Medical Aid International

Supporting Healthcare in Low Resource Environments

Comprehensive Review of Hospital Equipment in LMICs: An Initial Audit

October 2024

Contents

Introduction

Medical Aid International, in partnership with the Intuitive Foundation, has completed the pilot biomedical engineering initiative to foster capacity-building in low-to-middle-income countries (LMICs).

The initiative comprises six main categories:

1. Candidate selection
2. Onboarding survey
3. Initial audit
4. Online Biomedical Engineering Course
5. Maintenance log
6. Follow-up audit

The overarching aim of this biomedical engineering initiative is to assess the efficacy of Medical Aid International's holistic online biomedical engineering course by:

1. Measuring the change in participants' confidence in performing engineering tasks pre- and post-course.
2. Comparing pre- and post-course equipment audits.
3. Identifying which preventative and corrective maintenance tasks were performed as a direct result of Medical Aid International's online course via records kept in the maintenance log.

This report examines only the data collected from pre-course activities (onboarding survey and initial audit). The aim of this report is to simply present baseline data. As such, the intent is not to validate any hypothesis. As this information was collected before taking the online course, individual assumptions on satisfactory and safe equipment have not yet been informed by the knowledge learned from the Online Biomedical Engineering Course. Accordingly, we anticipate significant changes in the post-course audit and expect to see higher instances of unsafe and unsatisfactory equipment identified after the second audit.

A Word from the Chief Executive

This report builds on our existing research into the standards of medical equipment at healthcare facilities in Low and Middle Income Countries (LMICs), and provides a comprehensive overview into the safety, satisfaction, and rates of use of said equipment.

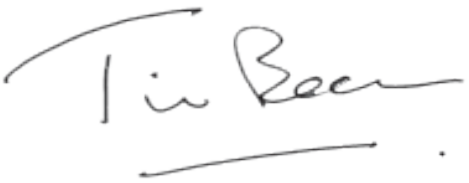
As we reflect on the findings of our recent report, I want to extend my gratitude to the 73 participants across 23 healthcare facilities in 12 Sub-Saharan African countries who contributed invaluable data to this project. This analysis has provided critical insights into the current state of medical equipment and the challenges faced in these regions.

At Medical Aid International, our commitment to advancing biomedical engineering forms an integral part of our overall healthcare strategy. As such, we have invested heavily in this area, undertaking extensive research to further understand all the specific needs of healthcare facilities and to continue our journey of support. Our biomedical engineering course, and this project as a whole, addresses these key challenges by providing technical skills, and fostering a deeper understanding and awareness of equipment management and maintenance.

The report highlights a significant gap between local perceptions of satisfactory and safe medical equipment, and the relevant standards established in Western countries. While many pieces of equipment were rated as satisfactory and safe by participants, the data indicates that only 33% meet our minimum benchmark standards. This underscores three key facts: the need for procurement based on the unique needs of the LMIC environment, further training (this data was collected before participants had completed our biomedical engineering course – it will be interesting to see the results post-course), as well as the urgent need for greater focus on enhancing the quality and reliability of medical equipment across facilities. Of course, as highlighted above, the key to this is sending the correct equipment in the first place – all equipment sent must be suitable for the challenging LMIC environment (significantly reducing the amount of maintenance required, while increasing reliability) – patient safety is clearly compromised if this does not happen.

By addressing these challenges, we aim to ensure that healthcare providers have access to safe, effective medical equipment, which is crucial for delivering quality patient care. Through our ongoing research and collaboration with local engineers and healthcare facilities, we aim to equip them to overcome existing barriers and enhance healthcare delivery.

I would like to thank everyone involved for making this project successful. In particular, Dr Catherine Mohr, the President of the Intuitive Foundation, who has had the ongoing vision to both develop biomedical engineering services across LMICs and use this strategy to obtain accurate and relevant data in order to influence healthcare policy moving forward. We look forward to sharing additional research findings as we continue this work and partnership.



Tim Beacon – Chief Executive Officer, Medical Aid International

Executive Summary

The following report analyses 2930 items of medical equipment data submitted by 73 participants across 23 healthcare facilities throughout 12 Sub-Saharan African countries.

There is a significant discrepancy in what local engineers enrolled in this study perceive as satisfactory medical equipment, and equipment that meets minimum benchmark standards in the West. This study found that, on average, 72%[1] of the equipment was reported as satisfactory by participants. Similarly, 71%[2] of the equipment was deemed safe, and 81%[3] of the equipment had been used within the past six months. However, in the data analysis phase, when these three criteria are applied in tandem, analysis found that on average only 56%[4] of medical equipment is simultaneously satisfactory, safe, and recently used (i.e., acceptable). There is high variability in equipment conditions across the 23 healthcare facilities, ranging from a level of 0% to 99% of acceptable equipment. When slightly more stringent equipment-specific benchmark criteria are implemented, for the purpose of characterising this data against Western standards, the percentage of equipment deemed benchmark compliant is 33%[5]. In the analysis of factors affecting benchmark compliance in medical equipment, we found a significant association between the provision of accessories and higher rates of compliance. This suggests that prioritising the availability and/or quality of accessories could effectively increase the percentage of benchmark-compliant equipment.

