in 12 Nigerian hospitals

Structural
Lack of pulse oximeters for detection of hypoxaemia and monitoring oxygen therapy·
Lack of access / availability of oxygen sources (e.g. cylinders, concentrators)·
Lack of reliable power source (for concentrators)·
Lack of knowledge about equipment selection and procurement·
Perceived high cost and inadequate financing structures
Technical
Inadequate technical expertise in procurement and installation·
Inappropriate selection of technology for local context (e.g. high humidity, high temperature)·
Lack of trained technicians for medical equipment·
Lack of maintenance protocols and procedures
Clinical
Lack of training on hypoxaemia and oxygen therapy·
Inadequate assessment of patients for hypoxaemia·
Lack of clinical guidelines and aids·
Lack of high-dependency areas·
Low quality neonatal care

Table 4: Comparison of oxygen cylinders and oxygen concentrators*

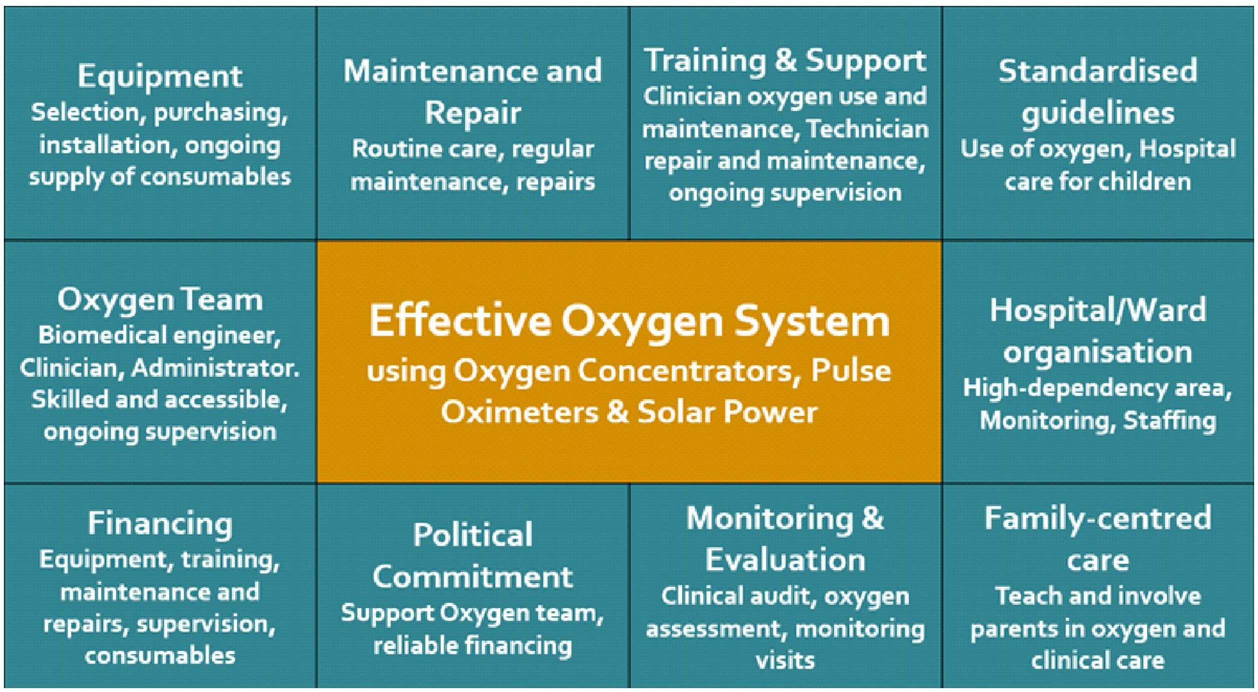
	Oxygen cylinders	Oxygen concentrators
Capital cost	Low (higher if including regulators and flowmeter assemblies)	Moderate
Running cost	High: frequent refilling, transport, and logistics	Low: power, maintenance
Power source	None required	Required, continuously
Reliability	Good, so long as supply lasts	Good, on selected models
Continuous supply	No, limited by volume (Large H-type cylinders last 2-4 days with continuous low-flow use)	Yes, limited by equipment or power failure
Maintenance	Minimal: check regulators, leakage	Essential: simple preventive and intermittent repairs
Training	Yes, clinical use of oxygen, care of cylinders and connections	Yes, clinical use of oxygen, care of concentrators and connections, technical maintenance

** Adapted from [2,11,33]*

Provision of three times this constant mean-based estimate would be expected to provide adequate oxygen to treat >80% of children during the peak season (and >95% of children outside the peak season). This would require a minimum capacity of between 1,311 and 24,367 L/day (median 5,449 L/day), or a capacity to treat between 1 and 13 patients per day (median 2.2 patients/day).

We identified a number of additional considerations that may affect oxygen demand. Frequent strikes in Government hospitals created additional variability in admissions both for Government hospitals (reductions when closed to admissions) and to mission hospitals (to which patients are diverted or attend in preference), and may require additional oxygen capacity. Larger hospitals reportedly attracted more severely unwell patients who have greater oxygen requirements. Smaller hospitals may have less severely unwell patients, but low admission numbers means the relative variability is greater and oxygen needs are more variable and more difficult to estimate. Hospitals that have child and neonatal areas in close proximity may be able to more efficiently share oxygen sources, while hospitals that have multiple separate wards may require extra oxygen sources to reach all sick children. Providing oxygen where it is not currently available may increase the number of admissions (particularly for those hospitals that currently limit admissions due to their lack of capacity to provide oxygen therapy). Oxygen demand outside of the paediatric areas is likely to be high, particularly in larger hospitals with substantial surgical and obstetric capacity, and may result in additional draw on oxygen resources intended for paediatric use.

Pulse oximetry is the standard method for assessing children for hypoxaemia, and can correctly identify 20-30% more children with hypoxaemia than relying solely on clinical signs [16,17]. Relying on clinical signs alone is unreliable, as even the best combinations of clinical signs have unacceptably low sensitivity and specificity and result in both overuse and underuse of oxygen [17,18]. Currently, no hospitals routinely assess children using pulse oximetry, and only 3 hospitals have oximeters in paediatric areas. Establishing routine pulse oximetry practices for admitted children and newborns will be essential to improving oxygen therapy in Nigerian hospitals.



**From manual on use of oxygen therapy in children World Health Organization, 2016 [32]*

Fig. 2: Components of an effective oxygen system using oxygen concentrators, pulse oximeters and solar power*

Discussion

We have conducted the first needs assessment of oxygen for children and newborns in South-West Nigerian hospitals, and have identified opportunities and challenges to improving oxygen systems. Currently, hospitals have access to a variety of oxygen sources including oxygen cylinders and oxygen concentrators, however reliability of supply is generally poor due to limited oxygen availability, limitations in clinical practice, and perceived high cost (table 3).

The provision of safe and effective oxygen therapy to sick children requires (i) prompt and accurate identification of hypoxaemia, (ii) appropriate use of supplemental oxygen, and (iii) appropriate clinical evaluation and management of the underlying condition [16].

