Biomedical Equipment for COVID-19 Case Management

Zambia COVID-19 Treatment Facility Survey Report

April 2021

PATH

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The work described within the report was carried out as part of PATH's COVID-19 Respiratory Care Response Coordination project, which is a partnership between PATH, the Clinton Health Access Initiative, and Every Breath Counts Coalition to support country decision-makers in the development and execution of a comprehensive respiratory care plan to meet the demands of COVID-19. The project is also pursuing strategies to help prioritize and improve access to oxygen therapy and other essential equipment involved in respiratory care as an integral part of health systems strengthening, beyond the pandemic response.

For questions or comments, please contact: Dr. Christopher Chanda (MOH), national coordinator of Anesthesia and Critical Care Services, at chrischanda2@gmail.com; Mr. Wisdom Chelu (MOH), chief anesthetic officer, at Wisdom.Chelu@MOH.gov.zm; Zach Clemence, Market Dynamics Officer, zclemence@path.org or PATH Market Dynamics at oxygen@path.org.

PATH

Mailing Address
PO Box 900922
Seattle, WA 98109 USA

Street Address
2201 Westlake Avenue
Suite 200
Seattle, WA 98121 USA

www.path.org

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Abbreviations

BMES	Biomedical Equipment Survey
COVID-19	coronavirus disease 2019
CPAP	continuous positive airway pressure
ECG	electrocardiogram
ESFT v2.0	Essential Supplies Forecasting Tool, version 2
HDU	high dependency unit
ICU	intensive care unit
LPM	liters per minute
MOH	Ministry of Health
NIBP	non-invasive blood pressure
POX	pulse oximeter
PSA	pressure swing adsorption
SpO2	blood oxygen saturation
TCO	total cost of ownership
UTH	University Teaching Hospital
WHO	World Health Organization

Executive summary

To assist the government of Zambia in its COVID-19 response, PATH conducted a Biomedical Equipment Survey in eight government-owned health facilities across the country. The survey aimed to quantify the treatment capacity, including supplies and equipment, human resources, and oxygen production capacity for providing respiratory care at COVID-19 treatment centers. The sampled facilities included five large referral hospitals, designated for treatment of COVID-19 patients. All the assessed institutions need urgent procurement of medical equipment for oxygen delivery, monitoring devices to support safe oxygen administration to patients, and accompanying consumables. Also, across all facilities there is insufficient staff trained to adequately manage COVID-19 patients requiring respiratory care.

Three of the surveyed facilities, Chinsali General Hospital, Kalindawalo General Hospital, and Levy Mwanawasa University Teaching Hospital (UTH), were recently constructed and commissioned to provide additional capacity to treat COVID-19 patients. At the time of assessment, they were missing critical components of a complete respiratory care system, such as oxygen wall outlets, medical devices, and accessories and consumables for oxygen therapy. For instance, Kalindawalo, at the time of assessment, was missing suction bottles, regulators, and flowmeters that would allow for use of the central suctioning system. Such components are key to delivering oxygen from source to patient. The severe lack of equipment and supplies in these facilities could be partly attributed to their quick commissioning, but as seen by equipment and supplies availability in the other surveyed facilities, lack of access to oxygen and critical care is a systemic challenge.

The other facilities assessed, Ndola Teaching Hospital and the UTHs, have been functional for many years and were comparatively more equipped but still in need of support with their equipment. For example, the total number of functional oxygen concentrators across all facilities is few (37). These devices are concentrated at Cancer Diseases Hospital (15) and Women and Newborn Hospital (11).[a] Overall, such a small volume of total oxygen concentrators demonstrates that facilities are relying predominantly on oxygen cylinders and/or pressure swing adsorption (PSA) plants for oxygen supply. Furthermore, there does not appear to be a correlation between quantity, or distribution, of oxygen delivery devices and monitoring devices (pulse oximeters and patient monitors), which suggests a lack of safe oxygen delivery.

Oxygen production at public health facilities is also insufficient. While all facilities reported having functional oxygen plants, maintenance of on-site PSA plants is a significant challenge. As a result, their oxygen cylinder-filling capacity is only partially utilized, and all plants will need upgrades or repairs to their high-pressure filling compressors to increase production capacity. Additionally, facilities usually buy supplementary oxygen gas from the private sector, even when they can produce their own supply. These companies are based in urban areas, posing a distribution challenge to rural facilities. Reliable maintenance/upgrades of PSA plants, as well as procurement of additional oxygen cylinders, is one way to reduce dependence on private oxygen suppliers and government expenditure on cylinder rentals.

As of April 2021, Zambia is still experiencing increased COVID-19 cases[1] and increased oxygen demand.[2] After analyzing baseline oxygen availability, the assessment team estimated the oxygen need at the surveyed facilities under two scenarios: a 100% capacity scenario, where all beds allocated for COVID-19 patients at the surveyed health facilities are occupied, and a 50% capacity scenario, where

[a] These two facilities are UTHs.

half of allocated beds are occupied.[b] This estimation of need was used alongside an estimation of total available oxygen supply at facilities in order to produce an oxygen gap, for which an oxygen supply source mix was created and costed. In a COVID-19 surge scenario where 100% of COVID-19-allocated beds are occupied across all the surveyed facilities, there would be an oxygen gap of approximately 3,610 liters per minute (LPM). To fill this gap with oxygen delivery sources would cost approximately US$3.464 million, which would cover costs for procurement and operation for 6 months. Oxygen therapy should always be safely administered with the assistance of pulse oximetry, and the cost to fill the estimated gap for pulse oximetry devices is approximately $261,150. Overall, Zambia health facilities of the highest levels are lacking essential respiratory care equipment and supplies and must urgently procure additional supplies, strengthen treatment and maintenance capacity, and consider other investments in reliable and comprehensive oxygen system infrastructure, production, and delivery.

[b] The increased oxygen need from these COVID-19 patients was assessed using the World Health Organization's Essential Supplies Forecasting Tool version 2.

Introduction

The Zambia Ministry of Health (MOH), through the Department of Clinical Care and Diagnostic Services, and working in partnership with the Anesthesia and Critical Care Unit and PATH Zambia, conducted a Biomedical Equipment Survey (BMES) of respiratory care equipment and supplies in five COVID-19 treatment centers. The purpose of this assessment was to understand current COVID-19 treatment capacity and enable a comparison to an estimated potential increased oxygen demand around COVID-19-related patient surges. The estimated gaps between current treatment capacity and estimated need can be filled with either procurement of medical equipment or relocation of existing equipment, along with training to effectively utilize and maintain available equipment.

The assessment aimed to quantify various elements of effective oxygen systems, including infrastructure to support oxygen supply systems, oxygen delivery equipment and supplies, monitoring equipment for safe oxygen administration, and oxygen production equipment and supply (see Table 1 for more details).

Table 1. Elements of effective oxygen systems.

Infrastructure	Oxygen delivery equipment and supplies	Monitoring equipment	Oxygen production equipment and supply
• Human resources for oxygen and critical care management of COVID-19 patients • Primary and back-up power supply • Water supply • Capacity to maintain biomedical equipment	• Resuscitation devices • Ventilators and other airway management devices • Associated consumables	• Pulse oximeters • Patient monitors	• Oxygen concentrators • Oxygen cylinders and manifolds • Pressure swing adsorption plants and liquid oxygen storage

This report first discusses our data collection methodology, then makes observations about baseline oxygen availability across the COVID-19 treatment centers, and finally estimates the potential oxygen demand increases these facilities could experience from a COVID-19 surge, making recommendations for increasing respiratory care treatment capacity. Specific recommendations for immediate scale-up of treatment capacity and oxygen availability at each facility is provided in the conclusion of this report. Overall, this assessment / oxygen need estimation for COVID-19 treatment centers supports the Comprehensive Rapid Assessment of Oxygen Production and Delivery Systems in Zambia, the MOH's official plan for rapid scale-up of oxygen availability and Acute Emergency and Intensive Care Services.[c]

The data analyzed in this report were collected from June to August 2020 and reflect the status of the surveyed facilities at that time. The COVID-19 emergency response has resulted in rapid changes to health system capacity and operations in many countries; therefore, it is important to note that this report does not attempt to quantify such changes. Continued monitoring of new equipment allocation and functionality is recommended to assess respiratory care access over time.

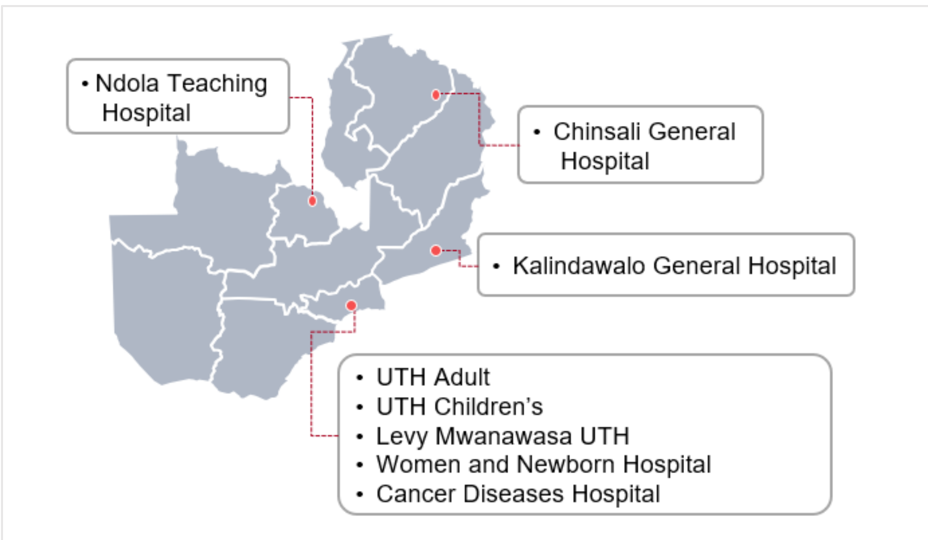
[c] For more information, please contact either Dr. Christopher Chanda (MOH), national coordinator of Anesthesia and Critical Care Services, at chrischanda2@gmail.com, or Mr. Wisdom Chelu (MOH), chief anesthetic officer, at Wisdom.Chelu@MOH.gov.zm.

Methods

The BMES used a data collection tool created by the World Health Organization (WHO) and adapted by PATH for use in Zambia, in collaboration with the Zambia MOH Department of Clinical Care and Diagnostic Services and the Anesthesia and Critical Care Unit. The BMES was hosted on the SurveyCTO data collection platform, and questions were informed by the WHO list of priority medical devices for COVID-19 case management.[3] Initial data collection was done in person, as well as collected electronically on tablets, during the months of June to August 2020 by a team of anesthetic providers and medical equipment officers. Collected data were cleaned and approved by the MOH contact persons before data analysis was done.

The health facilities surveyed included the University Teaching Hospitals, or UTHs (UTH Adult, UTH Children's, Women and Newborn Hospital, Cancer Diseases Hospital, and Levy Mwanawasa UTH); Ndola Teaching Hospital; Chinsali General Hospital; and Kalindawalo General Hospital (see Figure 1 for location of facilities by province). The province of Lusaka has the highest density of facilities because it contains the UTH facilities.

