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ASSESSING PREVENTATIVE MAINTENANCE AND SUSTAINABILITY OF OXYGEN CONCENTRATORS IN HEALTH FACILITIES IN PAPUA NEW GUINEA

Running title: *Importance of Equipment Maintenance*

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ABSTRACT:
The lifespan of medical equipment depends on preventative maintenance. Properly functioning oxygen concentrators are the only practical sources of oxygen in many Low & Middle Income Countries and their use reduces mortality in hospitalised children. We provided 82 concentrators with pulse oximeters, split flow meters, oxygen tubing, and an oxygen analyser to 38 health facilities. Training and instructions on how to perform preventative maintenance were provided. The concentrators were monitored for three years after they were installed, by assessing the proportion of concentrators still producing optimal oxygen at greater than 85% purity, the proportion that underwent weekly maintenance checks, and the proportion that were faulty and repaired. A logbook for weekly documentation of performance, maintenance, faults and repairs, was employed. Faults were additionally identified by a biomedical engineer during the visits. Twenty nine oxygen concentrators underwent regular maintenance checks, 25 (86.2%) of which had a median of 30 (IQR: 9 - 65) checks. Twenty-four were functioning well throughout the three years. One concentrator was used for 23,807 hours before requiring repair. Fourteen (24%) of the 58 concentrators used at the start of the programme had problems, two were repaired, and 12 were replaced. Concentrator failure was mostly caused by excessive movement, dust, and leaking in the internal tubing. Routine preventative maintenance, thorough documentation of performance and reporting of problems, and having access to clinicians and a knowledgeable biomedical engineer are essential for oxygen concentrator longevity in health care facilities in low-resource settings.

Keywords: Oxygen concentrator, Preventative maintenance, Papua New Guinea

INTRODUCTION:

Preventative maintenance of medical equipment is vital to ensure it is operating within manufacturer's specifications, to enhance longevity, and to protect the health workers and patients from hazards [1-3]. Ideally medical equipment in all facilities should be checked and maintained by biomedical engineers [2]. In low resource settings, there are shortages of biomedical engineers and lack of spare parts to perform repairs and costs for technicians to travel to remote areas can be high. As a result, oxygen concentrator maintenance has been inconsistent, and many malfunction oxygen concentrators have not been repaired [4, 5].

The health workers who are using the equipment and who have been trained on oxygen concentrator preventative maintenance are now performing the maintenance as more reliable oxygen concentrators become available [2, 6-8]. Preventative maintenance practices performed by the health workers include adjusting, cleaning, calibrating output or readings, changing filters, basic troubleshooting and replacing worn out parts [2, 3]. It has been argued that decentralising preventative maintenance to health workers using the oxygen concentrators is beneficial [2, 6-8] and minimises the need for onsite checks by biomedical engineers

The benefits of oxygen concentrators in low and middle income countries (LMIC) including Papua New Guinea (PNG) are well established [6-8]. This study aimed to describe the steps in performing preventative maintenance, assess the proportion of oxygen concentrators that have undergone the weekly maintenance and performance checking, the proportion of oxygen concentrators providing greater than 85% oxygen purity as checked by oxygen analyser, and identify the problems and corrective actions undertaken at the end of three years post installation.

MATERIALS AND METHODS:

This was a prospective, follow-up study conducted from 2017 to 2019 that was part of the large effectiveness trial on oxygen concentrators powered by solar power and mains power in 38 rural health facilities in Papua New Guinea.

Ethics approval was obtained from the Medical Research Advisory Committee (MRAC No. 18.12) and School of Medicine and Health Sciences Research and Ethics Committee, University of Papua New Guinea.

The feasible steps for oxygen concentrator maintenance was designed and health care workers were instructed to apply each specific step over the period of three years. During that period, the sustainability of oxygen concentrators distributed to the health facilities were documented.