Throughout this report, it is important to keep in mind that this assessment was conducted by engineers prior to completing the Medical Aid International Online Course; accordingly, their baseline knowledge is unknown.

The primary means of equipment acquisition on a hospital basis is via donations (on average 56% of equipment is donated, 31% purchased new). This statistic changes significantly using a simple average; of the 2930 items of equipment, 46% are donated and 47% are purchased new.

[1] This is a weighted average where all 23 facilities hold equal weight. The simple average is 80%.

[2] This is a weighted average where all 23 facilities hold equal weight. The simple average is 80%.

[3] This is a weighted average where all 23 facilities hold equal weight. The simple average is 84%.

[4] This is a weighted average where all 23 facilities hold equal weight. The simple average is 67%.

[5] This is a weighted average where all 23 facilities hold equal weight. The simple average is 42%.

Candidate Selection

The Intuitive Foundation provided funding for 70 participants across 25 sites. The selection of candidates was left to the discretion of Medical Aid International. The aim of the selection criteria was to identify the candidates who were most likely to complete the entire initiative and who would provide the highest quality and most accurate data, while simultaneously representing a broad range of healthcare facilities.

Methods

The online application was emailed to everyone within Medical Aid International's and the Intuitive Foundation's mailing list, and advertised across Medical Aid International's social media accounts. The request was made to forward the application. This snowball sampling approach was successful as many applicants were not in the original database. However, this distribution method did bias the applicant pool to those familiar with the two organisations, and those with email and social media access. The application was live for four weeks; within this period, 292 applications from 1083 engineers were received from 29 countries. Appendix Table 1A.1 highlights the breakdown of these applications.

The exclusion criteria were as follows: 1. The facility must be in a low-to-middle income country. This excluded one application from Albania. 2. The facility must not have staff who have already completed the Medical Aid International Biomed training. This excluded 18 sites.

Each application was marked on a rubric (Table 1) to standardise grading and remove selection bias.

Table 1. Applicant Selection Rubric

	0	1	2	3
Complete Application	Application errors	No application errors	-	-
English Ability *of total score*	-	Response is unreadable.	Adequately written but has some distracting errors.	Clearly conveys the message without distracting errors.
Content-Response To Prompt *of total score*	-	Does not answer the question.	Attempts to answer the question.	Thoroughly answers the question.
Content-Enthusiasm *of total score*	-	Demonstrates no enthusiasm nor excitement towards project.	Demonstrates some enthusiasm and/or excitement towards project.	Demonstrates enthusiasm and/or excitement towards project.
Content-Reach/Impact *of total score*	-	Site and/or applicants demonstrate minimal ability to be a wider catalyst for change.	Site and/or applicants demonstrate some ability to be a wider catalyst for change.	Site and/or applicants demonstrate ability to be a wider catalyst for change.
Need *of total score*	-	Appears to be well-funded, advertises speciality services and specialised equipment.	Appears to have some funding, lacks speciality services and equipment.	Appears to have minimal/no funding, lacks basic services and equipment.

Complete Application

Seventy-three facilities failed to follow instructions and submit a completed application. Each healthcare facility was asked to file one joint application and list the name and email for all participating engineers and provide the contact information for the hospital manager. Many facilities submitted unique applications for each participant, did not provide a manager contact, or simply did not complete the application in its entirety. These were immediately excluded from consideration.

The remaining applicants were assessed on their written paragraph.

English Ability

Command of the English language was identified as a critical selection criterion as the online biomedical engineering course is offered in English (and French), the audits are in English, and all communication with Medical Aid International staff was to be in English. We inferred that the stronger the command of English, the greater the probability the applicants would have at comprehending audit instructions and providing clear, detailed equipment reports.

So as not to bias the selection towards facilities with Western-trained or influenced applicants, the English scoring was incredibly generous (see rubric in Table 1). Grammar, spelling, and punctuation were not assessed. Formatting inconsistencies (odd spacing, capitalisation, etc.) were ignored as many of these applications were composed on a phone, making formatting more challenging.

Content

Response

The first category scored how well the candidates responded to the prompt: "Please write a short paragraph detailing why your healthcare facility should be selected." Many applications simply reported on the services offered at the facility or gave a description of the local community but did not expand on why their facility should be selected. These responses, depending on the detail, scored between a 1 and a 2. A score of 3 was reserved for applicants who explicitly answered the question in appropriate length as to why their facility should be selected.

Enthusiasm

Involvement in this project requires a large time commitment and includes rather demanding tasks (i.e., the audit), in addition to a rigorous but rewarding biomedical engineering course. As such, commitment and enthusiasm from all participants, students, and managers alike, are a necessity. Statements that contributed favourably to a high score of a 3 included the following:

- Express excitement and anticipation
- Express not only a desire to benefit the hospital but to enhance personal development
- Reference criteria in MOU or application (i.e. toolkit, asset tagging, requirement for a designated biomed space, etc.) suggesting that they have carefully read and understood the project
- Mention sharing knowledge amongst colleagues and peers at other facilities

Reach/Impact

The third content category is intended to assess the reach and impact applicants would have on their community following completion of the course and provision of accompanying resources. Statements that contributed favourably to a high score of a 3 included the following:

- Large hospital (300+ beds)
- Only hospital in the region
- Large catchment area
- Teaching centre or university hospital
- References mentoring others

Need

The final category is need. Need was not initially intended to be a separate category; however, after reading multiple applications, it became apparent that there was a vast discrepancy in need that could not be overlooked. Some facilities located in urban metropolitan areas boasted of high-tech medical equipment (confirmed by an internet search), an abundance of highly specialised surgeons, and a plethora of biomedical engineers. While there is no doubt that these facilities would still benefit from the online engineering course, the course is aimed at providing foundational knowledge. Accordingly, facilities reporting no tools and a myriad of broken essential lifesaving medical equipment scored a 3 for need. In comparison, those with specialised equipment (i.e., dialysis machines, 4D ultrasounds, MRIs, etc.) scored a 1.