Figure 1. Hospitals surveyed by province.



The MOH recommended these facilities for the BMES because they are mainly referral (tertiary and secondary) hospitals to which COVID-19 patients are likely to be referred when in need of critical respiratory care (see Table 2). For instance, Levy Mwanawasa UTH was designated as a COVID-19 treatment center because it has an 850-bed capacity and is now the largest hospital in the country. It was opened on August 8, 2011 but has been undergoing construction in phases and was only completed last year (2020). Chinsali and Kalindawalo General Hospitals were built to increase availability of good-quality health services for people in the Eastern Province. Previously, there were very few hospitals in between towns, which made the distance to the nearest hospital too far for many people seeking care. They were designated as COVID-19 treatment centers due to the high quality of their services and their bed capacities. Both were opened in February of 2020.

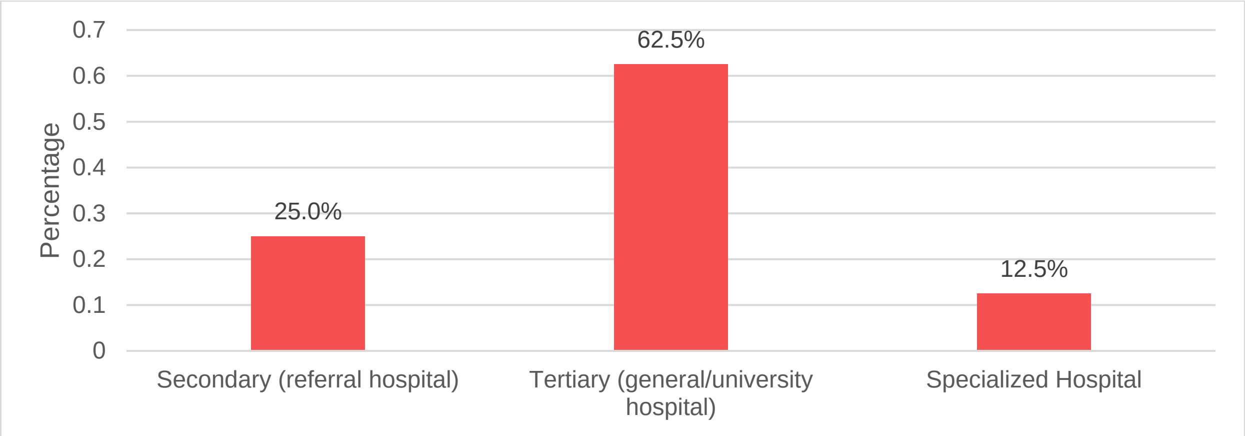
Overall, most facilities in the survey sample are tertiary hospitals, two facilities are secondary hospitals, and only the Cancer Disease Hospital is a specialized hospital (see Figure 2). Currently, PATH is supporting the MOH in conducting extended data collection to survey a greater number of facilities across various levels of the health system.

Table 2. Facility characteristics.

Province	District	Facility names	Facility type	Geography
Lusaka	Lusaka	Cancer Diseases Hospital	Specialized hospital	Urban
		Levy Mwanawasa UTH	Tertiary*	Urban
		UTH Adult	Tertiary*	Urban
		UTH Children's	Tertiary*	Urban
		Women and Newborn Hospital	Tertiary*	Urban
Muchinga	Chinsali	Chinsali General Hospital	Tertiary*	Peri-urban
Eastern	Petauke	Kalindawalo General Hospital	Secondary (referral hospital)	Peri-urban
Copperbelt	Ndola	Ndola Teaching Hospital	Tertiary*	Urban

Abbreviation: UTH, University Teaching Hospital.
*Tertiary facilities are general/university hospitals.

Figure 2. Facility type distribution in sample.



Baseline treatment capacity

Availability of beds is a major factor influencing treatment capacity. Facilities were surveyed for their total bed capacity (including beds of all types) and intensive care unit (ICU) bed capacity (Table 3). ICU beds are especially important for treatment of severe and critical COVID-19 cases, as they provide consistent oxygen therapy at high flow rates; severe COVID-19 patients typically require flow rates upwards of 5 liters per minute (LPM), and critical COVID-19 patients require rates from 15 LPM to 70 LPM (if providing oxygen therapy via high-flow nasal cannula).[4] In the section below, bed capacity is compared across health facilities and to population data for the provinces where facilities are located (Table 4).[d]

Key findings are as follows:

- Ndola Teaching Hospital had the largest number of total beds (851), closely followed by UTH Adult (850). Ndola Teaching Hospital is in the second most populous province of Zambia (Copperbelt), which aligns with its high bed count.
- Kalindawalo General Hospital (220) and Chinsali General Hospital (220) had the fewest total beds of the eight facilities. Chinsali is in the Muchinga Province, which is the least populous of the provinces containing surveyed facilities. Kalindawalo is in the Eastern Province, which is less populous than Lusaka, and it has fewer total beds than all the facilities located in Lusaka.
- Chinsali General Hospital reported the greatest number of ICU beds (24), while Women and Newborn Hospital and Cancer Disease Hospital reported none.

Table 3. Total facility beds.

Facility name	Province	District	Total # beds*	# ICU beds
Ndola Teaching Hospital	Copperbelt	Ndola	851	10
UTH Adult	Lusaka	Lusaka	850	15
Levy Mwanawasa UTH	Lusaka	Lusaka	730	12
UTH Children's	Lusaka	Lusaka	365	8
Women and Newborn Hospital	Lusaka	Lusaka	332	8
Cancer Diseases Hospital	Lusaka	Lusaka	252	0
Chinsali General Hospital	Muchinga	Chinsali	220	12
Kalindawalo General Hospital	Eastern	Petauke	220	12
Grand total			**3,820**	**77**

*ICU beds are included within the count for total beds.
Abbreviations: ICU, intensive care unit; UTH, University Teaching Hospital.

[d] Population data for 2020 were the most recent data that could be found, available from Zambia Statistics Agency (zamstats.gov.zm).

Table 4. Population of Zambia by province.

Province	Population (2020)
Lusaka	3,360,183
Copperbelt	2,669,635
Southern	2,135,794
Eastern	2,065,590
Central	1,743,999
Northern	1,520,004
Luapula	1,276,608
Muchinga	1,095,535
Western	1,076,683
North-Western	950,789

Source: Zambia Population and Demographic Projections, 2011-2035. https://www.zamstats.gov.zm/phocadownload/Zambia%20Census%20Projection%202011%20-%202035.pdf . Page 11. Accessed April 19, 2021.

Infrastructure

While bed counts are important for evaluating health facility capacity, additional health facility characteristics can impact effective use of beds. For instance, ICU beds that rely on piped medical oxygen could be constrained by the number of wall units installed in an ICU ward. Additionally, facility characteristics, such as type of electricity source, can limit treatment capacity when using oxygen delivery devices that require power, like oxygen concentrators.

Furthermore, oxygen therapy and patient ventilation require trained clinical staff, including specialized training to safely intubate patients for ventilation. In this assessment, the following definitions were used to describe staff with varying levels of expertise: “critical care specialists” are top-level clinical staff trained in administering oxygen therapy and critical care and can be supported by “critical care nurses,” also trained to administer oxygen therapy. Having these two clinical staff types is ideal, but in their absence, “clinical officer anesthetists” may be able to support treatment of severely and critically ill patients in need of oxygen, although their training may be less. “Medical officers” are clinical staff with generalized skills and likely are not trained to administer oxygen therapy.

Durable medical equipment also requires biomedical engineers and/or trained health facility staff to preform preventative and corrective maintenance as needed. The following section makes observations on facility infrastructure that supports oxygen systems, including staff, power supply sources, ambulance availability, and oxygen piping.

Key findings:

- All facilities reported having staff dedicated to the management, installation, and maintenance of medical equipment.
- All facilities, except for Kalindawalo General Hospital, reported having clinical staff with experience in invasive mechanical ventilation/intubation.
- There are very few clinical staff across most of the facilities, with disproportionate numbers of critical care nurses, critical care specialists, and anesthetists at UTH Adult (Table 5). This is surprising because UTH Adult reported having 14 ICU beds, which was not many more than several of the other facilities. Furthermore, the facility with the most ICU beds (Chinsali General Hospital, 24) had no critical care specialist or nurses at the time of the assessment, indicating a dearth of expertise to administer oxygen therapy and critical care at this facility.
- Having both a generator and connection to a central electricity grid was the most common source of power across surveyed facilities (Table 6).
- Cancer Disease Hospital and Kalindawalo General Hospital reported having no ambulances at all. Of the facilities that did have ambulances, they had very few in total, and only some had ambulances equipped with medical oxygen (Table 7).
- All facilities reported having a wall pipe network of medical gases that included oxygen (Table 8).[e]

[e] Piping systems allow oxygen or other medical gases to be piped directly from a supply source, such as a cylinder manifold or PSA plant, to the wards or patient beds within a health facility.

Table 5. Clinical staff quantities.

Facility name	Clinical officer anesthetist	Critical care nurses	Medical officers	Critical care specialists	Anesthetists
Cancer Diseases Hospital	1	2	0	1	1
Chinsali General Hospital	0	0	10	0	0
Kalindawalo General Hospital	0	0	1	0	0
Levy Mwanawasa UTH	0	0	2	0	0
Ndola Teaching Hospital	4	11	3	2	2
UTH Children’s	0	3	1	0	0
UTH Adult	0	17	0	30	30
Women and Newborn Hospital	0	0	0	0	0
Grand total	**5**	**33**	**17**	**33**	**33**

Abbreviation: UTH, University Teaching Hospital.

Table 6. Electricity source.

Facility name	Electricity source	Generator count
Cancer Diseases Hospital	Both central grid and generator	2
Chinsali General Hospital	Central electricity grid	1
Kalindawalo General Hospital	Both central grid and generator	1
Levy Mwanawasa UTH	Both central grid and generator	2
Ndola Teaching Hospital	Both central grid and generator	1
UTH Children’s	Both central grid and generator	2
UTH Adult	Both central grid and generator	1
Women and Newborn Hospital	Central electricity grid	0

Abbreviation: UTH, University Teaching Hospital.

Table 7. Ambulances.

Facility name	Ambulances present	# ambulances with oxygen
Cancer Diseases Hospital	No	0
Chinsali General Hospital	Yes	1
Kalindawalo General Hospital	No	0
Levy Mwanawasa UTH	Yes	2
Ndola Teaching Hospital	Yes	2
UTH Children's	Yes	1
UTH Adult	Yes	2
Women and Newborn Hospital	Yes	0
Grand total	**6 of 8 facilities**	**9**

Abbreviation: UTH, University Teaching Hospital.

Table 8. Oxygen piping.