Selection of the most appropriate equipment for the provision of oxygen is informed by substantial data from Africa [11,19–26], Asia [24,27,28], and the Pacific [2,3,9]. Selection of the source of oxygen is typically a choice between oxygen cylinders and oxygen concentrators (with larger hospitals also considering oxygen generators) [9,11] (table 4). Oxygen concentrators have become increasingly popular, particularly due to favourable long-term costs, but do require reliable power, appropriate model selection [29], and an effective programme of clinician and engineer training, maintenance, and equipment replacement. Given the variability in estimated oxygen demand between hospitals, and multiple other hospital-specific factors, the selection and configuration of oxygen equipment will vary substantially and require context-specific solutions.

Delivery of oxygen to patients requires additional consumables and equipment (regardless of oxygen source). Oxygen administration to children is most efficiently achieved using nasal prong or nasal catheters [30]. There is consensus on the value of devices to divide oxygen flow from one source to multiple patients, and its particular importance in paediatrics. Older 'flow-splitter' devices have largely been replaced by flow-meter assemblies that allow the individual titration of oxygen to five patients.

Like many clinicians in resource-limited settings[12], Nigerian clinicians report that lack of guidelines and training are major barriers to the use of pulse oximetry and oxygen. Clinical guidelines for the clinical use of oxygen are available (including in the WHO Pocketbook of Hospital Care for Children[31], WHO Manual on Use of Oxygen Therapy in Children [32], and Oxygen therapy for acute respiratory infections in young children in developing countries [33], but were not used at any of the Nigerian hospitals studied. Guideline-based clinical training and supervision will be important to improve oxygen therapy in Nigerian hospitals.

The cost of oxygen to both hospitals and patients is high, and this is likely to influence clinical practice and patient adherence even more than is currently recognised. The median cost of a 3-day admission for pneumonia (₦21,925) exceeds the monthly minimum wage (₦18,000), making it inaccessible for the majority of the population living in poverty. Improving this will require both more cost-effective oxygen systems and fairer methods for recouping costs from patients.

Effective and sustainable oxygen solutions are likely to be most successful when implemented as part of broader quality improvement activities[10]. These include the development of an 'expert' local oxygen team, promotion of clinical quality improvement activities, and attention to financing and organisation/political structures. While oxygen solutions are necessarily context-specific, figure 2 highlights key areas for consideration.

This study has a number of limitations. While hospitals were selected to be representative of major non-tertiary hospitals in south-west Nigeria, generalisation of results beyond this may be limited. Admission and case-mix data were limited by low quality medical records systems (particularly regarding the registration of sick neonates) and data on hypoxaemia prevalence was unavailable. While this limits our ability to make accurate oxygen need estimates we offer a pragmatic approach to oxygen needs assessment that may be useful to others who face similar challenges. This was a cross-sectional study and represents hospitals at a particular point in time. We recognise that service capacity and qualities varies over time and are influenced by many factors, and we have endeavoured to represent the participating hospitals accurately.

Conclusions

Oxygen is an essential medicine that is not available to many sick children and neonates in Nigerian hospitals. Addressing this will require improving detection of hypoxaemia through routine use of pulse oximetry, improving access to oxygen through equipment, training, and maintenance structures, and commitment to building hospital and state structures that can sustain and expand oxygen initiatives.

Acknowledgements

This project is funded by the Bill and Melinda Gates Foundation through Murdoch Children's Research Institute and the Department of Paediatrics, University College Hospital, Ibadan. We acknowledge the valuable involvement of directors and staff at all participating hospitals, including their attendance at a major stakeholders meeting and cooperation during site visits.

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Appendix

Health Facility Data Collection Form

Please complete all questions. Write additional information in the blank space if required.

1. **State / Province:**

2. **Health Facility Name:**
   a. Key contact person
   b. Other contacts

3. **Number of beds**
   a. for children:
   b. for newborns:

4. **Staff**
   a. Doctors
      i. Permanent
      ii. House officers
      iii. Corps members
   b. Nurses >> Nurses with paediatric training?
   c. Public Health Nurses
   d. Midwives
   e. Community Health Workers
      i. Community Health Officers
      ii. Community Health Extension Workers
      iii. Health Assistants
   f. Day / Night staffing
      (*e.g. 24 hour, 3 shifts*)

5. Catchment Area & Referrals

a. What catchment area does this hospital serve?

b. What is the estimated catchment population?

c. Which other hospitals refer patients to this hospital? (Referral FROM)

d. Which hospital are patients from this hospital sent? (Referral TO)

e. Is transport available for referral of sick children to other facilities? Yes / No

>> If yes, describe (e.g. private car, taxi etc.)

6. Power Supply

a. What sources of power are available? (*Tick all that apply - describe*)

☐ Mains power connection -
☐ Generator -
☐ Solar / Photovoltaic -
☐ Other (*specify*) -

b. How many hours per day is power available, on average (any source)? (*circle*)

<6 hours	6-12 hours	12-18 hours	>18 hours

c. How often is power interrupted?

Monthly	Weekly	Daily	Hourly

7. Oxygen Equipment

a. Oxygen Concentrators:

i. Working and Present [ ] >> if available: - meter reading? [ ]

ii. Not Working / Broken [ ] - last service? [ ]

b. Oxygen Cylinders:

i. Working and Present [ ] >> if available: - cost per cylinder? [ ]

ii. Not Working / Broken [ ] >> comments (e.g. size, supplier, patient cost) [ ]

c. Pulse Oximeters:

i. Working and Present [ ]

ii. Not Working / Broken [ ]

d. Pulse Oximeters Sensors:

i. Working and Present [ ]

ii. Not Working / Broken [ ]

e. Are Oxygen supplies available? (e.g. nasal prongs/catheter, tubing etc.) Yes / No

8. Health Facility Characteristics

a. Is there a vaccine refrigerat Yes / No

b. What security system is present? (Tick all that apply)

☐ Security guard
☐ Locked external door
☐ Other (*specify*) –

9. Record Keeping

a. How are admissions, diagnoses, and deaths recorded? (Tick all that apply / describe)

☐ Computer program -
☐ Admission Book -
☐ Individual patient file -
☐ Other (*specify*) –

10. Education and Quality of Care

a. Do you have any regular educational sessior Yes / No

i. If Yes, describe

b. Do you have regular audit/M&M/clinical review meeting Yes / No

ii. If Yes, describe

c. Do you use a standard treatment guidelines/protocol Yes / No
(e.g. WHO Pocketbook of Hospital Care for Children; Nigerian Standard Treatment Guidelines)

If yes:

iii. Which guideline (and what edition)?

iv. Is the guideline present on the ward? Yes / No

v. Are wall charts relating to the guideline present? Yes / No

11. Equipment & Supplies

a. Which of the following medications and supplies ***available, working*** and ***not expired*** for use in this hospital? (*If possible, check supply. Comment in box below, e.g. if externally sourced*)