Site Distribution

Once every facility received a score, they were subdivided into four groups determined by the number of applicants at each facility. The groupings/buckets were as follows: extra-small (facilities consisting of 1 applicant), small (2-3 applicants), medium (4-6 applicants), and large (7+ applicants).

The bucket sizes needed to reflect the wider application pool while simultaneously totalling 70 participants at 25 facilities. The division is outlined in Table 2.

Table 2. Health Facility Buckets

	XS (1 applicant)	S (2-3 applicants)	M (4-6 applicants)	L (7+ applicants)	Total
Facilities	11	8	4	2	25 Facilities

Site Notification

All 25 sites were notified of their success and given ample time to agree to the terms and conditions of the MOU and return all consent forms. Two sites were unable to meet these requirements and were replaced with the next highest scoring candidates.

Onboarding Survey

Upon return of all signed documents, every participant was asked to complete a Google form providing background information on themselves and their hospital. Over the course of this project there have been changes to the participating students. Some have been replaced, as they were moved to different facilities, and some sites have acquired more technicians/engineers who have been included in the training. While the total number of toolkits has remained at 70, the number of online courses provided to participating students, at the time of writing, is 76.

The data set below represents 74 individuals. One student did not complete the survey, and one requested their data not be used.

Participant Overview

In summary, the participants (mean age 35) are educated (61% hold university degrees) with an average of 7 years' work experience. The sites on average estimate that 26% of their equipment is non-operational. Seventy-six percent (76%) of participants state that the number one reason for non-operational equipment is due to a lack of spare parts. Additionally, 73% of individuals say they do not have the tools, or the tools they have are insufficient or inadequate, to maintain and fix medical equipment.

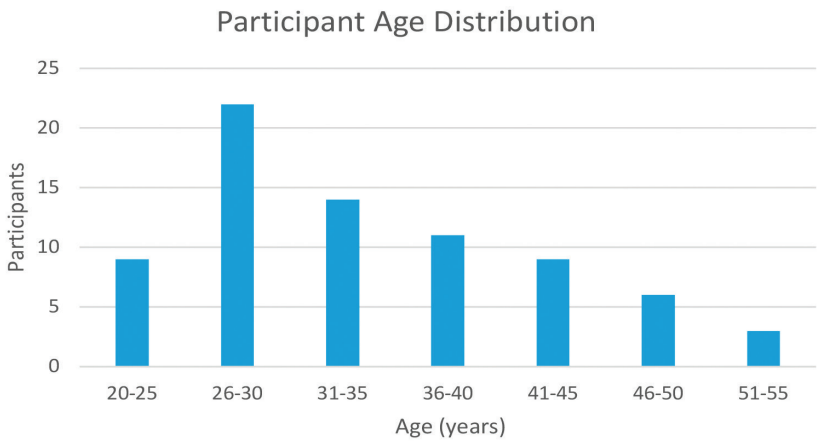
The following section graphically demonstrates the responses to each question in the onboarding survey:

Question 0: What is your age?

Summary:

- Youngest: 23 years
- Oldest: 55 years
- Average: 35 years

Figure 1.

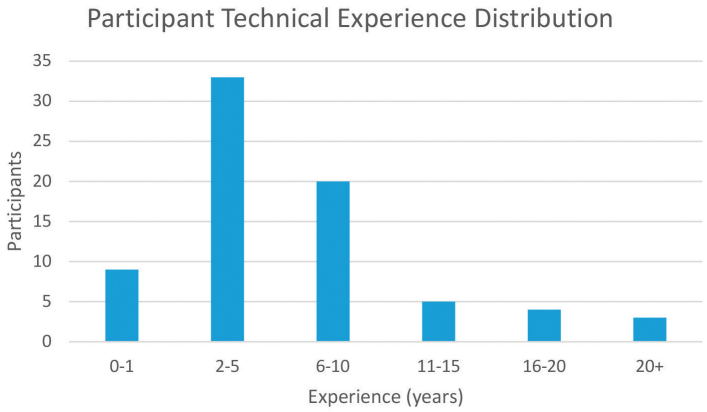


Question 1: How many years have you been working as an engineer/technician?

Summary:

- Least experience: 0 years
- Most experience: 30 years
- Average experience: 7 years

Figure 2.