Facility name	Availability/type of wall pipe network of medical gases
Cancer Diseases Hospital	Yes - oxygen, air, and vacuum
Chinsali General Hospital	Yes - oxygen, air, and vacuum
Kalindawalo General Hospital	Yes - oxygen, air, and vacuum
Levy Mwanawasa UTH	Yes - oxygen, air, and vacuum
Ndola Teaching Hospital	Yes - oxygen
UTH Children's	Yes - oxygen
UTH Adult	Yes - oxygen
Women and Newborn Hospital	Yes - oxygen

Abbreviation: UTH, University Teaching Hospital.

Oxygen delivery equipment

The facility BMES quantified existing, functional oxygen delivery equipment of various device types. These types included ventilators, suction devices, and resuscitation devices.

Ventilators

Ventilators assist patient breathing in cases of respiratory distress and are an important device type for respiratory care and treatment of severe and critical COVID-19 cases. The BMES quantified various types of ventilators, including portable ones and intensive care ventilators for adults and pediatrics. Intensive care ventilators for adults were the most common type of ventilator reported (Figure 3). The total quantity of functional ventilators (104) is greater than the total ICU beds across the facilities surveyed (77), suggesting that severe respiratory illness may be sometimes treated outside of ICUs and/or facilities lack absorptive capacity for these devices, and they go unused. The number of nonfunctional ventilators counted are also shown in Figure 3.

Functional ventilators are not evenly distributed across health facilities. Chinsali General Hospital has nearly half of all devices, while Ndola Teaching Hospital and UTH Children's Hospital have far fewer devices. Chinsali does have the greatest number of ICU beds; however, there does not seem to be a relationship between number of ventilators and number of ICU beds among the other facilities (Table 9).

Figure 3. Number of ventilators by type.

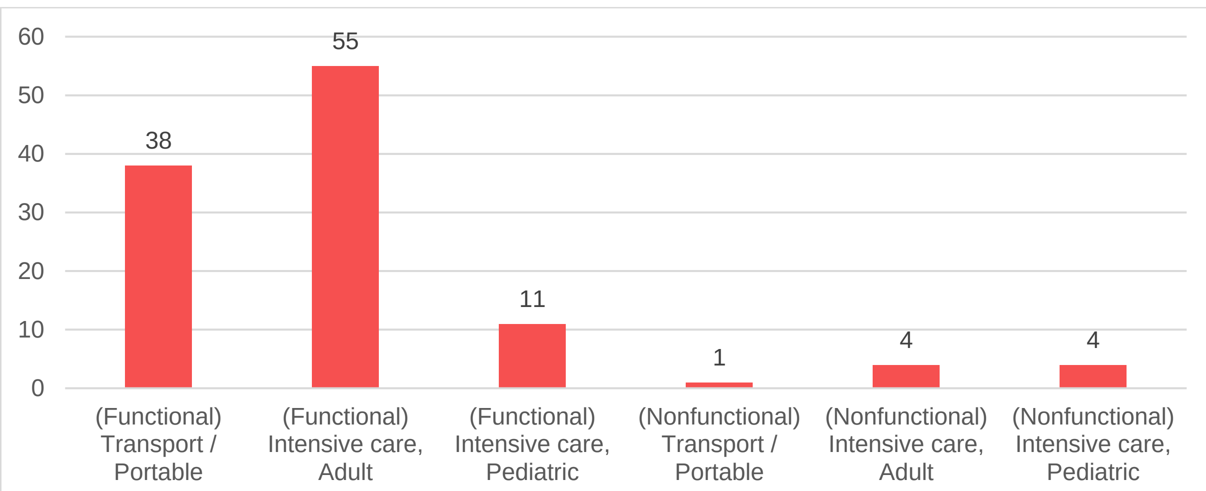


Table 9. Distribution of functional ventilators across facilities.

Facility name	# of functional ventilators	% of total functional ventilators surveyed	# of beds	# of ICU beds
Cancer Diseases Hospital	0	0%	252	0
Chinsali General Hospital	45	43%	220	12
Kalindawalo General Hospital	14	13%	220	12
Levy Mwanawasa UTH	14	13%	730	12
Ndola Teaching Hospital	6	6%	851	10
UTH Children's	3	3%	365	8
UTH Adult	12	12%	850	15
Women and Newborn Hospital	10	10%	332	8
Grand total	**104**	**100%**	**3,820**	**77**

Abbreviations: ICU, intensive care unit; UTH, University Teaching Hospital.

Suction devices

Suction devices are important for improving patient breathing. The BMES collected data on three types of devices: manual, electric, and central vacuum. Figure 4 shows that electric suction devices are by far the most common device type. Most of the functional devices were reported by Ndola Teaching Hospital (47), followed closely by UTH Adult (30) and Women and Newborn Hospital (28). The fewest devices were reported by Chinsali General Hospital and Levy Mwanawasa UTH, reporting 2 devices apiece (Table 10).

Figure 4. Number of suction devices by type.

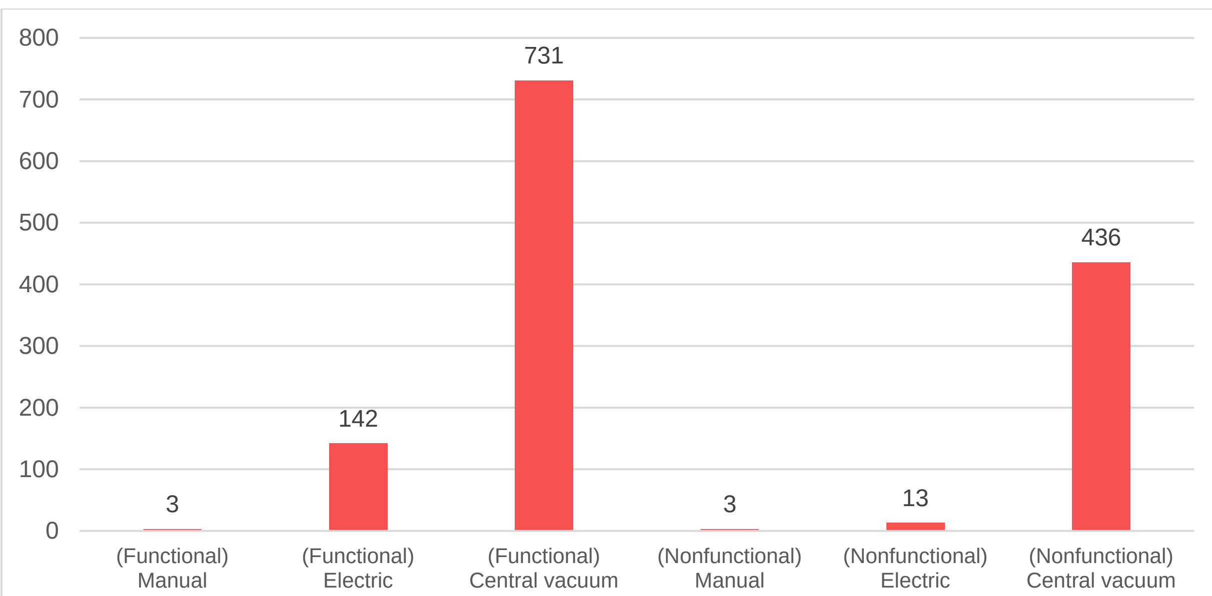


Table 10. Distribution of functional suction devices across facilities.

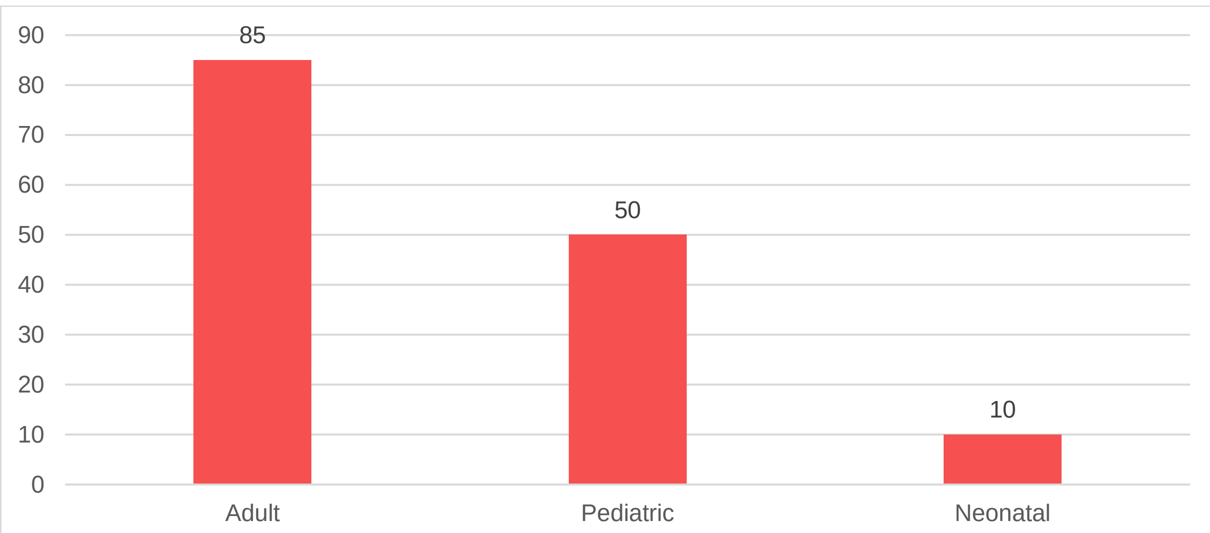
Facility name	# of functional suction devices	% of total functional suction devices surveyed	# of beds	# of ICU beds
Cancer Diseases Hospital	11	1%	252	0
Chinsali General Hospital	2	0%	220	12
Kalindawalo General Hospital	5	1%	220	12
Levy Mwanawasa UTH	732	84%	730	12
Ndola Teaching Hospital	47	5%	851	10
UTH Children's	21	2%	365	8
UTH Adult	30	3%	850	15
Women and Newborn Hospital	28	3%	332	8
Grand total	**876**	**100%**	**3,820**	**77**

Abbreviations: ICU, intensive care unit; UTH, University Teaching Hospital.

Resuscitation devices

These devices are used to mechanically ventilate patients. Facilities reported three device types: adult, pediatric, and neonatal. Figure 5 shows that adult resuscitation devices were the most common.

Figure 5. Number of resuscitation devices by type.



Note: Nonfunctional resuscitation devices were not surveyed.

Table 11. Distribution of functional resuscitation devices across facilities.

Facility name	# of functional resuscitation devices	% of total functional resuscitation devices surveyed	# of beds	# of ICU beds
Cancer Diseases Hospital	15	10%	252	0
Chinsali General Hospital	0	0%	220	12
Kalindawalo General Hospital	8	6%	220	12
Levy Mwanawasa UTH	0	0%	730	12
Ndola Teaching Hospital	44	30%	851	10
UTH Children's	41	28%	365	8
UTH Adult	0	0%	850	15
Women and Newborn Hospital	37	26%	332	8
Grand total	**145**	**100%**	**3,820**	**77**

Abbreviations: ICU, intensive care unit; UTH, University Teaching Hospital.