	Medication		**Infection control**
Yes / No	Amoxycillin oral	Yes / No	Hand-washing facility
Yes / No	Penicillin inj	Yes / No	Soap
Yes / No	Gentamicin inj	Yes / No	Safe sharps disposal
Yes / No	Ceftriaxone inj	Yes / No	Waste disposal
Yes / No	Measles vaccine	Yes / No	Chlorhexidine/Iodine solution
Yes / No	Pentavalent vaccine	Yes / No	Cord clamp & Gentian violet
Yes / No	BCG vaccine	Yes / No	Alcohol swabs
Yes / No	Hep B vaccine	Yes / No	Sterile gloves
Yes / No	Sterile water for injection		
Yes / No	IV fluids (5%/10% dextrose, saline)		
Yes / No	Alcohol swabs		
	Equipment		**Lab & Imaging**
Yes / No	Scales (newborn and child)	Yes / No	X-ray facility
Yes / No	Thermometers	Yes / No	Haemoglobin (Hb)
Yes / No	Resuscitation equipment for newborn	Yes / No	Blood group & Cross-match
Yes / No	Blood sugar / dextrostix	Yes / No	Urinalysis
Yes / No	Syringes, needles, cannulas	Yes / No	CSF microscopy
		Yes / No	Malaria smear / rapid test
		Yes / No	Sputum smear microscopy for TB

Comments

12. Clinical Data

a. 2014

i.		Total Paediatric Admissions
ii.		Paediatric Deaths
iii.		Pneumonia Admissions
iv.		Pneumonia Deaths
v.		Births
vi.		Neonatal Deaths
vii.		Number of referrals to other facilities

b. 2013

viii.		Total Paediatric Admissions
ix.		Paediatric Deaths
x.		Pneumonia Admissions
xi.		Pneumonia Deaths
xii.		Births
xiii.		Neonatal Deaths
xiv.		Number of referrals to other facilities

c. 2012

xv.		Total Paediatric Admissions
xvi.		Paediatric Deaths
xvii.		Pneumonia Admissions
xviii.		Pneumonia Deaths
xix.		Births
xx.		Neonatal Deaths
xxi.		Number of referrals to other facilities

i.

13. Further Details

a. Number of doctors that cover the entire hospital during call

b. Number of nurses per shift

c. Number of doctors working in paediatrics unit (children and neaonate)

d. Number of nurses working in Paediatrics unit (children and neonates)

e. How many oxygen concentrators do you have in the paediatric unit and the entire hospital?

f. How many pulse oximeters do you have in paediatric unit and the entire hospital?

g. If you use generators, the power equivalent of each generator—its KVA— and the hours of usage, for example, 250KVA , 10am-2pm; 120 KVA, 7pm-10pm

h. The monthly consumption of fuel for generators, for example, average of 2000L of diesel at N5/L

I. The role of technicians/engineers in the hospital. Do they repair medical equipment, do they do routine maintenance check or repair on damage? Do you have private engineers/technicians to repair your medical equipment.

j. On average, your yearly consumption of oxygen—the total number of oxygen cylinder being used in a year and the cost implication. For example, 105 small cylinders, and 60 big cylinder. The hospital spends on average N1.2m every year provide oxygen for patient care.

k. How much is patient charged for oxygen, N1000/hr, N3,500/day or N2500 irrespective of duration

l. What is the cost of admission?

m

m. What is the cost of 5 day course of common antibiotic (Ampicillin, Penicillin, and Gentamycin?)

n. What is the total cost to the family for 5 year old admitted to your hospital on account of pneumonia (admission fee, medication, consumables. Laboratory)

Oxygen for children and newborns in non-tertiary hospitals in South-west Nigeria: A needs assessment

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Abstract

Background: Oxygen is important for the treatment of hypoxaemia associated with pneumonia, malaria, and other medical, obstetric, and surgical conditions. Access to oxygen therapy is limited in many of the high mortality settings where it would be of most benefit.

Methods: A needs assessment of 12 non-tertiary hospitals in south-west Nigeria, assessing structural, technical and clinical barriers to the provision of safe and effective oxygen therapy.

Results: Oxygen supply was reported to be a major challenge by hospital directors. All hospitals had some access to oxygen cylinders, which were expensive and frequently ran out. Nine (75%) hospitals used oxygen concentrators, which were limited by inadequate power supply and lack of maintenance capacity. Appropriate oxygen delivery and monitoring devices (nasal prongs, catheters, pulse oximeters) were poorly available, and no hospitals had clinical guidelines pertaining to the use of oxygen for children. Oxygen was expensive to patients (median US$20/day) and to hospitals. Estimated oxygen demand is reported using both a constant mean-based estimate and adjustment for seasonal and other variability.

Conclusions: Making oxygen available to sick children and neonates in Nigerian hospitals will require: improving detection of hypoxaemia through routine use of pulse oximetry; improving access to oxygen through equipment, training, and maintenance structures; and commitment to building hospital and state structures that can sustain and expand oxygen initiatives.

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Keywords: *Oxygen, needs, assessment, children, non- tertiary hospital*

Résumé

Contexte: L'oxygène est important pour le traitement de l'hypoxémie associée à la pneumonie, paludisme et autresconditions médicaux, obstétriques et chirurgicales. L'accès à la thérapie d'oxygène est limité dans la plupart des lieux avec tauxde mortalitéélevés où il serait le plus bénéfique.

Méthodes: Une évaluation des besoins de 12 hôpitaux non tertiaires dans le sud-ouest du Nigeria, évaluant les obstacles structurels, techniques et cliniques à la mise à disposition d'un traitement sûr et efficace de la thérapie d'oxygène.

Résultats: L'approvisionnement en oxygène a été signalé comme étant un défi majeur par les directeurs d'hôpitaux. Tous les hôpitaux avaient un accès à des bouteilles d'oxygène, qui étaient coûteux et fréquemment manquaient en oxygène. Neuf (75%) des hôpitaux utilisaient des concentrateurs d'oxygène, qui ont été limités par l'alimentation inadéquate d'électricité et le manque de capacité d'entretien. Les dispositifs appropriés de livraison et de surveillance d'oxygène (sondes nasales, cathéters, oxymètres de pouls) étaient difficilement accessibles, et pas d'hôpitaux avaient des directives cliniques relatives à l'utilisation d'oxygène pour les enfants. L'oxygène était cher aux patients (médian 20 US $/jour) et aux hôpitaux. L'estimée demanded'oxygène est signalé à la foisà l'aided'une moyenne de base constanted'estimation et ajustement saisonnière et autres variabilités.

Conclusions: Mettrel'oxygène disponible pour les enfants et nouveau-nésmalades dans les hôpitaux nigérians nécessitera à: améliorer la détection de l'hypoxémie par l'utilisation systématique de l'oxymétrie de pouls; améliorer l'accès à l'oxygène à travers l'équipement, la formation et les structures de maintenance; et l'engagement à la construction des structuresd'hôpital etd'état qui peuvent soutenir et étendre les initiatives d'oxygène.