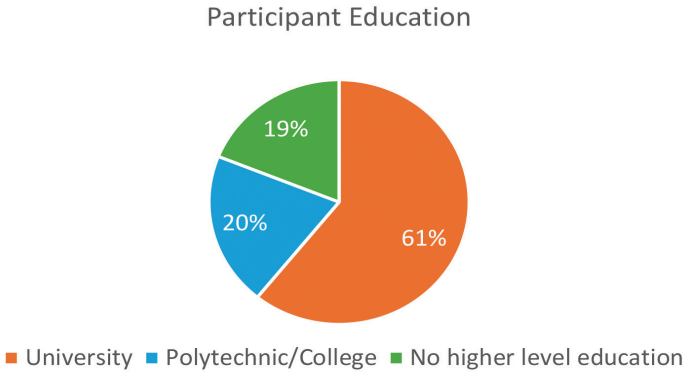


Question 2a: Did you go to university for engineering?

Summary:

- University: 45 participants (61%)
- College/Polytechnic:15 participants (20%)
- No higher-level education: 14 participants (19%)

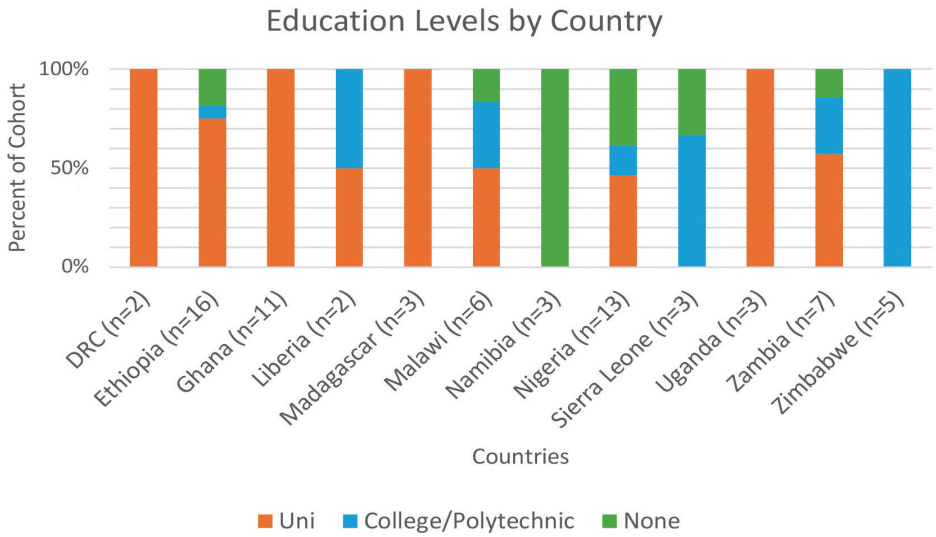
Figure 3.



The surprisingly large portion of highly educated individuals suggests that the selection method may have inadvertently favoured high-calibre healthcare facilities that can attract talent.

Figure 4 analyses education by country. All participants from Ghana, Democratic Republic of Congo (DRC), Madagascar, and Uganda attended university. Namibia is the only country where no participants attained higher education.

Figure 4.



n= number of participants within each country

Question 2b: If you went to university for engineering, which university did you attend?

Below are the most frequented universities. See Appendix Table 1A.2 for the full list.

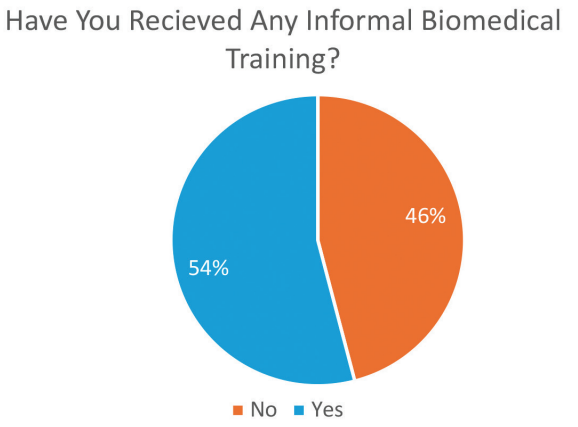
Table 3. Most Frequented Universities

University/College/Polytechnic	Country	Attendees
University of Ghana	Ghana	6
Jimma University	Ethiopia	6
Evelyn Hone College	Zambia	3
Mbarara University of Science and Technology	Uganda	3
Malawi University of Science and Technology	Malawi	3
Federal University of Technology, Owerri	Nigeria	2
University of Antananarivo	Madagascar	2
Mekelle University	Ethiopia	2

Question 3: Have you received any biomedical engineering training outside of formal education (for example: supplier-led trainings, online courses)?

Just over half of the participants have received biomedical training outside of formal education. No details were collected on what type of training individuals participated in.

Figure 5.



Question 4-8: Skills Assessment

Questions four through seven asked participants to assess their confidence in their skills on a Likert scale. Question eight asked participants to score the respect they perceive from their colleagues towards them as biomedical engineers. The averages and standard deviations are shown in Table 4.