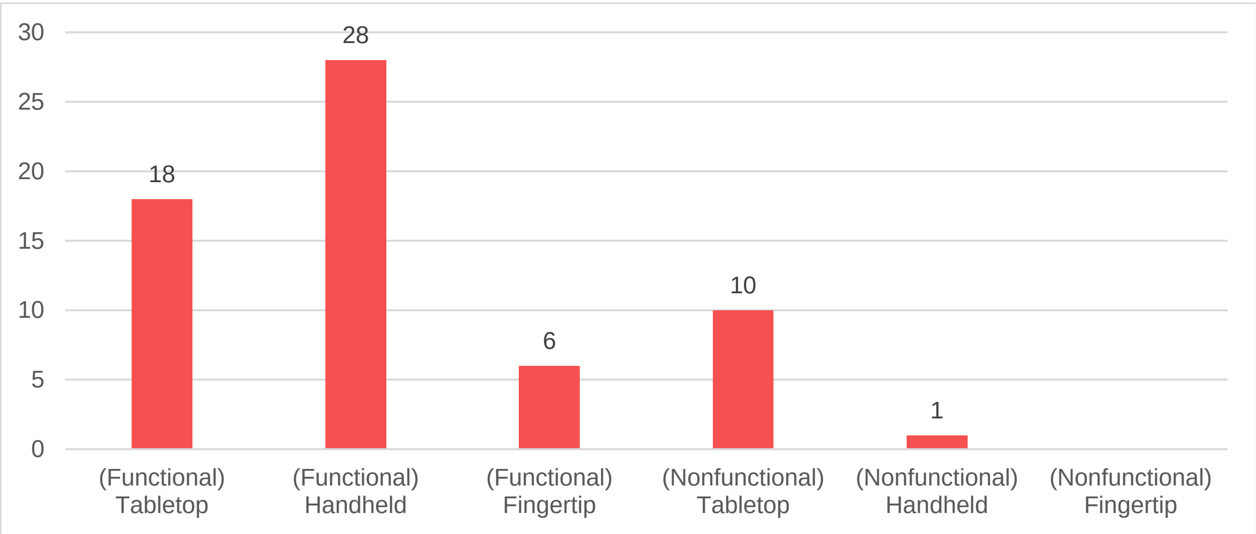
Monitoring equipment

Pulse oximeters (POXs)

POXs are critical to safe oxygen administration[f]. These devices help monitor the level of oxygen in a patient's blood and alert the health care worker if oxygen drops below safe levels. This allows for timely identification of hypoxemia and an opportunity for intervention. These devices are essential in any setting in which a patient receives oxygen—such as during surgery, in emergency rooms and ICUs, in hospital treatment and recovery wards, and for treatment of respiratory disease, including but not limited to COVID-19. The three types of POXs surveyed were fingertip, handheld, and tabletop. Figure 6 shows that handheld devices were the most common device type reported.

Like ventilators, POXs are not evenly distributed across facilities (Table 12). Considering that pulse oximetry is used alongside oxygen delivery, it is concerning that oxygen and pulse oximetry distribution does not align. This suggests that ability to administer oxygen therapy may be constrained by not having enough monitoring devices or that oxygen is administered without pulse oximetry.

Figure 6. Number of pulse oximeters by type.



[f] Recent studies have suggested that clinical guidance should include consideration of the effect of skin pigmentation on pulse oximetry measurement accuracy. As pulse oximetry is expanded, efforts should be made to identify and disseminate the most recent clinical recommendations for patient care, to effectively treat all patients: https://www.nejm.org/doi/full/10.1056/NEJMc2029240.

Table 12. Distribution of functional POXs across facilities.

Facility name	# of functional POXs	% of total functional POXs surveyed	# of beds	# of ICU beds
Cancer Diseases Hospital	0	0%	252	0
Chinsali General Hospital	11	21%	220	12
Kalindawalo General Hospital	3	6%	220	12
Levy Mwanawasa UTH	5	10%	730	12
Ndola Teaching Hospital	3	6%	851	10
UTH Children's	8	15%	365	8
UTH Adult	16	31%	850	15
Women and Newborn Hospital	6	12%	332	8
Grand total	**52**	**100%**	**3,820**	**77**

Abbreviations: ICU, intensive care unit; POX, pulse oximeter; UTH, University Teaching Hospital.

Patient monitors

Like POXs, patient monitors provide information on patient vitals, enabling health care workers to effectively deliver oxygen therapy. The types of patient monitors surveyed were “multiparameter” (with measurements of temp, end-tidal CO_2, blood oxygen saturation [SpO_2], non-invasive blood pressure [NIBP], central venous pressure, arterial pressure, electrocardiogram [ECG]), “non-multiparameter” (with standard temp, end-tidal C02, SpO_2, NIBP, ECG), and “non-multiparameter basic” (with temp, SpO_2, NIBP). Figure 7 shows that multiparameter monitors were slightly more common than the other two types. The total number of patient monitors (76) is slightly less than total number of ICU beds (77) across the surveyed facilities. However, it is important to note that patient monitors should be used for patient safety in many other wards, and therefore the reported totals are very low.

Table 13 shows that most patient monitors reported were at Kalindawalo General Hospital (27), closely followed by Ndola Teaching Hospital (22). Overall, there are very few functional devices across facilities, given the total number of beds that require monitoring support.

Figure 7. Number of patient monitors by type.

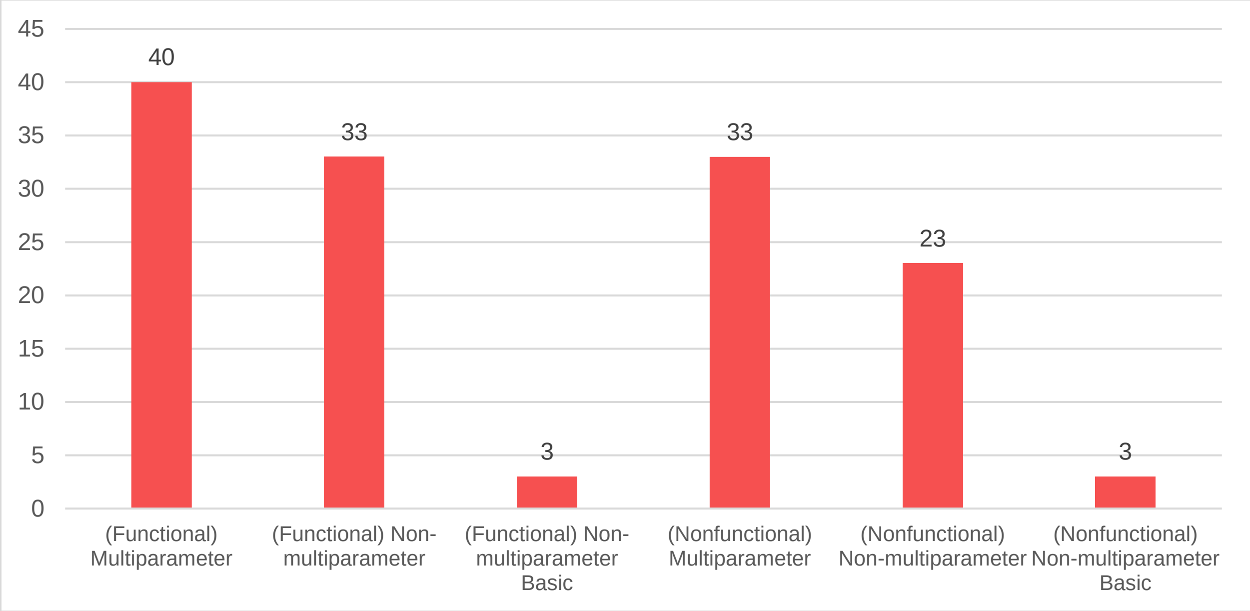


Table 13. Distribution of functional patient monitors across facilities.

Facility name	# of functional patient monitors	% of total functional patient monitors surveyed	# of beds	# of ICU beds
Cancer Diseases Hospital	10	13%	252	0
Chinsali General Hospital	1	1%	220	12
Kalindawalo General Hospital	27	36%	220	12
Levy Mwanawasa UTH	12	16%	730	12
Ndola Teaching Hospital	22	29%	851	10
UTH Children's	0	0%	365	8
UTH Adult	3	4%	850	15
Women and Newborn Hospital	0	0%	332	8
Grand total	**75**	**100%**	**3,820**	**77**

Abbreviations: ICU, intensive care unit; UTH, University Teaching Hospital.

Oxygen production equipment and supply

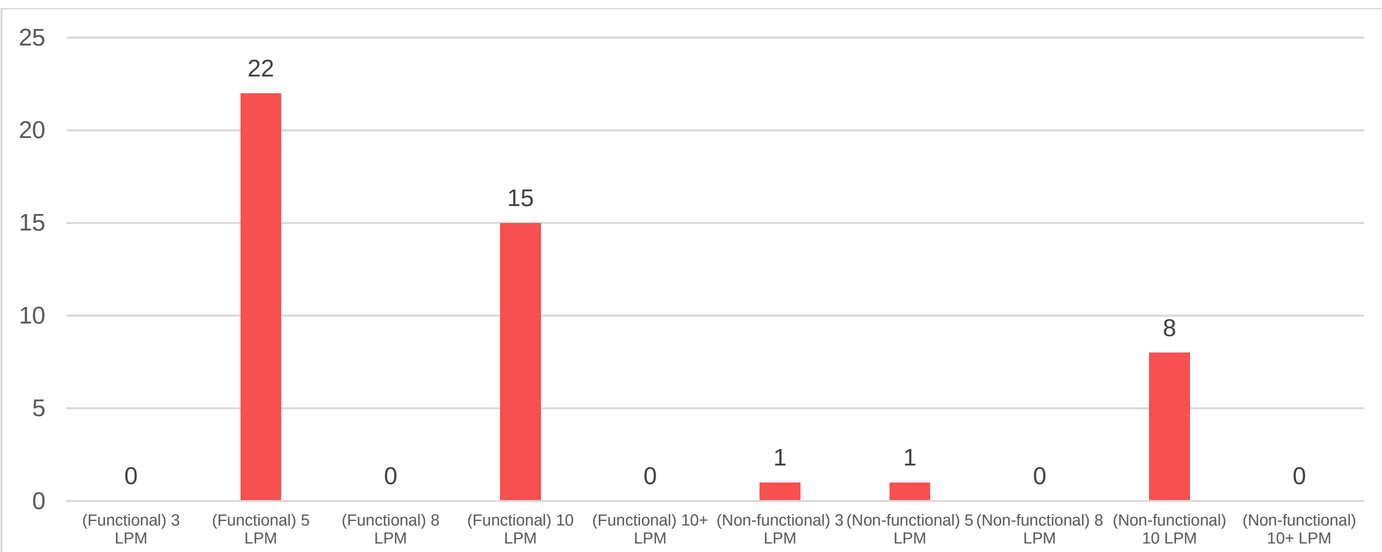
This section quantifies equipment that can produce and store oxygen for treatment. This includes oxygen concentrators and pressure swing adsorption (PSA) plants, which can purify atmospheric oxygen for medical use, as well as oxygen cylinders for medical oxygen storage and cylinder manifolds.