Mots-clés: *Oxygène, besoins, évaluation, enfants, hôpital non tertiaire*

Introduction

Oxygen is an essential medicine that has been saving lives for over 100 years [1]. It is important for the treatment of hypoxaemia associated with pneumonia and other lung diseases, sepsis, malaria, neonatal conditions and other severe illnesses, and is widely used in obstetric, surgical, and anaesthetic care. However, oxygen availability is poor in the low-resource settings that bear the greatest burden of morbidity and mortality globally [1].

Previous studies have shown that relatively inexpensive improvements in oxygen systems can reduce pneumonia case fatality rates among children by up to 35% [2,3]. However, such systems require context-specific planning, technical expertise, and sustained attention to training and supervision [2].

In Nigeria, the leading causes of child mortality are malaria (21%), acute respiratory infections (15%), and neonatal causes (at least 27%; comprising prematurity 12%, birth asphyxia 10%, and sepsis 5%) [4], which together account for three-quarters of admissions to a tertiary hospital [5]. Hypoxaemia is common in these conditions, affecting up to half of children with acute respiratory infection, 30% with malaria, and 41% with neonatal conditions – and is a strong predictor for mortality [5,6].

Despite the inclusion of oxygen on the Nigerian Essential Medicines List [7] and growing demand for oxygen solutions in many hospitals, little is known about the oxygen needs or capacities in non-tertiary hospitals in Nigeria.

This study evaluates the current capacity of non-tertiary hospitals in south-west Nigeria to safely and effectively provide oxygen to sick children and newborns, estimates oxygen needs, and describes potential options to improve oxygen supply (Study ID: BMGF OPP1123577).

Materials and methods

We conducted a cross-sectional evaluation of hospitals using a health needs assessment framework [8] to identify and describe capacity and issues in providing oxygen to children and newborns in hospitals. This study was done in preparation for a multi-centre field trial evaluating the introduction of a comprehensive oxygen system (including pulse oximeters, oxygen concentrators, and solar power).

We assessed all health facilities in Oyo state for inclusion according to the following criteria: they had to be either government or mission run secondary health facilities, and admit at least 150 children per year. After we could not identify a sufficient number of hospitals in Oyo state alone, we selected additional hospitals in 3 other states (Ondo, Ogun, Osun) using the same criteria. This therefore provided a representative sample of major secondary health facilities in south-west Nigeria.

We developed a Facility Assessment Form (see Appendix), based on WHO facility assessment tools used in oxygen assessments in Papua New Guinea [2,9,10] and the Gambia [11]. Our assessment covered a broad range of structural, technical and clinical barriers to the provision of safe and effective oxygen therapy we had identified from the literature [2,10,12]. These included issues relating to power supply, financing, human resources (technical and clinical), maintenance structures, medical education and clinical guidelines, essential medical and laboratory supplies, and types of oxygen equipment (including oxygen concentrators, oxygen cylinders, and pulse oximeters).

We used semi-structured interviews with key individuals at each hospital and detailed field visits by clinicians and technicians to obtain data. Key individuals interviewed included hospital directors, chief paediatric medical officers, chief nursing officers, medical records officers, maintenance technicians, laboratory technicians, and other administrative officers.On completion of the facility visit and interviews, the complete data for each hospital were collated and returned to the Medical Director for correction and confirmation of accuracy. Follow up visits and phone calls were made when necessary.

Admission and case-mix data were obtained for the period 1 January 2014 to 30 June 2015. This was obtained from the admission books on each ward by a trained nurse data collector then cross-checked against records in the hospital medical records department to ensure complete capture.

We calculated daily mean oxygen requirements using local hospital admission data and estimated hypoxaemia prevalence (20% neonates, 10% children), mean oxygen duration (3 days) and flow rates (1L/min neonate, 2L/min child) using extrapolated local [5,13] and international [14] data. Case mix assumptions were: 30% malaria, 20% ALRI, 25% neonatal and 10% sepsis [5, 13].

Actual oxygen demand is influenced by seasonal variability (higher in peak season),day-to-day variability in admissions and case-mix (higher with particular conditions and severity of illness), and variability in inter-patient oxygen requirement (including both flow-rate and duration of treatment)[15]. This temporal variability in oxygen demand is expected to be higher in small hospitals than in larger hospitals [15].Using previous mathematical modelling we estimated that providing capacity for 3 times the mean oxygen demand would cover actual oxygen demand approximately 80% of the time during the peak season (and >95% outside the peak season) [15].

Tabulation and graphing of results were done using Excel (Microsoft), and statistical analysis performed using Stata version 15 (Statacorp).

Results

We conducted identification and screening of hospitals in cooperation with the State Hospital Management Board (Figure 1). The Oyo State Hospital Management Board provided a list of 432 government, private, and mission secondary health facilities, of which 24 active hospitals were screened in initially. We identified an additional 8 government and mission hospitals from Ogun, Osun and Ondo states giving a total of 32 hospitals for determination of eligibility. Twelve hospitals met the inclusion criteria and were included in our study, providing representation of medium-sized hospitals that admit children in South-West Nigeria. A multidisciplinary team of paediatricians and engineers/technicians visited all the included hospitals to conduct facility assessments between May and June 2015.

Admission and case-mix data

Table 1 describes the key characteristics of each hospital. The median annual paediatric admissions was 767 (range 185-3431),of which 25% (range 3-59%) were neonatal admissions. Reported numbers of paediatric beds predicted actual admissions with large variation, with an average of 34.6 (95% CI 4.4-64.7) admissions per bed annually. Seasonal variation affected admissions substantially, with weekly admissions between May and July being approximately twice the weekly admissions between November and January. Government hospitals were severely impacted by industrial action, with closures of all such facilities for 30% of days (range 54-163 days) between January 2014 and June 2015. Senior clinicians at multiple sites reported incomplete record keeping (especially for newborn admissions) and incomplete and inaccurate case-mix data.

Most hospitals (11/12) had a dedicated neonatal area and the five largest hospitals had dedicated neonatal nursing staff. All hospitals had nursing coverage 24 hours a day, though staffing numbers varied greatly. Only two hospitals had nurses with paediatric training. Two-thirds of hospitals (8/12) had access to a paediatrician; the remainder had access to a Family Medicine