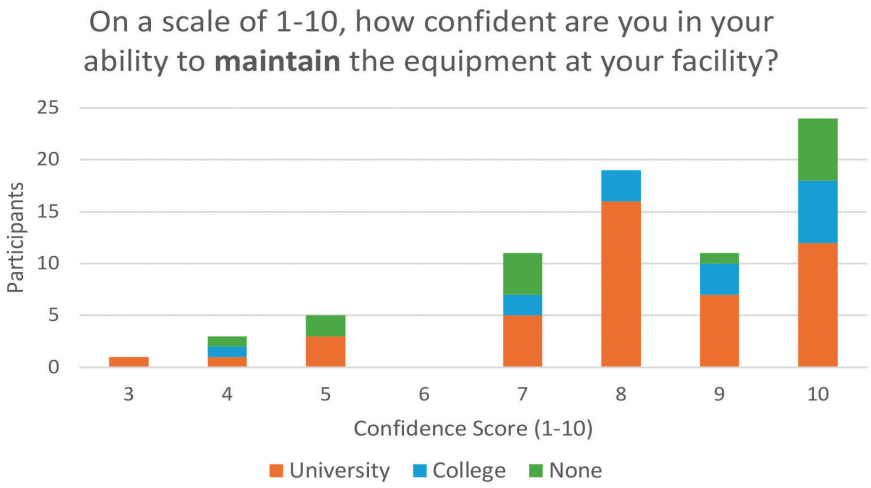
Table 4. Average Confidence Scores

	Question	Average (1-10)	Stdv.
4.	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to maintain the equipment at your facility?	8.2	1.8
5.	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to fix the equipment at your facility?	7.9	1.8
6.	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to professionally communicate with medical personnel (doctors, nurses, surgeons, etc.)?	8.6	1.6
7.	On a scale of 1-10 (1 being not at all, 10 being very confident), how confident are you in your ability to train medical personnel (doctors, nurses, surgeons, etc.) on how to use the medical equipment at your healthcare facility?	8.0	1.8
8.	On a scale of 1-10 (1 being not at all, 10 being highly respected), how much do you think the medical personnel (doctors, nurses, surgeons, etc.) at your healthcare facility respect you as an engineer?	7.8	1.9

Q4: How confident are you in your ability to maintain the equipment at your facility?

The bar chart in Figure 6 shows the distribution of confidence levels in ability to maintain equipment among participants with different education levels. Most participants, regardless of their educational background, reported high confidence levels (7-10) in their ability to maintain equipment.

Figure 6.

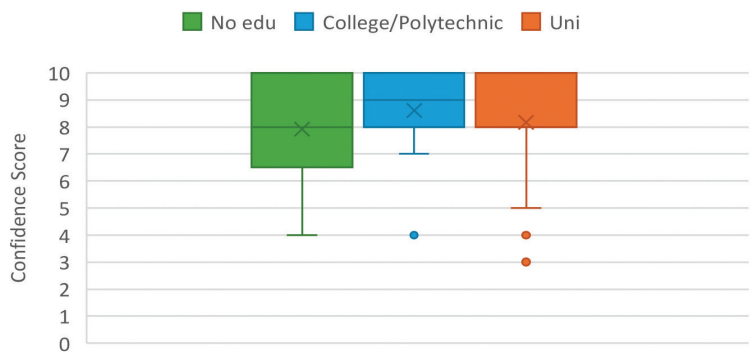


Participants without higher education reported similarly high confidence levels as those with higher level education, indicating that they feel capable of maintaining equipment despite their lack of formal education.

An ANOVA test concludes that the difference between the means in university educated, college-educated, and no higher education is not statistically significant (see Appendix Table 1A.3). Accordingly, education level does not appear to impact self-assessed ability to maintain equipment.

Figure 7 provides a visual summary of the distribution of confidence levels. The interquartile range (IQR) for each group shows that most participants rated their confidence between 7 and 10, although there are a few outliers scoring as low as 3 and 4. The overlap in the whiskers of the box plot indicates that there is no significant difference in confidence levels among the different education groups, supporting the ANOVA test results.

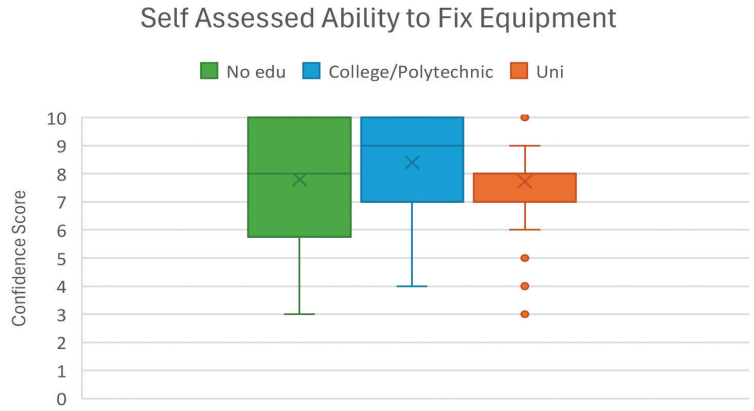
Figure 7.



Q5: How confident are you in your ability to fix the equipment at your facility?

The bar chart in Figure 8 shows the distribution of confidence levels in self-assessed ability to fix equipment among participants with different education levels. Most participants, regardless of their educational background, reported high confidence levels (7-10) in their ability to fix equipment.

Figure 8.