Oxygen concentrators

Oxygen concentrators can separate and purify atmospheric oxygen to provide it to patients at various flow rates. WHO recommends high flow rates of oxygen for severe and critical COVID-19 patients,[5] but oxygen provided at lower flow rates is critical for treatment of respiratory distress and illness of other kinds as well. Figure 8 shows that sizes 5 LPM and 10 LPM were the only sizes reported in the dataset, and the overall total for functional devices was very low (37).

Table 14 shows that the very few reported concentrators were predominantly at Cancer Diseases Hospital (15) and Women and Newborn Hospital (11). Overall, such a small volume of total oxygen concentrators demonstrates that facilities are relying predominantly on oxygen cylinders and/or PSA plants for oxygen supply.

Figure 8. Number of oxygen concentrators by size.



Abbreviation: LPM liters per minute.

Table 14. Distribution of oxygen concentrators across facilities.

Facility name	# of functional oxygen concentrators	% of total functional oxygen concentrators surveyed	# of beds	# of ICU beds
Cancer Diseases Hospital	15	41%	252	0
Chinsali General Hospital	0	0%	220	12
Kalindawalo General Hospital	0	0%	220	12
Levy Mwanawasa UTH	0	0%	730	12
Ndola Teaching Hospital	8	22%	851	10
UTH Children's	3	8%	365	8
UTH Adult	0	0%	850	15
Women and Newborn Hospital	11	30%	332	8
Grand total	**37**	**100%**	**3,820**	**77**

Abbreviations: ICU, intensive care unit; UTH, University Teaching Hospital.

Oxygen cylinders

Oxygen cylinders are metal canisters that require regular refills and delivery to health facilities by an oxygen supplier. They require minimal maintenance and no electricity, making them a suitable oxygen source in some settings with poor infrastructure. However, they still require reliable refills to be of any value to providing oxygen therapy. Like other oxygen delivery and production devices, they are dependent on availability of oxygen consumables, such as masks, tubing, and cylinder assembly units, to facilitate oxygen delivery. Table 15 shows total quantities of cylinders by size and connection type across the facilities surveyed.

The most common type and size of cylinder was the 1,360 L (size F) with a bullnose connection type. The facilities reporting the highest counts of cylinders were UTH Adult (385) and Ndola Teaching Hospital (146). Table 16 shows the grand total of cylinder manifolds across facilities, by cylinder capacity of the manifold (manifolds that can fit 2-8 cylinders) and switching type. The Cancer Diseases Hospital reported having a 21-cylinder manifold size, with manual switch, which is not shown in this table due to its outlier size.

Table 15. Total number of cylinders by size and connection type.

Facility name	"D" (340L) Pin-index	"D" (340L) Bull-nose	"E" (680L) Pin-index	"E" (680L) Bull-nose	"F" (1360L) Pin-index	"F" (1360L) Bull-nose	"G" (3400L) Pin-index	"G" (3400L) Bull-nose	"J" (6800L) Pin-index	"J" (6800L) Bull-nose
Cancer Diseases Hospital	0	0	0	0	30	0	0	0	0	0
Chinsali General Hospital	0	0	0	0	0	0	0	0	0	0
Kalindawalo General Hospital	1	0	0	0	0	0	0	0	0	0
Levy Mwanawasa UTH	0	0	0	0	0	0	0	0	0	0
Ndola Teaching Hospital	6	0	0	0	0	146	0	0	0	0
UTH Children's	0	5	0	0	0	11	0	0	0	0
UTH Adult	0	0	0	0	0	385	0	0	0	0
Women & Newborn Hospital	0	0	0	0	0	0	0	0	0	0
Grand total	**7**	**5**	**0**	**0**	**30**	**542**	**0**	**0**	**0**	**0**

Abbreviation: UTH, University Teaching Hospital.

Table 16. Total number of cylinder manifolds across all facilities.

Cylinder capacity (number of cylinders a manifold can fit)	Total # per switching type		Total
	Manual switch	Automatic switch	
2	1	0	**1**
3	3	0	**3**
4	0	0	**0**
5	2	1	**3**
6	0	0	**0**
7	0	0	**0**
8	0	2	**2**
Grand total			**9**

PSA plants

PSA plants are health facility–based factories that use pressure to separate oxygen from the atmosphere and purify it to medical grade oxygen. Table 17 shows the PSA plants at five surveyed facilities and their production capacities.

Table 17. Production capacities / status of PSA plants at five surveyed facilities.

Facility name	Status	Filling	Oxygen plant capacity	Cylinder / 24 hrs.
Levy Mwanawasa UTH	Functional	No	120 m³/ h	N/A
Kalindawalo General Hospital	Functional	No	30 m³/ h	N/A
UTH Adult	Functional	Yes	60 m³/ h	60-85
Chinsali General Hospital	Functional	No	30 m³/ h	N/A
UTH Children's	Not functional	Yes	30 m³/ h	25

Abbreviation: PSA, pressure swing adsorption; UTH, University Teaching Hospital.

Oxygen consumables

Oxygen consumables refer to any devices or oxygen delivery interfaces which facilitate oxygen therapy. These are typically single use, or sometimes reusable, but have a short life span compared to medical devices and require different practices for management. Because consumables are not like durable devices, their availability can greatly fluctuate over time. This means that consumable quantities could be lower or higher than average on an individual facility level, depending on whether that facility had recently ordered new inventory at the time of the assessment. Table 18 gives the grand total, average, and standard deviation of consumables counted across facilities. If facilities were systematically purchasing consumables for oxygen delivery, we would expect there to be a correlation between number of consumables and oxygen delivery device availability, as well as a correlation between consumables that are paired together to administer oxygen therapy (such as laryngoscopes and airways for intubation). Many facilities reported either having zero consumables or “unknown” (which was also counted as zero in the table below), so it is difficult to draw any conclusion about device-to-consumable pairing or consumable-to-consumable pairing. What we can observe from the data is that consumables sized for adults are much more widely used, which makes sense given the demographic typically served by the surveyed facilities. Standard deviation describes the spread of the number of consumables across the surveyed facilities. A high standard deviation shows that there were many facilities who had either many more or far fewer consumables than other facilities in the dataset.

Table 19 shows counts of ventilator accessories across facilities. Overall, there are very few ventilator accessories reported across facilities. Of the total number of functional ventilators counted (104), only a small fraction of these may have a spare accessory to replace any that become worn out or broken.

Table 18. Status of consumables across facilities.

Consumable	Grand total	Average	Standard deviation
Nasal cannula / prongs - adult	127	32	64
Nasal cannula / prongs - pediatric	0	0	0
Nasal cannula / prongs - neonate	4	1	2
Nasal catheter - adult	0*	0	0
Nasal catheter - pediatric	1	0	1
Nasal catheter - neonate	0*	0	0
Oxygen mask - adult	91	23	46
Oxygen mask - pediatric	0	0	0
Venturi mask - adult	0*	0	0
Venturi mask - pediatric	0*	0	0
Non-rebreather mask - adult	22	4	9
Non-rebreather mask - pediatric	0*	0	0
Simple face mask	0	0	0
Macintosh (curved blade) laryngoscope without video	45	6	11
Macintosh (curved blade) laryngoscope with video	1	0	0
Miller (straight blade) laryngoscope without video	3	1	2
Miller (straight blade) laryngoscope with video	0*	0	0
Adult - laryngeal mask	22	6	10
Adult - colorimetric end-tidal CO2 detector	0*	0	0
Pediatric - laryngeal mask	2	1	1

Pediatric - colorimetric end-tidal CO2 detector	0*	0	0
Nasopharyngeal airway - single use	6	2	3
Nasopharyngeal airway - reusable	0*	0	0
Oropharyngeal (Guedel) airway - single use	1,427	357	599
Oropharyngeal (Guedel) airway - reusable	0	0	0

*Number of consumables was unknown by survey respondents. In the absence of data, values are assumed to be 0.

Table 19. Number of ventilator accessories across facilities.

Accessory	Grand total	Average	Standard deviation
Heat and moisture exchange device for ventilation	0	0	0
Heated ventilator circuits	0	0	0
Reusable ventilator circuits	7	1	2
Electrostatic bacterial filters	6	1	2
Humidifiers	7	1	2
Flow sensors	6	1	2
Expiration sensors	4	1	1
Breathing masks	3	0	1
High-flow, low-flow oxygen therapy	1	0	0
Oxygen sensor within date	4	1	1
Disposable circuits	3	0	1

COVID-19 oxygen needs estimation

The following section describes, in five steps, how oxygen and pulse oximetry needs were estimated for the facilities in the dataset. Oxygen need was estimated in relation to the health facility's capacity to treat patients. With data from the MOH, we were able to identify the number of beds that are allocated for COVID-19 treatment at each of the surveyed facilities and then estimate oxygen requirements for two different scenarios:

- **Scenario 1**: Facility beds that are allocated for treatment of COVID-19 patients are at 100% capacity.
- **Scenario 2**: Facility beds that are allocated for treatment of COVID-19 patients are at 50% capacity.

A capacity-based approach was taken, in favor of a COVID-19 progression-based model, as estimates in the context of bed occupancy allow for simpler conceptualization of oxygen need. The estimation approach is laid out in the five steps described below.

Step 1. WHO Essential supplies forecasting tool (ESFT), version 2, used to estimate COVID-19 patient oxygen need

The first step of the oxygen estimation was to use a modified version[g] of the WHO COVID-19 Essential supplies forecasting tool (COVID-ESFT), version 2, to estimate oxygen need for each facility based on its allocated beds for COVID-19 treatment. Some key assumptions were made for oxygen estimation:

- Where the count of allocated beds for COVID-19 patients was unknown, 20% of beds would be allocated. This was based on the observation that roughly 20% of beds at UTH Adult and Levy Mwanawasa UTH were known to be allocated for COVID-19 patients.
- 100% of ICU beds at a facility would be available for treatment of COVID-19 patients requiring critical care.
- All beds allocated for COVID-19 patient care would be able to provide oxygen therapy, with ICU beds providing typical oxygen flow rates required for COVID-19 critical care (15 LPM), and all other allocated beds providing typical oxygen flow rates required for COVID-19 severe care (5 LPM).
- Critical patients have an average inpatient stay of two weeks, and severe patients, one week.

Table 20 shows how many beds were allocated per facility for COVID-19 patients and how they are divided between severe and critical care. Results of the 100% capacity scenario estimation for oxygen need are presented in the far-right column.

g The ESFT v2.0 was used for a particular function—to estimate oxygen need from a specified number of available beds, providing oxygen at a particular flow rate.

Table 20. COVID-19 oxygen need estimation, 100% capacity scenario.