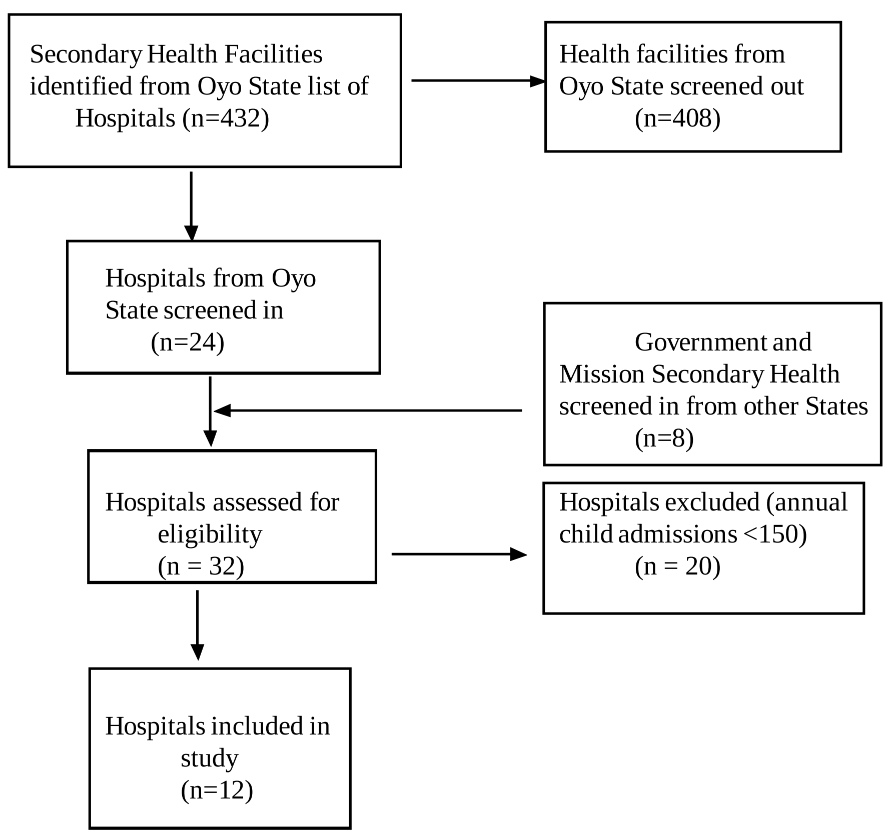


Fig.1: Flow diagram of screening, inclusion and exclusion of hospitals

Table 1: Characteristics of 12 secondary health facilities, estimated oxygen demand, and current oxygen capacity

	1	2	3	4	5	6	7	8	9	10	11	12
Hospital Type	State	Mission	Mission	State	State	State	State	State	Mission	Mission	Mission	State
Beds)	13	32	63	36	46	60	48	36	20	14	70	25
(child + neonatal	(9+4)	(20+12)	(38+25)	(26+10)	(22+24)	(44+16)	(20+28)	(16+20)	(15+5)	(12+2)	(40+30	(21+4)
Admissions (annual)	185	507	2343	238	791	849	3431	1945	431	344	2345	744
Child	180	444	1649	231	552	679	1959	1111	292	325	972	683
Neonate	5	63	693	7	239	170	1473	834	139	19	1373	61
Est. O2Demand (L/day)	437	1199	5545	563	1872	2009	8122	4603	1021	814	5550	1761
Child (Mean L/day)	426	1051	3904	546	1307	1607	4636	2329	691	770	2301	1616
Neonate (Mean L/day)	11	148	1641	17	565	402	3486	1974	330	44	3249	145
3X mean (L/day)	1311	3598	16636	1690	5615	6027	24367	13810	3063	2443	16650	5283
Est. O2 Demand (pts/day)	0.2	0.5	2.5	0.2	0.8	0.8	4.0	2.3	0.5	0.3	3.1	0.7
Child (Mean pts/day)	0.1	0.4	1.4	0.2	0.5	0.6	1.6	0.9	0.2	0.3	0.8	0.6
Neonate (Mean pts/day)	0.0	0.1	1.1	0.0	0.4	0.3	2.4	1.4	0.2	0.0	2.3	0.1
3x mean (Pts/day)	0.5	1.4	7.5	0.6	2.5	2.5	12.1	6.9	1.4	0.9	9.2	2.0
Paediatric Staff												
Access to Paediatrician	No[i]	No[i]	Yes[ii]	No[i]	No	Yes	Yes	Yes	Yes	Yes[ii]	Yes[ii]	Yes
Medical	7	4	6	7	12	17	16	11	5	6	4	2
Nursing (paediatric)	11	7	18	26	31	62	26	33 (3)	9 (2)	4	18	16 (2)
Time on strike (%)	30%	Nil	Nil	30%	30%	30%	10%	10%	Nil	Nil	Nil	21%
Power Supply (hr/day)	6-12	6-12	12-18	6-12	6-12	12-18	12-18	6-12	>18	>18	12-18	6-12
Mains (hr/day)	<6	<6	<6	trivial	<6	<6	<6	trivial	6-12	6-12	trivial	trivial
Generators (hr/day)	~7	~7	~7	~8	~7	~7	~16	~12	~12	<6	~18	~7
Power Interruptions	hourly	hourly	hourly	hourly	hourly	hourly	hourly	hourly	>daily	>daily	hourly	hourly
Oxygen Supply												
Oxygen cylinder	Yes[iv]	Yes[iv]	Yes	Yes[iv]	Yes	Yes	Yes[iii]	Yes	Yes[iv]	Yes[iv]	Yes[iv]	Yes[iv]
Oxygen concentrators	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Reliability	V Poor	Poor	Fair	V Poor	Fair	Poor	Poor	Fair	Fair	Poor	Poor	Poor
Oxygen delivery	Poor	Poor	Fair	Poor	Fair	Fair	Poor	Good	Fair	Poor	Good	Good
Re-use nasal prongs	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes
Pulse oximeters	0	0	0	0	0	3	0	0	1	1	0	0
Maintenance capacity & procedures	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Fair

Clinical guidelines, education & review	Poor	Fair	Poor	Poor	Fair	Poor	Good	Fair	Fair	Poor	Fair	Poor
Care Systems												
Clinical records	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Administrative records	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Fair	Poor
Medication & supplies	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Infection control	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Neonatal resuscitation	Poor	Poor	Poor	Poor	Poor	Good	Good	Poor	Poor	Poor	Poor	Poor

Notes: (i) Family Medicine Consultant only; (ii) part-time; (iii) piped system connected to large oxygen cylinder; (iv) not available in paediatric areas. Summary indicators of oxygen supply and care systems include composite measures for oxygen supply reliability (presence of oxygen source, access to resupply, quantity to meet need), oxygen delivery devices (nasal prongs/catheter presence, access to resupply, quantity to meet need), clinical records (quality of case note and admission book documentation), administrative records (quality of medical record summary statistics procedures, documentation, and reporting), medication and supplies (checklist of essential items), infection control (availability and visible use of water and soap in clinical areas, reported infection control procedures), neonatal resuscitation (presence of resuscitation bag, neonatal mask, resuscitation table/cot).

consultant (n=3) or only junior paediatric doctors (n=1). No hospitals had clinical guidelines relating to hypoxaemia, pneumonia or the use of oxygen – and only one hospital had any clinical guidelines at all. Most hospitals (8/12) held regular staff education and half (6/12) held clinical review (e.g. mortality and morbidity) meetings.

Oxygen supply

All hospitals had some access to oxygen cylinders or oxygen concentrators, however provision of oxygen to children was limited by inadequate power supply, inadequate oxygen equipment, and high cost. Challenges in providing oxygen were recognised by many hospital directors, including one director who described oxygen as "my biggest headache".