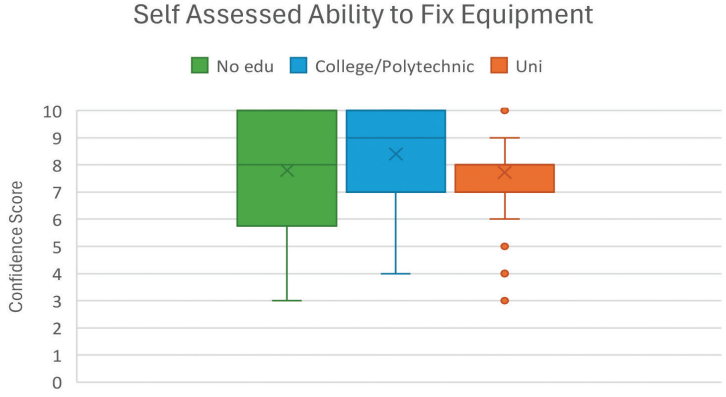


Participants without higher education reported similarly high confidence levels, indicating that they feel capable of fixing equipment despite their lack of formal education.

An ANOVA test concludes that the difference between the means in university-educated, college-educated, and no higher education is not statistically significant (see Appendix Table 1A.4). Accordingly, education level does not appear to impact self-assessed ability to fix equipment.

Figure 9 provides a visual summary of the distribution of confidence levels. Once again, the IQR for each group shows that most participants rated their confidence between 7 and 10. The overlap in the whiskers of the box plot indicates that there is no significant difference in confidence levels among the different education groups, supporting the ANOVA test results.

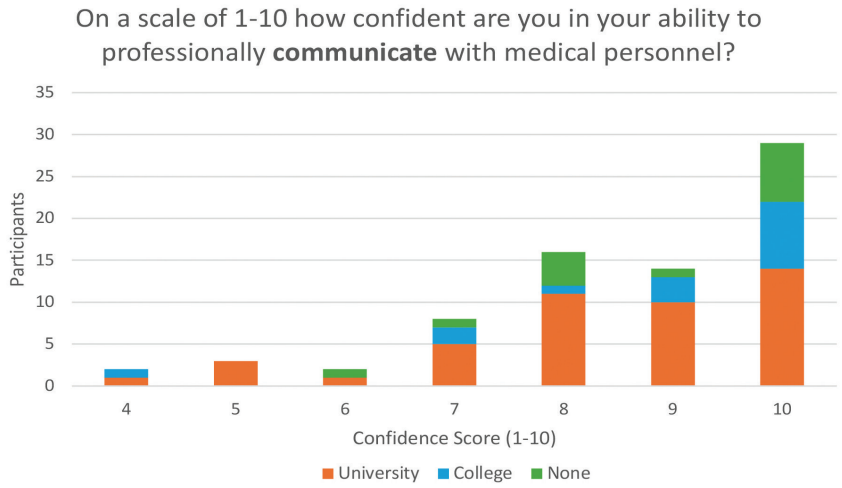
Figure 9.



Q6: How confident are you in your ability to professionally communicate with medical personnel?

The bar chart in Figure 10 shows the distribution of confidence levels among participants with different education levels.

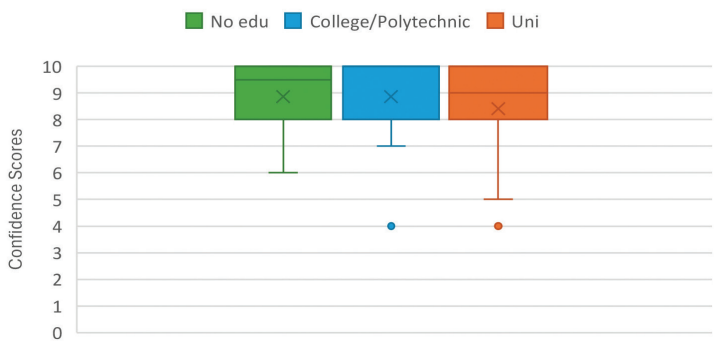
Figure 10.



An ANOVA test concludes that the difference between the means in university-educated, college-educated, and no higher education is not statistically significant (see Appendix Table 1A.5). Accordingly, education level does not appear to impact self-assessed ability to professionally communicate with medical personnel.

As before, Figure 11 illustrates that there is no significant difference in confidence levels among the different education groups, supporting the ANOVA test results.

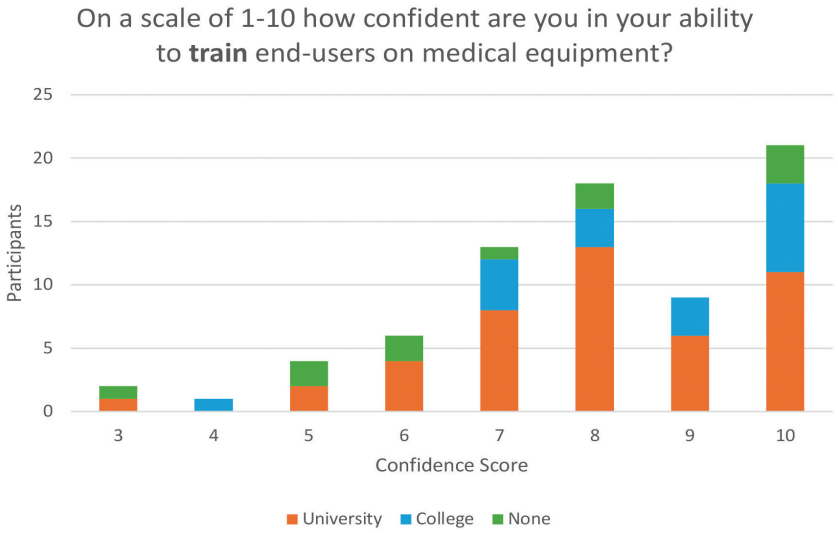
Figure 11.