Facility name	Total # beds	# of ICU beds	# beds allocated for COVID-19 patients*	# beds providing critical care for COVID-19 patients (15 LPM)	#beds providing severe care for COVID-19 patients (5 LPM)	Estimated oxygen need for COVID-19 patients (LPM)
Ndola Teaching Hospital	851	10	170	10	160	950
UTH Adult	850	15	150	15	135	900
Levy Mwanawasa UTH	730	12	150	12	138	870
UTH Children's	365	8	73	8	65	445
Women and Newborn Hospital	332	8	66	8	58	410
Cancer Diseases Hospital	252	0	50	0	50	250
Chinsali General Hospital	220	12	44	12	32	340
Kalindawalo General Hospital	220	12	44	12	32	340
Grand total	**3,820**	**77**	**747**	**77**	**670**	**4,506**

Abbreviations: ICU, intensive care unit; LPM, liters per minute; UTH, University Teaching Hospital.

*Except for UTH Adult and Levy Mwanawasa UTH, beds allocated for COVID-19 were unknown, so a 20% allocation was assumed. UTH Adult and Levy Mwanawasa UTH had available data for expected beds allocated for COVID-19, which was was roughly 20% of their total beds (thus 20% allocation for the others).

Step 2. Total available oxygen supply calculated for each facility using BMES data and data provided by the MOH

Total available oxygen supply was calculated by summing the available supply across PSA plants, oxygen cylinders, and oxygen concentrators (Table 21). For additional details on estimating oxygen supply availability, please see Appendix B.

Table 21. Total available oxygen supply per facility.

Facility name	Supply from PSA plants (LPM)	Supply from cylinders (LPM)	Supply from oxygen concentrators (LPM)	Total supply per facility (LPM)
Cancer Diseases Hospital	0	9	150	159
Chinsali General Hospital	500	0	0	500
Kalindawalo General Hospital	500	0	0	500
Levy Mwanawasa UTH	2,000	67	0	2,067
Ndola Teaching Hospital	0	19	40	59
UTH Children's	0	15	15	30
UTH Adult	1,000	67	0	1,067
Women and Newborn Hospital	0	41	55	96
Grand total				**4,478**

Abbreviations: LPM, liters per minute; PSA, pressure swing adsorption; UTH, University Teaching Hospital.

Step 3. Oxygen gap (in LPM) calculated for each facility

The oxygen gap for each facility was calculated by subtracting the oxygen supply available for COVID-19 patients from the estimated oxygen need for COVID-19 patients (Table 22). Oxygen supply available for COVID-19 patients is a fraction of total available oxygen supply at a facility since some oxygen supply must be reserved for non-COVID-19 patients. Please see Appendix B for additional details and assumptions for the oxygen gap estimation.

Table 22. Oxygen supply gap by scenario.

Facility name	100% capacity (maximum patient load)			50% capacity (decreased patient load)		
	Estimated oxygen need for COVID-19 patients (LPM)	Oxygen supply available for COVID-19 patients*	Oxygen gap (LPM)	Estimated oxygen need for COVID-19 patients (LPM)	Oxygen supply available for COVID-19 patients**	Oxygen gap (LPM)
Ndola Teaching Hospital	950	12	938	475	12	463
UTH Adult	900	213	687	525	213	312
Levy Mwanawasa UTH	870	413	457	495	413	82
UTH Children’s	445	6	439	222	6	216
Women and Newborn Hospital	410	19	391	205	19	186
Cancer Diseases Hospital	250	32	218	125	32	93
Chinsali General Hospital	340	100	240	230	100	130
Kalindawalo General Hospital	340	100	240	230	100	130
Grand total	**4,505**	**895**	**3,610**	**2,507**	**896**	**1,611**

Abbreviations: LPM, liters per minute; UTH, University Teaching Hospital.
*20% of total available oxygen supply, **Oxygen supply available for COVID-19 patients is kept at 20% in the 50% capacity scenario, because it is unlikely that oxygen supply for COVID-19 patients would decrease when less COVID-19 patients are occupying beds.

Step 4. Oxygen gap calculated for each facility using PATH’s total cost of ownership (TCO) tool for oxygen delivery devices

Input into the TCO[h] included not only oxygen gaps (in LPM) but also facility characteristics, such as electricity source and hours of operation, creating a costed oxygen supply source mix for each facility. The user of the TCO tool can decide which oxygen products to use to fill the oxygen gap and can choose between cylinders, PSA plants, and oxygen concentrators.[i]

The product mix chosen for each facility[j] was informed by the MOH’s official rapid scale-up plan, the Comprehensive Rapid Assessment of Oxygen Production and Delivery Systems in Zambia. This ensured that the products chosen aligned with the technical expertise of facility staff and managers and the priorities of the Zambia government. For instance, size J cylinders (6,800 L) are the most recommended in the MOH plan for procurement, so size J cylinders were forecasted in the TCO. Oxygen concentrators

[h] Link to download TCO tools for oxygen and pulse oximetry and their delivery sources / devices: https://www.path.org/resources/quantification-and-costing-tools/#:~:text=The%20Quantification%20and%20Costing%20Tools,need%20with%20different%20device%20types.
[i] Cylinder sizes in the TCO were small (3,400 L), medium (6,800 L), and large (8,500 L). Oxygen concentrator sizes were small (5 LPM), medium (8 LPM), and large (10 LPM). PSA plant sizes were small (50 LPM), medium (200 LPM), and large (500 LPM).
[j] The UTH facilities were grouped together for estimation, resembling the recommendation structure in the MOH’s oxygen strategy.

of size 8 and 10 LPM were forecasted in the TCO because these sizes can treat COVID-19 patients requiring higher flow rates.

Output of the tool included quantities of equipment and supplies required to fulfill oxygen need from COVID-19, plus their associated capital and operational costs. Costs are forecasted for a period of six months. Table 23 shows the product mix required to fill the oxygen gap at each facility under the 100% capacity scenario. It also shows the total cost to procure and operate equipment for six months. Results for the 50% capacity scenario can be found in Appendix B.

Table 23. Total procurement quantities and cost for 100% capacity scenario.

Facility name	**Oxygen gap (LPM)**	**Quantity of equipment, by type**				**Capital expense (USD)**	**Operating expense (USD)**	**Total cost (6 mo.)**
		PSA plant (500 LPM)	Oxygen concentrator (10 LPM)	Oxygen concentrator (8 LPM)	Oxygen cylinders (6,800L) (refilled weekly)			
Ndola Teaching Hospital	938	1	10	-	502	$264,000	$440,000	$704,000
UTH (including Adult, Women and Newborn, Children's, and Cancer Diseases)	1,733	1*	-	-	1,833	$398,000	$1,517,000	$1,915,000
Levy Mwanawasa UTH	457	-	-	-	680	$74,000	$553,000	$627,000
Chinsali General Hospital	240	-	10	10	89	$30,000	$79,000	$109,000
Kalindawalo General Hospital	240	-	10	10	89	$30,000	$79,000	$109,000
Grand total	**3,608**	**2**	**30**	**20**	**3,193**	**$796,000**	**$2,668,000**	**$3,464,000**

Abbreviations: LPM, liters per minute; UTH, University Teaching Hospital.

*UTH already has a PSA plant; however, survey data indicated this plant requires service. In the absence of details on the type of repairs or upgrades needed for this plant, the cost of a new plant has been inserted. Costs could potentially be lower depending on the facilities' investment choices regarding oxygen supply sources.

Step 5. Pulse oximetry need and costs calculated for each facility using the PATH's TCO tool for pulse oximetry

Oxygen therapy should always be monitored with pulse oximetry to make sure patients are receiving the correct amount of oxygen to treat their hypoxemia.[k,6] Pulse oximetry is also critical for diagnosing

[k] It is estimated that in 15 countries with the highest pneumonia burden, improved medical interventions, including oxygen provision due to pulse oximetry implementation, could avert up to 148,000 deaths.[6]

hypoxemic patients and therefore an essential tool for triage.[l] The PATH TCO for pulse oximetry was used for estimating pulse oximetry needs across all facilities, with bed counts as inputs.[m] Two types of POXs are recommended: spot-check devices and continuous-monitoring devices. Cost estimates are forecasted for six months to account for operational expenses.[n] Pulse oximetry needs were estimated for each facility and are presented in Table 24.

Table 24. Pulse oximetry needs estimation by facility.

Facility name	Spot-check units (fingertip POXs)		Continuous-monitoring units (handheld POXs)		Total cost, USD (six months)
	Quantity	Cost (six months)	Quantity	Cost (six months)	
Ndola Teaching Hospital	168	$15,830	90	$41,740	**$57,570**
UTH Adult	167	$15,730	82	$38,030	**$53,760**
Levy Mwanawasa UTH	144	$13,560	81	$37,560	**$51,120**
UTH Children's	71	$6,690	40	$18,550	**$25,240**
Women and Newborn Hospital	65	$6,120	37	$17,160	**$23,280**
Cancer Diseases Hospital	50	$4,710	25	$11,590	**$16,300**
Chinsali General Hospital	42	$3,960	28	$12,980	**$16,940**
Kalindawalo General Hospital	42	$3,960	28	$12,980	**$16,940**
Grand total	**749**	**$70,560**	**411**	**$190,590**	**$261,150**

Abbreviations: POX, pulse oximeter; UTH, University Teaching Hospital.

Estimation conclusion

The oxygen supply gap in Zambia COVID-19 treatment centers, estimated to be approximately 3,610 LPM, is significant. This shortage would be experienced under the scenario where 20% of beds in each facility are occupied by COVID-19 patients. In total, that would be only 747 patients, or 20% (747/3,820) of all available beds across the eight facilities. This scenario is very plausible, considering caseloads seen in previous COVID-19 surges in Zambia. A review of situation reports published by the Zambia National Public Health Institute shows how hospital caseloads have fluctuated in the past several months. One of the highest caseloads was seen at the end of January, where 495 individuals were hospitalized, 339 of which were reportedly receiving oxygen therapy and 35 of which were in critical condition.[7,o] This shows that previous COVID-19 surges have come very close to experiencing the forecasted oxygen and equipment/supply needs estimated in a scenario where all COVID-19-allocated beds are occupied.

The estimated cost for filling the oxygen supply gap at facilities (Table 23) is almost US$3.5 million under a scenario where all COVID-19-allocated beds are occupied (100% capacity scenario). The product mix

[l] According to Raphael Kazidule, nurse at Queen Elizabeth Central Hospital, Malawi (February 2019), in the absence of pulse oximetry, health care workers often rely on clinical signs, such as difficulty breathing, to make a diagnosis of hypoxemia. These methods are likely to miss many hypoxemic patients who may require rapid intervention to avert mortality.

[m] Number of POXs needed are estimated based on an assumption that there should be one spot-check POX for every five general beds and one spot-check POX for every bed with added services. For continuous-monitoring POXs, one device should be available for every two beds with added services and one device for every critical care bed.

[n] Estimated capital cost is US$40.00 for a fingertip POX and $230.00 for a handheld POX. Operating expenses includes maintenance, other labor, and replacement parts for devices.