Of the nine hospitals that used concentrators, one hospital conducted preventive maintenance and four could attempt onsite repairs. One hospital reported recently discarding 12 concentrators which had been donated approximately 2 years before. No hospitals used 'flowmeter assemblies' or 'flow splitters' to share concentrators between multiple children; one hospital shared oxygen using a dual-outlet concentrator; others did not share at all. Oxygen tubing and nasal prong were reported to be readily available at only two hospitals, and while most hospitals (7/12) reused nasal prongs cleaning methods were poorly defined and variable. Three hospitals had pulse oximeters available in paediatric areas; no hospitals tested all patients routinely on admission.

(Table 2), and oxygen was variably charged per hour, per day, or per admission. For a 3-day admission with severe pneumonia, the overall median charge was estimated to be ₦21,925 (US$110), with oxygen accounting for approximately 36% of this. Only one hospital provided oxygen (and other care) free to children (though special State-sponsored arrangements).

Hospital systems

Power supply was frequently interrupted at all hospitals, and diesel generators were the main source of power during the day. Rationing of power was employed universally, and emergency power outside daytime work hours required the use of small petrol generators. The cost of using petrol generators after hours was often passed on to the patient.One hospital had solar power to supply vaccine fridges; another hospital had a solar power array which was not functional due to faulty design (this was confirmed upon inspection by the assessment team's solar engineer).

All hospitals had good supply of essential medications and supplies, mostly provided through user-pay private-public partnerships. All hospitals had basic washing facilities in each ward area. Only two hospitals had neonatal resuscitation equipment readily available in the delivery room. Most hospitals (9/12) had Xray facilities and all hospitals had access to basic laboratory tests (haematocrit, malaria test).

Table 2: Costs of oxygen to facilities and patients

Item	Median cost (range) Naira	Median cost (range) USD
Oxgyen costs to facility		
Refill H-type oxygen cylinder	₦10,000 (7,510-11,000)	$50.25 (37.74-55.28)
Annual cylinder refill cost	₦756,000 (96,850-2,280,000)	$3,799 (484-11,400)
Costs to patient		
3-day admission for pneumonia	₦21,925 (0-60,500)	110.18 (0-304.02)
-Admission/Bed Fee	₦825 (0-7,500)	$$4.12 (0-37.70)
-Medication/Supplies	₦11,400 (0-21,980)	$57.29 (0-110.45)
-Oxygen (2 days)	₦7,800 (0-48,000)	$39.20 (0-241.21)

Note: June 31 2015 exchange rate $1 USD: ₦199 Naira.

Cylinder oxygen was expensive (table 2), costing hospitals between ₦96,000 to 2.2 million (US$484 to 11,400) per year in refill costs alone. Transport costs were not recorded but would have been substantial as most hospitals received supply from BOC in Lagos (approximately a 3 to 6-hour drive each way). Costs to patients were substantial

Estimated oxygen demand

The constant mean-based estimated oxygen demand ranged from 437 to 8,122 Litres per day (median 1,816L/day). This is equivalent to between 0.1 and 4.0 patients being on oxygen every day throughout the year (median 0.7 patients/day). Neonates accounted for 36% of the estimated total demand.

Table 3: Limitations to the provision of safe and effective oxygen therapy to children in 12 Nigerian hospitals

Structural
Lack of pulse oximeters for detection of hypoxaemia and monitoring oxygen therapy·
Lack of access / availability of oxygen sources (e.g. cylinders, concentrators)·
Lack of reliable power source (for concentrators)·
Lack of knowledge about equipment selection and procurement·
Perceived high cost and inadequate financing structures
Technical
Inadequate technical expertise in procurement and installation·
Inappropriate selection of technology for local context (e.g. high humidity, high temperature)·
Lack of trained technicians for medical equipment·
Lack of maintenance protocols and procedures
Clinical
Lack of training on hypoxaemia and oxygen therapy·
Inadequate assessment of patients for hypoxaemia·
Lack of clinical guidelines and aids·
Lack of high-dependency areas·
Low quality neonatal care

Table 4: Comparison of oxygen cylinders and oxygen concentrators*

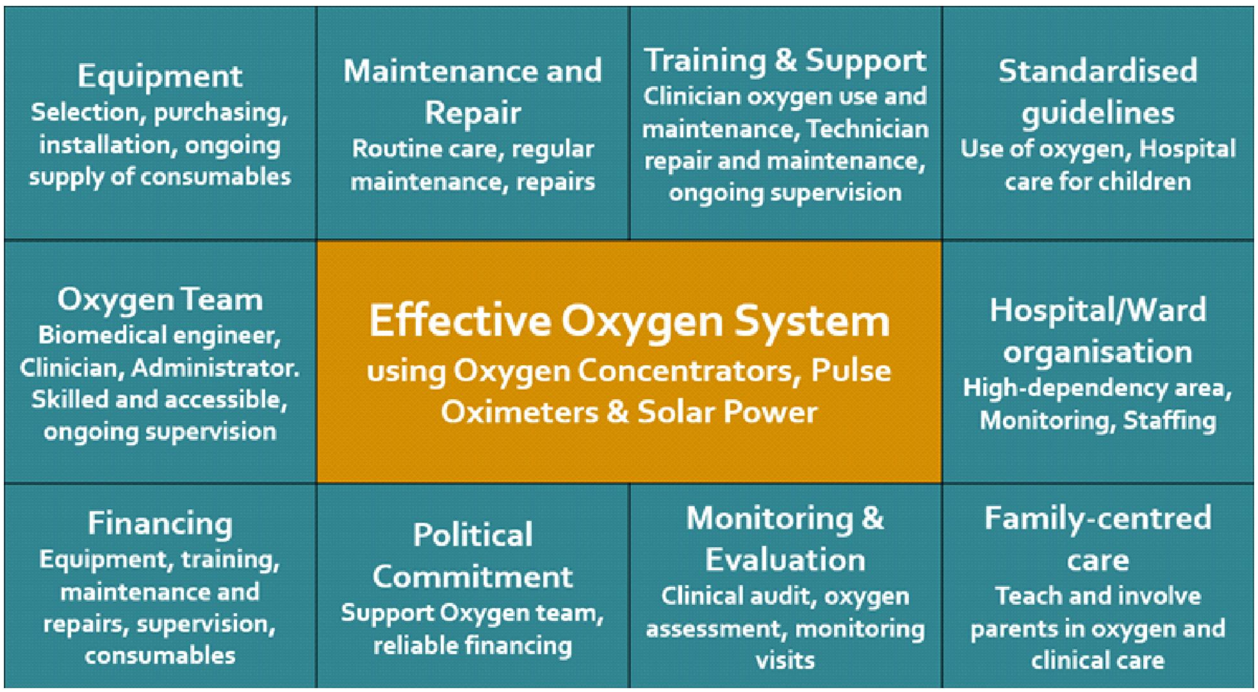
	Oxygen cylinders	Oxygen concentrators
Capital cost	Low (higher if including regulators and flowmeter assemblies)	Moderate
Running cost	High: frequent refilling, transport, and logistics	Low: power, maintenance
Power source	None required	Required, continuously
Reliability	Good, so long as supply lasts	Good, on selected models
Continuous supply	No, limited by volume (Large H-type cylinders last 2-4 days with continuous low-flow use)	Yes, limited by equipment or power failure
Maintenance	Minimal: check regulators, leakage	Essential: simple preventive and intermittent repairs
Training	Yes, clinical use of oxygen, care of cylinders and connections	Yes, clinical use of oxygen, care of concentrators and connections, technical maintenance

** Adapted from [2,11,33]*

Provision of three times this constant mean-based estimate would be expected to provide adequate oxygen to treat >80% of children during the peak season (and >95% of children outside the peak season). This would require a minimum capacity of between 1,311 and 24,367 L/day (median 5,449 L/day), or a capacity to treat between 1 and 13 patients per day (median 2.2 patients/day).