Q7: How confident are you in your ability to train end-users on medical equipment?

The bar chart in Figure 12 shows the distribution of confidence levels in the ability to train end-users among participants.

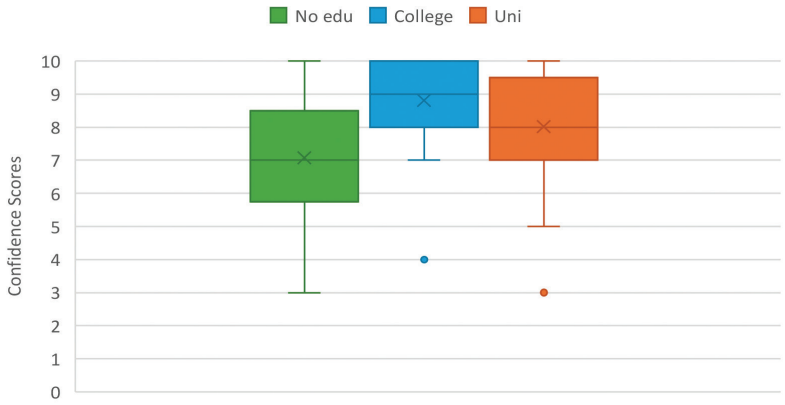
Figure 12.



An ANOVA test concludes that the differences between some of the means are statistically significant (see Appendix Table 1A.6). Education level may impact individual's self-assessed ability to train end users.

The plot in Figure 13 provides a visual summary of the distribution of confidence levels among participants with different education levels. It shows a range of confidence levels, indicating some variability based on education. The reduced overlap of the whiskers in this box plot suggests that there are more distinct differences between the education groups compared to previous questions. This indicates that the education level may play a more significant role in self-assessed confidence for training end-users.

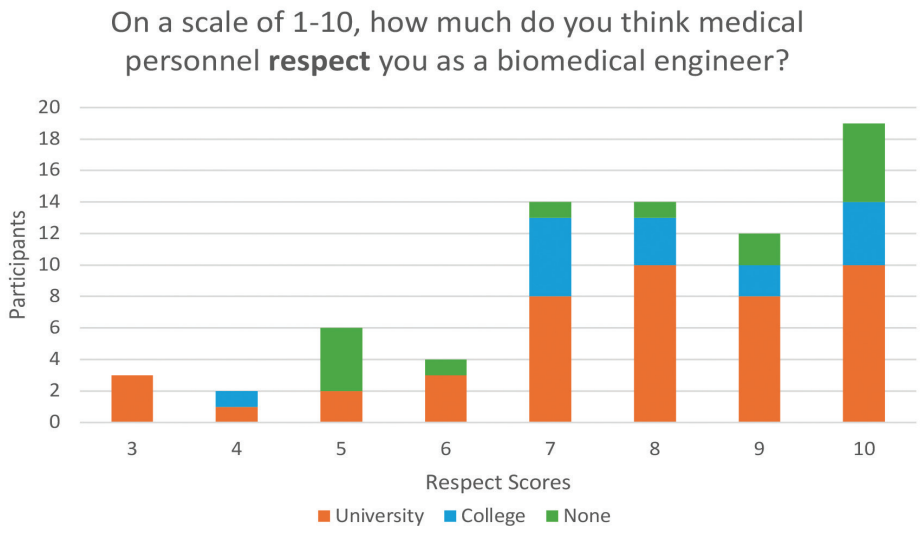
Figure 13.



Q8: How much do you think medical personnel respect you as a biomedical engineer?

The bar chart in Figure 14 shows the distribution of perceived respect levels among participants with different education levels. Most participants, regardless of their educational background, reported high respect levels (7-10).

Figure 14.



An ANOVA test concludes that the difference between the means in university-educated, college-educated, and no higher education is not statistically significant (see Appendix Table 1A.7). Accordingly, education level does not appear to impact an individual's perceived respect level. The overlap in the whiskers of the box plot in Figure 15 indicates that there is no significant difference in perceived respect levels among the different education groups, supporting the ANOVA test results.

Figure 15.

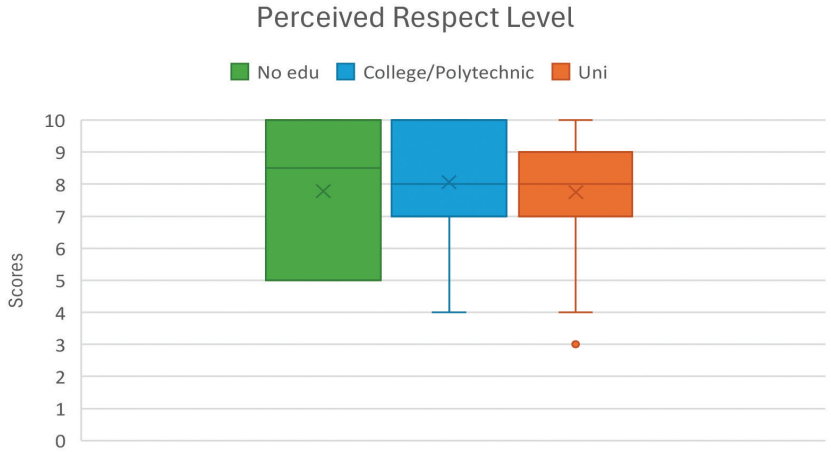


Figure 16 demonstrates the average self-assessed skills scores via education levels. While overall, those with a college/polytechnic background appear to assess themselves more favourably, this difference is not statistically significant, except for Question 7.