[o] Additional archived reports can be found here: http://znphi.co.zm/news/situation-reports-new-coronavirus-covid-19-sitreps/.

recommendation to fill the gap was based on the MOH’s Comprehensive Rapid Assessment of Oxygen Production and Delivery Systems in Zambia. This increases the likelihood that facilities have the absorptive capacity for the chosen products, since the recommendation aligns with technical expertise of facility staff and managers and the priorities of the Zambia government; however, the product mix is not optimized for cost. Facilities may be able to reduce costs, or change the breakdown between capital and operational costs, by choosing different products. Overall, it is important that a facility has the clinical and technical capacity to manage and maintain whatever product mix is ultimately chosen.

Pulse oximetry is a critical investment that should be made alongside other oxygen equipment and supplies and should be available whenever administering oxygen therapy. The needs estimation for pulse oximetry is also based on the COVID-19 100% capacity scenario (20% of all beds occupied for COVID-19 patients). The estimated cost to fill the pulse oximetry gap across facilities is just over US$261,000, which includes procurement and six months of operation for the devices (capital costs for POXs are much greater than operational expenses). From the BMES assessment, facilities had very few available devices, showing an incredibly constrained ability to provide safe oxygen, even without the added burden of COVID-19 patients. Overall, procurement of pulse oximetry should be prioritized.

Lastly, in addition to oxygen delivery devices and pulse oximetry, there is a wide range of accessories and consumables that are recommended to provide a complete package of items for administering safe and reliable respiratory care. These items include masks, tubing, and intubation equipment, among other items. These items must also be considered when scaling up oxygen delivery devices. Please see Appendix B for more details.

Recommendations for oxygen scale-up

COVID-19 treatment centers in Zambia require urgent procurement of medical devices, accessories, and consumables for respiratory care. Facilities such as Ndola Teaching Hospital and the UTHs, although having been open for years, have low quantities of oxygen delivery devices like ventilators. Across all facilities, the ability to monitor oxygen delivery appears to be insufficient, given the very limited number of devices in proportion to oxygen delivery devices and beds. Also, the types of device available at the different facilities vary widely, suggesting unstandardized health service delivery across facilities of the same level. For instance, Chinsali General Hospital and the UTHs are all considered tertiary-level facilities, yet Chinsali reported having nearly half of all functional ventilators (45). The reverse trend is observed with suction devices, for which Chinsali reported having only 2 while the UTHs collectively reported having 101.

Monitoring devices (i.e., patient monitors and pulse oximetry) did not correlate with bed counts or oxygen delivery devices across all facilities. This suggests either many patients go without safe oxygen delivery and/or oxygen monitoring constrains the number of patients who can receive oxygen therapy.

Overall treatment capacity also seems to be a constraining factor to providing respiratory care. The scarcity of clinical staff reported at facilities is alarming, especially at the newer facilities: at the time of assessment, Chinsali, Kalindawalo, and Levy Mwanawasa all reported having zero staff in the categories of clinical officer anesthetist, critical care nurses, critical care specialists, and anesthetists.

Oxygen supply also appears to be extremely dependent on cylinder supply from the private sector. Very few oxygen concentrators were available at the surveyed facilities. At the time of this assessment, the assessment team strongly recommended procuring oxygen concentrators to supplement oxygen cylinder use in health facilities. Overall, it is ideal to have availability of multiple oxygen supply sources and avoid sole reliance on any one supply source, which could result in complete unavailability given an adverse event such as power outages, device failure, or unreliable restock of supply, accessories, consumables, or spare parts.[p]

[p] The assessment team, which visited facilities, made an informal estimate that UTH Adult requires about 400 oxygen concentrators to meet rising oxygen demand. The US Agency for International Development, through its DISCOVER-Health (District Coverage of Health Services) project, had procured 1,000 oxygen concentrators recently, 150 of which were supplied to UTH Adult.

Conclusion

BMES data collection in Zambia was able to characterize and quantify the respiratory care capacity of several key facilities. Understanding the availability of respiratory care equipment in health facilities is the first step to accurately estimating the gap in equipment supply and understanding capabilities and limitations for treating COVID-19 patients in particular, as well as patients generally. If these recommendations and challenges are observed by stakeholders, and if facilities are supported in oxygen scale-up and procurement of respiratory care commodities, treatment capacity can be greatly increased in both the immediate and long-term future.

Rapid scale-up of baseline treatment capacity at facilities will be critical to the emergency response to potential surges in oxygen demand from COVID-19 cases. Increased capacity to provide respiratory care is also valuable beyond the pandemic response, since oxygen demand for woman, children, and newborns; during surgery; and for treatment of pneumonia and other respiratory illness is ever present. After the pandemic response, equipment may be reallocated to provide oxygen resources to areas of greatest need.

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Data collection team:

- Mr. Emmanuel Mwale, Zambia Ministry of Health (MOH)
- Mr. Masuzyo Zyambo, MOH
- Dr. Hazel Mphanshya, MOH
- Dr. Christopher Chanda, MOH
- Mr. Musakanya Chilekwa, MOH
- Dr. Micheal Kangwa, MOH
- Mr. Wisdom Chelu, MOH
- Mr. Jackson Mwanza, MOH
- Mr. Christopher Sinkala, MOH
- Dr. Earnest Muyunda, PATH

Supervision team:

- Dr. Christopher Chanda, MOH
- Mr. Wisdom Chelu, MOH
- Mr. Earnest Muyunda, PATH
- Inutu Kanyama, PATH

Report writing team:

- Hannah Erdy, PATH
- Zach Clemence, PATH
- Earnest Muyunda, PATH
- Inutu Kanyama, PATH
- Dr Christopher Chanda, MOH
- Ravi Doshi, PATH
- Lisa Smith, PATH

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Appendix A. Additional analysis

Government scale-up plan

The observations and recommendations within this guide aim to support and align with the Comprehensive Rapid Assessment of Oxygen Production and Delivery Systems in Zambia, the official rapid scale-up plan from the Ministry of Health (MOH). The key challenges and primary interventions identified in the plan are summarized below.[7]

The key challenges are as follows:

- Oxygen production capacity is insufficient in Zambia due to limited pressure swing adsorption (PSA) plants, insufficiently maintained plants or associated infrastructure, oxygen cylinder shortages, too few private suppliers of oxygen, and shortage of medical devices such as oxygen concentrators.
- National debt has constrained disbursement of funds to the health sector and has especially limited district-level operations.
- There are stockouts of essential medicines. Supply chains that stock service delivery points are inadequate for providing reliable resupply.

The primary interventions are to:

- Adopt a hub-and-spoke service delivery model, with one-to-two health centers for management of critical care cases per province.
- Establish a center in each district for treatment of moderate-to-severe cases. Each facility in the country should have the minimum respiratory care equipment to treat patients during referral wait times (several patients for up to a few hours).
- Provide oxygen production equipment appropriate for each level of care—either PSA plants, portable oxygen concentrators, or cylinders (as stand-alone units or hooked up to oxygen manifolds).
- Scale up oxygen production capacity to provide for increased COVID-19 demand in public health facilities.
- Assess oxygen needs and scale up supply at Levy Mwanawasa UTH, other UTHs, and ten provincial hospitals.
- Landscape private-sector oxygen suppliers and their capacity for oxygen production and supply. Maintain a province- and/or district-level database of suppliers who can deliver medical oxygen to prioritized health facilities across all the districts.
- Develop a system for the supply and delivery of oxygen to health facilities from private-sector suppliers (the system should prioritize district hospitals or equivalent and zonal health centers).
- Develop standard operating procedures for the management and maintenance of oxygen production and delivery equipment in health facilities.
- Quantify availability of biomedical equipment technicians and assist their uptake of standard operating procedures.

- Develop and adopt indicators for monitoring medical oxygen production and delivery systems; establish systems and procedures to routinely monitor and evaluate progress in comparison to these indicators.

Other strategic objectives meant to support a national COVID-19 respiratory disease response include:

- Strengthening and expanding access to acute and emergency care, high dependency units (HDUs), and intensive care units (ICUs) to effectively support the case management strategy.
- Lobbying and advocating for maintaining access to defined emergency and essential services—such as surgery, anesthesia, and obstetrics—during short or long intermittent periods of localized or nationwide public health quarantine.
- Expanding both the general and specialist health care workforce, especially those trained in critical care and anesthesia—enhancing their skills and ensuring supply of high-quality personal protection equipment; infection prevention and control of occupational environments, with participatory involvement in health facility decision-making and emergency health response insurance coverage; and special working and living conditions.
- Lobbying for procurement of critical care equipment, expansion of existing HDUs and ICUS, and establishment of new HDUs, especially in all first-level hospitals.

Additional details on estimating total available oxygen supply

The following data and assumptions were used to calculate available oxygen supply by equipment type. The MOH provided additional information on cylinder consumption and cylinder refills (Table 25). Facilities reported in the BMES whether they had cylinders supplied by private suppliers or filled cylinders via an on-site PSA plant. For facilities renting cylinders, their cylinder capacity was added to other existing capacities from plants and concentrators. For facilities filling cylinders (Chinsali and Kalindawalo), only plant production capacity was used. For oxygen concentrators, available supply was calculated by assuming devices would run at their maximum flow rate for 24 hours.

Table 25. Cylinder production capacities per facility.

Facility name	Cylinders consumed weekly*	Average size of cylinder used (L)**	Cylinder inventory*	Liter conversion of inventory	Cylinder-filling model
Cancer Diseases Hospital	70	1,360	30	0	Rental
Chinsali General Hospital	70†	1,360	0	0	On-site plant supply
Kalindawalo General Hospital	70†	1,360	1	340	On-site plant supply
Levy Mwanawasa UTH	496‡	1,360‡	0	0	Rental
Ndola Teaching Hospital	140	1,360	152	200,600	Rental
UTH Children's	114	1,360	16	16,660	Rental
UTH Adult	496	1,360	385	523,600	Rental
Women and Newborn Hospital	302	1,360	0	0	Rental

Abbreviation: BMES, Biomedical Equipment Survey; UTH, University Teaching Hospital.
* At time of BMES.
** Size F (1,360 L) was the most prevalent cylinder size in the BMES and therefore assumed to be most prevalent at all facilities.
† Chinsali and Kalindawalo are assumed to consume 70 cylinders per week because they are similar in size (beds) to the Cancer Diseases Hospital, for which cylinder size and consumption were known.
‡ Levy Mwanawasa cylinder consumption and size are assumed to be like UTH Adult, as these are the two major treatment centers.

Additional details on estimating the oxygen gap

It is important to note that estimated oxygen need from COVID-19, calculated using the World Health Organization COVID-19 Essential supplies forecasting tool (ESFT), version 2, was based on the number of beds allocated for COVID-19 patients and does not account for non-COVID-19 patients' oxygen need. Because of this, an important assumption was made to calculate the oxygen gap: total available oxygen supply at health facilities cannot all be allocated to COVID-19 patients; some of the oxygen supply must be reserved for non-COVID-19 patients. To account for this, oxygen supply available for COVID-19 patients was reduced in proportion to the number of beds they occupy. For example, in the 100% capacity scenario, COVID-19 patients will occupy 20% of total facility beds and therefore are allocated 20% of the total available oxygen supply. The other 80% of beds, and 80% of total available oxygen supply, are reserved for non-COVID-19 patients.