We identified a number of additional considerations that may affect oxygen demand. Frequent strikes in Government hospitals created additional variability in admissions both for Government hospitals (reductions when closed to admissions) and to mission hospitals (to which patients are diverted or attend in preference), and may require additional oxygen capacity. Larger hospitals reportedly attracted more severely unwell patients who have greater oxygen requirements. Smaller hospitals may have less severely unwell patients, but low admission numbers means the relative variability is greater and oxygen needs are more variable and more difficult to estimate. Hospitals that have child and neonatal areas in close proximity may be able to more efficiently share oxygen sources, while hospitals that have multiple separate wards may require extra oxygen sources to reach all sick children. Providing oxygen where it is not currently available may increase the number of admissions (particularly for those hospitals that currently limit admissions due to their lack of capacity to provide oxygen therapy). Oxygen demand outside of the paediatric areas is likely to be high, particularly in larger hospitals with substantial surgical and obstetric capacity, and may result in additional draw on oxygen resources intended for paediatric use.

Pulse oximetry is the standard method for assessing children for hypoxaemia, and can correctly identify 20-30% more children with hypoxaemia than relying solely on clinical signs [16,17]. Relying on clinical signs alone is unreliable, as even the best combinations of clinical signs have unacceptably low sensitivity and specificity and result in both overuse and underuse of oxygen [17,18]. Currently, no hospitals routinely assess children using pulse oximetry, and only 3 hospitals have oximeters in paediatric areas. Establishing routine pulse oximetry



**From manual on use of oxygen therapy in children World Health Organization, 2016 [32]*

Fig. 2: Components of an effective oxygen system using oxygen concentrators, pulse oximeters and solar power*

Discussion

We have conducted the first needs assessment of oxygen for children and newborns in South-West Nigerian hospitals, and have identified opportunities and challenges to improving oxygen systems. Currently, hospitals have access to a variety of oxygen sources including oxygen cylinders and oxygen concentrators, however reliability of supply is generally poor due to limited oxygen availability, limitations in clinical practice, and perceived high cost (table 3).

The provision of safe and effective oxygen therapy to sick children requires (i) prompt and accurate identification of hypoxaemia, (ii) appropriate use of supplemental oxygen, and (iii) appropriate clinical evaluation and management of the underlying condition [16].

practices for admitted children and newborns will be essential to improving oxygen therapy in Nigerian hospitals.

Selection of the most appropriate equipment for the provision of oxygen is informed by substantial data from Africa [11,19–26], Asia [24,27,28], and the Pacific [2,3,9]. Selection of the source of oxygen is typically a choice between oxygen cylinders and oxygen concentrators (with larger hospitals also considering oxygen generators) [9,11] (table 4). Oxygen concentrators have become increasingly popular, particularly due to favourable long-term costs, but do require reliable power, appropriate model selection [29], and an effective programme of clinician and engineer training, maintenance, and equipment replacement. Given the variability in estimated oxygen demand between hospitals, and multiple other hospital-specific factors, the selection and configuration of oxygen equipment will vary substantially and require context-specific solutions.

Delivery of oxygen to patients requires additional consumables and equipment (regardless of oxygen source). Oxygen administration to children is most efficiently achieved using nasal prong or nasal catheters [30]. There is consensus on the value of devices to divide oxygen flow from one source to multiple patients, and its particular importance in paediatrics. Older 'flow-splitter' devices have largely been replaced by flow-meter assemblies that allow the individual titration of oxygen to five patients.

Like many clinicians in resource-limited settings[12], Nigerian clinicians report that lack of guidelines and training are major barriers to the use of pulse oximetry and oxygen. Clinical guidelines for the clinical use of oxygen are available (including in the WHO Pocketbook of Hospital Care for Children[31], WHO Manual on Use of Oxygen Therapy in Children [32], and Oxygen therapy for acute respiratory infections in young children in developing countries [33], but were not used at any of the Nigerian hospitals studied. Guideline-based clinical training and supervision will be important to improve oxygen therapy in Nigerian hospitals.

The cost of oxygen to both hospitals and patients is high, and this is likely to influence clinical practice and patient adherence even more than is currently recognised. The median cost of a 3-day admission for pneumonia (₦21,925) exceeds the monthly minimum wage (₦18,000), making it inaccessible for the majority of the population living in poverty. Improving this will require both more cost-effective oxygen systems and fairer methods for recouping costs from patients.

Effective and sustainable oxygen solutions are likely to be most successful when implemented as part of broader quality improvement activities[10]. These include the development of an 'expert' local oxygen team, promotion of clinical quality improvement activities, and attention to financing and organisation/political structures. While oxygen solutions are necessarily context-specific, figure 2 highlights key areas for consideration.

This study has a number of limitations. While hospitals were selected to be representative of major non-tertiary hospitals in south-west Nigeria, generalisation of results beyond this may be limited. Admission and case-mix data were limited by low quality medical records systems (particularly regarding the registration of sick neonates) and data on hypoxaemia prevalence was unavailable. While this limits our ability to make accurate oxygen need estimates we offer a pragmatic approach to oxygen needs assessment that may be useful to others who face similar challenges. This was a cross-sectional study and represents hospitals at a particular point in time. We recognise that service capacity and qualities varies over time and are influenced by many factors, and we have endeavoured to represent the participating hospitals accurately.

Conclusions

Oxygen is an essential medicine that is not available to many sick children and neonates in Nigerian hospitals. Addressing this will require improving detection of hypoxaemia through routine use of pulse oximetry, improving access to oxygen through equipment, training, and maintenance structures, and commitment to building hospital and state structures that can sustain and expand oxygen initiatives.

Acknowledgements

This project is funded by the Bill and Melinda Gates Foundation through Murdoch Children's Research Institute and the Department of Paediatrics, University College Hospital, Ibadan. We acknowledge the valuable involvement of directors and staff at all participating hospitals, including their attendance at a major stakeholders meeting and cooperation during site visits.

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Appendix

Health Facility Data Collection Form

Please complete all questions. Write additional information in the blank space if required.