Preventative maintenance (PM) steps were:

Developing a maintenance check logbook: A simplified maintenance check logbook for health workers containing the specific tasks to be performed weekly to prevent mechanical failure was designed. The weekly duties include checking the number of hours the machine has been used, cleaning and replacing the filter, cleaning the machine external surface and checking the percentage of oxygen concentrated using an oxygen analyser.

Training of health workers by a biomedical engineer: Training workshops were conducted by a biomedical engineer with expertise in maintaining and repairing oxygen concentrators, and a senior clinician (paediatrician) with expertise in oxygen concentrator use and provision of oxygen before the installation. The biomedical engineer is a registered electrician with specific training on the Airsep Elite (Chart

Industries, New York NY, USA) oxygen concentrator: though he can service other oxygen concentrator brands.

The training for health workers (community health workers, nurses, health extension officers and doctors) was conducted in workshops held in various hospitals from 2016 to 2019 and during the investigator visits once or twice in a year from 2017 to 2019. The training covered how to operate the machines, perform the weekly oxygen concentrator checks and basic troubleshooting skills. It also covered checking the oxygen concentrators that were in active use on a weekly basis for the number of hours used; cleaning and replacing the filter; cleaning the external surface; and measuring the percentage of oxygen being generated using an oxygen analyser (Maxtec). Health workers were advised to place the machine on a stand so that it was off the floor and to place it at least 30 centimetres away from the wall, and keep it covered when not in use. These measures prevent dust from entering the machine, to ensure the flow of air into the machine is unobstructed, and to avoid a fire hazard.

Participants were also trained on identifying problems with the machine. The basic trouble shooting skills that were taught included recognising abnormal alarm sounds: intermittent or constant- indicating problems with the internal parts; machine sound- indicating pressure problem; and difference in amber light colour: persistent orange colour after 15 minutes- indicating that the machine was not generating 85% oxygen. In addition, a preventative maintenance protocol and weekly schedule for the user's logbook was provided.

Inventory and distribution of oxygen concentrators:

A total of 82 Airsep Elite 5 Litre/minute oxygen concentrators (Chart Industries, New York NY, USA) [3, 9] with pulse oximeters, flow splitters, delivery tubing and nasal prongs were distributed to 38 health facilities. This model of oxygen concentrator is robust and capable of functioning well at high environmental temperature and humidity, and has been used in Papua New Guinea since 2005 [3, 9, 10]. The district and rural hospitals received three oxygen concentrators and each health centre received two oxygen concentrators. An inventory of 82 oxygen concentrators, containing the name of the health facility and serial number of the oxygen concentrators delivered to each health facility, number of faulty concentrators, and the faults and corrective actions taken was maintained throughout the project. This information was important in locating the machines and provide maintenance in a timely manner.

Risk assessment and reporting of faulty oxygen concentrator:

Oxygen concentrators that produced abnormal alarm sounds and persistent orange amber light or which produced oxygen concentration below 85% were reported to the biomedical engineer or the investigator. For an efficient and effective communication, phone numbers and emails of biomedical engineer and the investigator were given to the health workers in each health facility or written on the oxygen concentrators that were in active use using stick on tape, and written in the logbook. When faults were identified, the investigator reported them to the biomedical engineer who attended to the problem if the health facilities were in close proximity and also instructed the health workers to perform basic physical rectifying strategies. Oxygen concentrators that could not immediately be fixed by health workers were stored away safely for assessment by the biomedical engineer at the next visit.

Monitoring of oxygen concentrator:

Maintenance and monitoring visits were scheduled once or twice a year during the period of three years post installation. On each visit, we checked the logbooks, provided ongoing training for the new staff and support of equipment usage, performed servicing as appropriate and ensured the concentration of oxygen delivered by concentrator was greater than 85%. The investigator also made telephone contact with each of the health facilities on a monthly basis.