There were several limitations to the estimation of available oxygen supply for COVID-19 patients. For one, the estimation assumes that COVID-19 patients consume the same amount of oxygen as their non-COVID-19 counterparts; however, COVID-19 patients take up far more oxygen resources than non-COVID-19 patients. Therefore, facilities would likely allocate more than 20% of total available oxygen supply to COVID-19 patients (who are occupying 20% of total beds). However, the estimation of total available oxygen supply at each facility is likely an overestimate. For example, PSA plants and oxygen concentrators are not operating at maximum capacity, 24/7, as they are assumed to in this estimate.[7] Leakage from oxygen cylinders is also a factor that would reduce total available supply. Overall, the overestimate for non-COVID-19 patient oxygen needs, and overestimate of total available oxygen supply, may work to cancel each other out and produce an estimate that is closer to reality as far as the amount of oxygen available for COVID-19 patients.[7]

Oxygen need estimation under a 50% capacity scenario

Table 26 shows the product mix and estimated costs to fill the oxygen gap from COVID-19 patients under a 50% capacity scenario (half the allocated beds for COVID-19 patents are occupied). This result has been separated into the appendix since stakeholder focus and planning should likely be paid to the 100% capacity scenario. This estimation for the 50% capacity scenario may provide a lower-end reference point for stakeholders and an idea of how costs may vary if investing in a reduced number of supplies.

Table 26. Total procurement quantities and cost for 50% capacity scenario.

Facility name	Oxygen gap (LPM)	Quantity of equipment, by type				Capital expense (USD)	Operating expense (USD)	Total cost (6 mo.)
		PSA plant (500 LPM)	OCs (10 LPM)	OCs (8 LPM)	Oxygen cylinders (6,800 L)			
Ndola Teaching Hospital	463		12		510	$69,000.00	$421,000.00	$490,000.00
UTH (incl. Adult, Women and Newborn, Children's, and Cancer Diseases)	607				902	$98,000.00	$733,000.00	$831,000.00

Levy Mwanawasa UTH	82				122	$14,000.00	$99,000.00	$113,000.00
Chinsali General Hospital	130		4	4	86	$18,000.00	$73,000.00	$91,000.00
Kalindawalo General Hospital	130		4	4	86	$18,000.00	$73,000.00	$91,000.00
Grand total	**1,412**		**20**	**8**	**1,706**	**217,000.00**	**1,399,000.00**	**1,616,000.00**

Abbreviations: LPM, liters per minute; OC, oxygen concentrator; PSA, pressure swing adsorption; UTH, University Teaching Hospital.

Overall, the cost to procure equipment under the 50% capacity scenario, where COVID-19 patients only occupy half of the allocated beds at each facility (10% of total beds), is much lower than the 100% capacity scenario. The 100% capacity scenario is estimated to cost almost US$3.4 million dollars, and the 50% capacity scenario is just over $1.6 million dollars.

Additional respiratory care products

In addition to oxygen delivery devices and pulse oximetry, there are essential accessories and consumables that must be available to administer oxygen therapy safely and reliably. Each of these items should be procured in proportion to the oxygen delivery devices or oxygen source they are paired with and be stocked sufficiently to provide clean consumables per patient. The ESFT v2.0, developed by the World Health Organization, forecasts equipment and supplies need based on an explicit ratio of an item to a particular bed type. For example, the tool recommends having one patient monitor with electrocardiogram per ICU bed. Different ratios are recommended for different equipment types and different bed types. Tables 27 and 28 show the total forecasted equipment and supply needs across all surveyed facilities, for both scenarios (100% and 50% capacity scenarios).

These equipment and supply needs match up to the ESFT v2.0 estimates for oxygen need for COVID-19 patients and therefore use the same input for bed counts (see Table 20 in the “COVID-19 oxygen needs estimation” section). These quantities do not consider the number of supplies already available at each facility. Additionally, they do not include oxygen source (i.e., concentrator, cylinder, or pipe supply) or POXs. These equipment pieces were forecasted separately, by facility, and are available to view in the “COVID-19 oxygen needs estimation” section.

Table 27. Total forecasted equipment and supplies need for COVID-19 under a 100% capacity scenario.

Item	Total quantity	Total cost (USD)
Infrared thermometer	37	$934
Pulse oximeter (adult + pediatric probes)	-	$0
Patient monitor, multiparametric with ECG, with accessories	77	$607,939
Patient monitor, multiparametric without ECG, with accessories	168	$217,787
Oxygen source (i.e., concentrator, cylinder, or pipe supply)	-	$0
Laryngoscope (direct or video type)	51	$4,104
Patient ventilator, intensive care, with breathing circuits and patient interface	51	$1,455,996
CPAP, with tubing and patient interfaces, with accessories	13	$71,892
High-flow nasal cannula, with tubing and patient interfaces	13	$25,648
Electronic drop counter, IV fluids	670	$109,563
Infusion pump	168	$167,528
Blood gas analyzer, portable with cartridges and control solutions	19	$8,965

Ultrasound, portable, with transducers and trolley	19	$149,411
Drill, for vascular access, with accessories, with transport bag	19	$15,875
Electrocardiograph, portable with accessories	19	$27,081
Suction pump	244	$440,051
Bubble humidifier, non-heated	737	$2,580
Tubing, medical gases, int. diam. 5 mm	19	$50
Flow splitter, 5 flowmeters 0–2 LPM, for pediatric use	19	$2,559
Flowmeter, Thorpe tube, for pipe oxygen 0–15 LPM	25	$2,539
Filter, heat and moisture exchanger, high efficiency, with connectors, for adult	914	$3,656
Conductive gel, container	23	$28
Catheter, nasal, 40 cm, with lateral eyes, sterile, single use; different sizes: 10/12/14/16/18 Fr	448	$3,451
Nasal oxygen cannula, with prongs, adult and pediatric	5,361	$3,753
Mask, oxygen, with connection tube, reservoir bag and valve, high-concentration single use (adult)	5,361	$10,186
Venturi mask, with percent O2 lock and tubing (adult)	5,361	$6,969
Compressible self-refilling ventilation bag, capacity > 1500 mL, with masks (small, medium, large)	26	$1,590
Airway, nasopharyngeal, sterile, single use; set with sizes 20/22/24/26/28/30/32/34/36 Fr	616	$252
Airway, oropharyngeal, Guedel; set with sizes 2 (70 mm), 3 (80 mm), 4 (90 mm), 5 (100 mm)	616	$123
Colorimetric end-tidal CO2 detector, single use (adult)	616	$8,002
Cricothyrotomy, set, emergency, 6 mm, sterile, single use	51	$28,213
Endotracheal tube introducer	616	$456
Tube, endotracheal	616	$671
Laryngeal mask airway	616	$1,834
Lubricating jelly, for critical patient gastro-enteral feeding and airway management & intubation	23	$79
Total cost		**$3,379,765**

Abbreviations: CPAP, continuous positive airway pressure; ECG, electrocardiogram; LPM, liters per minute; FR, French scale.

Table 28. Total forecasted equipment and supplies need for COVID-19 under 50% capacity scenario.

Item	Total quantity	Total cost (USD)
Infrared thermometer	17	$435
Pulse oximeter (adult + pediatric probes)	-	$0
Patient monitor, multiparametric with ECG, with accessories	77	$607,937
Patient monitor, multiparametric without ECG, with accessories	68	$87,970
Oxygen source (i.e., concentrator, cylinder, or pipe supply)	-	$0
Laryngoscope (direct or video type)	51	$4,104
Patient ventilator, intensive care, with breathing circuits and patient interface	51	$1,455,992
CPAP, with tubing and patient interfaces, with accessories	13	$71,892
High-flow nasal cannula, with tubing and patient interfaces	13	$25,648
Electronic drop counter, IV fluids	271	$44,255
Infusion pump	68	$67,669
Blood gas analyzer, portable with cartridges and control solutions	9	$4,171
Ultrasound, portable, with transducers and trolley	9	$69,524
Drill, for vascular access, with accessories, with transport bag	9	$7,387
Electrocardiograph, portable with accessories	9	$12,601
Suction pump	145	$260,304
Bubble humidifier, non-heated	298	$1,042
Tubing, medical gases, int. diam. 5 mm	9	$23
Flow splitter, 5 flowmeters 0–22 LPM, for pediatric use	9	$1,191
Flowmeter, Thorpe tube, for pipe oxygen 0–15 LPM	25	$2,539
Filter, heat and moisture exchanger, high efficiency, with connectors, for adult	914	$3,656
Conductive gel, container	23	$28
Catheter, nasal, 40 cm, with lateral eyes, sterile, single use; different sizes: 10/12/14/16/18 Fr	209	$1,606
Nasal oxygen cannula, with prongs, adult and pediatric	2,165	$1,516
Mask, oxygen, with connection tube, reservoir bag and valve, high-concentration single use (adult)	2,165	$4,114
Venturi mask, with percent O2 lock and tubing (adult)	2,165	$2,815

Compressible self-refilling ventilation bag, capacity > 1500 mL, with masks (small, medium, large)	26	$1,590
Airway, nasopharyngeal, sterile, single use, set with sizes 20/22/24/26/28/30/32/34/36 Fr	616	$252
Airway, oropharyngeal, Guedel, set with sizes 2 (70 mm), 3 (80 mm), 4 (90 mm), 5 (100 mm)	616	$123
Colorimetric end-tidal CO2 detector, single use (adult)	616	$8,002
Cricothyrotomy, set, emergency, 6 mm, sterile, single use	51	$28,213
Endotracheal tube introducer	616	$456
Tube, endotracheal	616	$671
Laryngeal mask airway	616	$1,834
Lubricating jelly, for critical patient gastro-enteral feeding and airway management & intubation	23	$79
Total cost		**$2,779,641**

Abbreviations: CPAP, continuous positive airway pressure; ECG, electrocardiogram; LPM, liters per minute; FR, French scale.

Equipping all facilities with equipment and supplies to treat COVID-19 patients under a scenario where all COVID-19-allocated beds are occupied would cost nearly $3.4 million. Equipping beds for a scenario where 50% of COVID-19-allocated beds are occupied would cost slightly less at $2.8 million. Overall, it is important to consider these items because their lack constrains ability to deliver respiratory and critical care. For instance, not having tubing or masks stocked for patients would inhibit ability to use oxygen concentrators, cylinders, and ventilators, among other devices. Implementing an inventory management system—and, ideally, an equipment management system as well—can help to monitor stock status, streamline reordering, and result in more reliable availability of equipment and supplies. Investing in such systems would be additional to the costs in the above two tables but would result in major cost savings in the long-term, beyond the COVID-19 emergency response.