1. **State / Province:** [ ]

2. **Health Facility Name:** [ ]
   a. Key contact person [ ]
   b. Other contacts [ ]

3. **Number of beds**
   a. for children: [ ]
   b. for newborns: [ ]

4. **Staff**
   a. Doctors
      i. Permanent [ ]
      ii. House officers [ ]
      iii. Corps members [ ]
   b. Nurses [ ] >> Nurses with paediatric training? [ ]
   c. Public Health Nurses [ ]
   d. Midwives [ ]
   e. Community Health Workers
      i. Community Health Officers [ ]
      ii. Community Health Extension Workers [ ]
      iii. Health Assistants [ ]
   f. Day / Night staffing
      (*e.g. 24 hour, 3 shifts*) [ ]

5. Catchment Area & Referrals

a. What catchment area does this hospital serve?

b. What is the estimated catchment population?

c. Which other hospitals refer patients to this hospital? (Referral FROM)

d. Which hospital are patients from this hospital sent? (Referral TO)

e. Is transport available for referral of sick children to other facilities? Yes / No

>> If yes, describe (e.g. private car, taxi etc.)

6. Power Supply

a. What sources of power are available? (*Tick all that apply - describe*)

☐ Mains power connection -
☐ Generator -
☐ Solar / Photovoltaic -
☐ Other (*specify*) -

b. How many hours per day is power available, on average (any source)? (*circle*)

<6 hours	6-12 hours	12-18 hours	>18 hours

c. How often is power interrupted?

Monthly	Weekly	Daily	Hourly

7. Oxygen Equipment

a. Oxygen Concentrators:

i. Working and Present [ ] >> if available: - meter reading? [ ]

ii. Not Working / Broken [ ] - last service? [ ]

b. Oxygen Cylinders:

i. Working and Present [ ] >> if available: - cost per cylinder? [ ]

ii. Not Working / Broken [ ] >> comments (e.g. size, supplier, patient cost) [ ]

c. Pulse Oximeters:

i. Working and Present [ ]

ii. Not Working / Broken [ ]

d. Pulse Oximeters Sensors:

i. Working and Present [ ]

ii. Not Working / Broken [ ]

e. Are Oxygen supplies available? (e.g. nasal prongs/catheter, tubing etc.) Yes / No

8. Health Facility Characteristics

a. Is there a vaccine refrigerat Yes / No

b. What security system is present? (Tick all that apply)

☐ Security guard
☐ Locked external door
☐ Other (*specify*) –

9. Record Keeping

a. How are admissions, diagnoses, and deaths recorded? (Tick all that apply / describe)

☐ Computer program -
☐ Admission Book -
☐ Individual patient file -
☐ Other (*specify*) –

10. Education and Quality of Care

a. Do you have any regular educational session Yes / No

i. If Yes, describe

b. Do you have regular audit/M&M/clinical review meeting Yes / No

ii. If Yes, describe

c. Do you use a standard treatment guidelines/protocol Yes / No
(e.g. WHO Pocketbook of Hospital Care for Children; Nigerian Standard Treatment Guidelines)

If yes:

iii. Which guideline (and what edition)?

iv. Is the guideline present on the ward? Yes / No

v. Are wall charts relating to the guideline present? Yes / No

11. Equipment & Supplies

a. Which of the following medications and supplies ***available, working*** and ***not expired*** for use in this hospital? (*If possible, check supply. Comment in box below, e.g. if externally sourced*)

	Medication		**Infection control**
Yes / No	Amoxycillin oral	Yes / No	Hand-washing facility
Yes / No	Penicillin inj	Yes / No	Soap
Yes / No	Gentamicin inj	Yes / No	Safe sharps disposal
Yes / No	Ceftriaxone inj	Yes / No	Waste disposal
Yes / No	Measles vaccine	Yes / No	Chlorhexidine/Iodine solution
Yes / No	Pentavalent vaccine	Yes / No	Cord clamp & Gentian violet
Yes / No	BCG vaccine	Yes / No	Alcohol swabs
Yes / No	Hep B vaccine	Yes / No	Sterile gloves
Yes / No	Sterile water for injection		
Yes / No	IV fluids (5%/10% dextrose, saline)		
Yes / No	Alcohol swabs		
	Equipment		**Lab & Imaging**
Yes / No	Scales (newborn and child)	Yes / No	X-ray facility
Yes / No	Thermometers	Yes / No	Haemoglobin (Hb)
Yes / No	Resuscitation equipment for newborn	Yes / No	Blood group & Cross-match
Yes / No	Blood sugar / dextrostix	Yes / No	Urinalysis
Yes / No	Syringes, needles, cannulas	Yes / No	CSF microscopy
		Yes / No	Malaria smear / rapid test
		Yes / No	Sputum smear microscopy for TB

Comments

12. Clinical Data

a. 2014

i. ☐ Total Paediatric Admissions

ii. ☐ Paediatric Deaths

iii. ☐ Pneumonia Admissions

iv. ☐ Pneumonia Deaths

v. ☐ Births

vi. ☐ Neonatal Deaths

vii. ☐ Number of referrals to other facilities

b. 2013

viii. ☐ Total Paediatric Admissions

ix. ☐ Paediatric Deaths

x. ☐ Pneumonia Admissions

xi. ☐ Pneumonia Deaths

xii. ☐ Births

xiii. ☐ Neonatal Deaths

xiv. ☐ Number of referrals to other facilities

c. 2012

xv. ☐ Total Paediatric Admissions

xvi. ☐ Paediatric Deaths

xvii. ☐ Pneumonia Admissions

xviii. ☐ Pneumonia Deaths

xix. ☐ Births

xx. ☐ Neonatal Deaths

xxi. ☐ Number of referrals to other facilities i.

13. Further Details

a. Number of doctors that cover the entire hospital during call

b. Number of nurses per shift

c. Number of doctors working in paediatrics unit (children and neaonate)

d. Number of nurses working in Paediatrics unit (children and neonates)

e. How many oxygen concentrators do you have in the paediatric unit and the entire hospital?

f. How many pulse oximeters do you have in paediatric unit and the entire hospital?

g. If you use generators, the power equivalent of each generator—its KVA— and the hours of usage, for example, 250KVA , 10am-2pm; 120 KVA, 7pm-10pm

h. The monthly consumption of fuel for generators, for example, average of 2000L of diesel at N5/L

I. The role of technicians/engineers in the hospital. Do they repair medical equipment, do they do routine maintenance check or repair on damage? Do you have private engineers/technicians to repair your medical equipment.

j. On average, your yearly consumption of oxygen—the total number of oxygen cylinder being used in a year and the cost implication. For example, 105 small cylinders, and 60 big cylinder. The hospital spends on average N1.2m every year provide oxygen for patient care.

k. How much is patient charged for oxygen, N1000/hr, N3,500/day or N2500 irrespective of duration

l. What is the cost of admission?

m

m. What is the cost of 5 day course of common antibiotic (Ampicillin, Penicillin, and Gentamycin?)

n. What is the total cost to the family for 5 year old admitted to your hospital on account of pneumonia (admission fee, medication, consumables. Laboratory)