Servicing the oxygen concentrator:

Servicing and maintenance was done by the biomedical engineer at each visit. The machines that were faulty were repaired and the others that were irreparable onsite were replaced or taken away for repair. We used functioning parts from concentrators that were irreparable to repair malfunctioning machines and placed an order for additional parts that were needed

Information was gathered from the logbook of oxygen concentrator checks, reports from the health workers, and documentation of events and occurrences during the visits by the paediatricians and the biomedical engineer. Oxygen equipment sustainability was assessed as the proportion of oxygen concentrators still functioning well at the end of three years of use. Data were entered into Microsoft Excel Version 2013 and analysed using IBM Statistical packages for Social Sciences (SPSS) 27. Percentages and frequencies were calculated for categorical data, median and interquartile ranges (IQR) were calculated for numerical non-parametric data.

RESULTS:

Eighty-two oxygen concentrators were distributed to 38 rural health facilities. Of the 38 health facilities, 22 (58%) were run by the Government and 16 (42%) by the churches. Of the 82 concentrators, 24 (29%) were held in reserve at the health facilities for later use and 58 (71%) were in active use from the beginning of the study. Of the 58, 14 (24%) had mechanical failure at some point in the three years; two were repaired and 12 were replaced. Regular assessments of 29 (50%) of the 58 concentrators were recorded in the logbooks in 15 (39%) of the 38 health facilities. The remaining health facilities had no record of regular maintenance checks and it was reported that the concentrator checks did not occur as scheduled in many health facilities (table 1).

One thousand and three (1003) oxygen concentrator checks were recorded in the logbooks. Twenty-five of the 29 concentrators from 15 health facilities had complete records of regular checks. For the 25 oxygen concentrators, the median number of checks recorded per concentrator was 30 (IQR 9-65). The median hours the concentrator was used in patient care was 726 (IQR 305 to 3785). The median percentage of oxygen generated was 96.2% (IQR 93-98%) during checks throughout the three years period (table 2). Twenty-four of the 25 oxygen concentrators (96%) that were regularly checked by health workers were functioning optimally well (fraction of oxygen generated greater than 85%) throughout the three years. Only one (4.0%) of the 25 concentrator that underwent regular checks, which was used for 23,807 hours in Kundiawa General Hospital, required repairing because it was generating less than 85% (79%) oxygen (table 2) as recorded in the logbooks.

The source of faulty oxygen concentrators were from two data sources: (i) logbook of oxygen concentrator checks and (ii) documented during biomedical engineer and investigator visits. Of the 58 oxygen concentrators that were in active use for up to three years, 14 (24%) had malfunctioned at some point. Of the 14 that were functioning poorly, only one at Kundiawa General Hospital has a record of maintenance checks documented in the logbook. The remaining 13 were checked and found to be faulty. 2/14 (14%) were repaired and put back into service whilst 12/14 (86%) were irreparable because of damaged circuit boards.

Excessive movement, dust and leakage in the internal tubing were identified as the main factors associated with the concentrators' malfunctioning. It was also noted that some of these oxygen concentrators were not functioning well despite infrequent use.

Table 1. Oxygen concentrator distribution and record of checking as per oxygen concentrator logbook and documentation during the scheduled visits

Variables	N	%
Government run health facilities (n = 38)	22	58
Churches run health facilities (38)	16	42
Number of health facilities that had a record of checking concentrators (38)	15	39
Total oxygen concentrator distributed (82)	82	100
Number of oxygen concentrator in active use since the beginning of the study (82)	56	68

Number of oxygen concentrator reserved for later use (82)	24	29
Of those in use, number of concentrators checked (58)	29	50
Of those in use, no record of checks (58)	13	22
Of those in use, oxygen concentrator poorly function (58)	14	24

Table 2. Oxygen concentrators that have complete variables checked at the end of 3 years documented in the logbook weekly oxygen concentrator check, n=25.

Variables	Values
Number of checks per oxygen concentrator; median (IQR)	30 (9-65)
Hours used per oxygen concentrator; median (IQR)	726 (305.45-3785)
Percentage oxygen concentration per oxygen concentrator; median (IQR)	96.2 (93-98)
Number of bubble checks per oxygen concentrator; median (IQR)	28 (8-61)
Number of filter changes per oxygen concentrator; median (IQR)	28 (9-60)
Number of external surface cleans per oxygen concentrator; median (IQR)	28 (9-65)
Number of oxygen concentrators have oxygen concentration (n = 25): • Fraction of oxygen greater than 85%*: n (%) • Fraction of oxygen less than 85%: n, (%)	 24, (96) 1, (4)

IQR: interquartile ranges;
*For oxygen concentrator to function optimally well, it has to generate >85% fraction of oxygen

DISCUSSION:

There were three main findings in our study.

First, only 40% of the health facilities had evidence of checking and performing preventative maintenance. Preventative maintenance was performed and recorded on approximately half of the oxygen concentrators that were in active use. Of the concentrators that had a regular record of checking, only one had malfunctioned. The other 13 that malfunctioned had no record of maintenance checking but were identified upon our visits. Only two were able to be repaired. This study, similar to the study conducted in Gambia [6] confirms the importance of preventative maintenance.

Second, the large majority of oxygen concentrators that had a complete record of maintenance checks were operating for over 700 hours, were checked at least 30 times, and were still fully functioning three years after installation. Preventative maintenance increases the lifespan of oxygen concentrators [6, 7], and more children who required oxygen have benefited from the oxygen generated [11, 12]. Health workers should be aware that most oxygen concentrators have lifespan of approximately 20,000 hours, mostly relating to the life span of zeolite [13]. Some oxygen concentrators can operate more than 20,000 hours if regular preventative maintenance were performed. One oxygen concentrator in our study was found to produce 79% oxygen concentration at 23,906 hours. In a study done in Nigeria an oxygen concentrator operating for 26,400 hours required maintenance [7], and in Gambia, one concentrator needed major repair at 59,424 hours [14]. There is enough evidence to suggest that oxygen concentrators can last for many years if regular preventative maintenance is performed [6, 7].

Third, a large proportion of oxygen concentrators that were not functioning well had significant mechanical failure. A damaged circuit board was the most common problem identified, and the contributing factors to the problem were excessive movement, dust and leakage in the internal tubing. Repairing was challenging because of limited spare parts, a problem common in other low resource settings [14]. To maximise the benefit of oxygen concentrator programme, all equipment should be from a single manufacturer and adequate provisions made for spare parts and replacement [8, 15].

The challenges faced by the health facilities and health workers were workforce shortages and turnover of staff; initial lack of confidence in using oxygen concentrators; irregular oxygen concentrator checks; difficult communication with investigator or biomedical engineer due to poor network coverage or cost; and new staff requiring training on oxygen concentrators.

There were further problems identified. Some patients remained hypoxemic despite using the equipment if oxygen concentrators were producing less than 85% oxygen and had not been checked using the oxygen analyser. Incorrect oxygen analyser readings occurred because of failure to calibrate the device. Incorrect regulation of oxygen flow rate to meet the patients' oxygen needs, and incorrect oxygen saturation monitoring using pulse oximetry were noted. Staff was informed and corrective actions were undertaken.

The following are required for quality improvement and sustainability of the oxygen concentrators: health facilities should improve on preventative maintenance documentation and report faulty machines; regular oxygen concentrator maintenance and performance checks using oxygen analyser, regular visits by a biomedical engineer and clinician experienced in oxygen concentrator use and oxygen administration for support, training and maintenance; ongoing training for the health workers using the oxygen concentrator; and support (financial and supervisory visits) from the provincial or national health authority).

A limitation of this study was the failure to record the number of hours used and preventative checks performed for 13 oxygen concentrators that had malfunctioned. Failures in relation to the amount of hours of usage could not be reported because hours of use data was not captured when a concentrator repair was performed. In addition, repair of oxygen concentrators requires a good level of experience, skill and spare parts.

CONCLUSION:

Most oxygen concentrators were still operational after three years. A biomedical engineer with competence in maintenance and repair; a user-friendly preventative maintenance routine; basic troubleshooting abilities; documentation of preventative maintenance practices and reporting of faulty machines; and clinical expertise are all needed.

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