Figure 16.

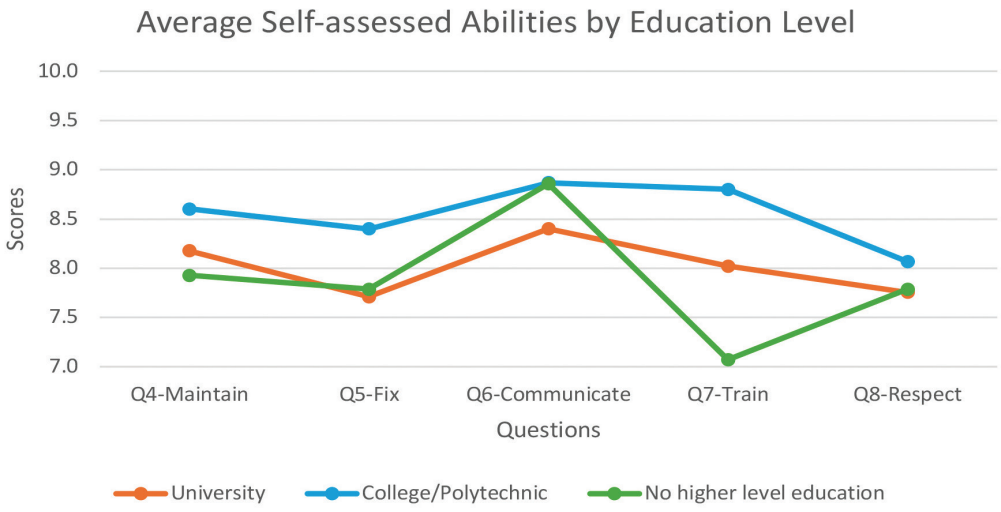


Table 5 shows the data points used to produce Figure 16.

Table 5. Average Confidence in Skillsets by Education

Education level	Q4-Maintain	Q5-Fix	Q6-Communicate	Q7-Train	Q8-Respect
University	8.2	7.7	8.4	8.0	7.8
College/Polytechnic	8.6	8.4	8.9	8.8	8.1
No higher-level education	7.9	7.8	8.9	7.1	7.8

Figure 17 demonstrates how self-assessed confidence fluctuates with average years of experience. Single-factor ANOVA analyses were performed for each question/skillset. Only the impact of years of experience on perceived respect levels is statistically significant. All other questions (ability to maintain, fix, communicate, and train) fail to reject the null hypothesis — years of experience has no significant impact on confidence in skillset. ANOVA tests can be found in Appendix Table 1A.8 through Table 1A.12.

Figure 17.

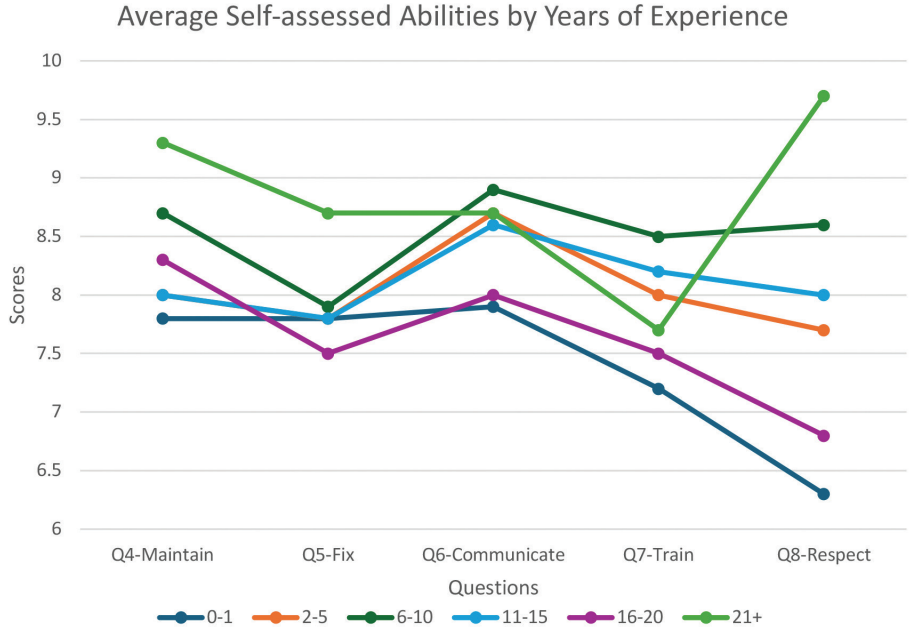


Table 6 shows the data points used to generate Figure 17.

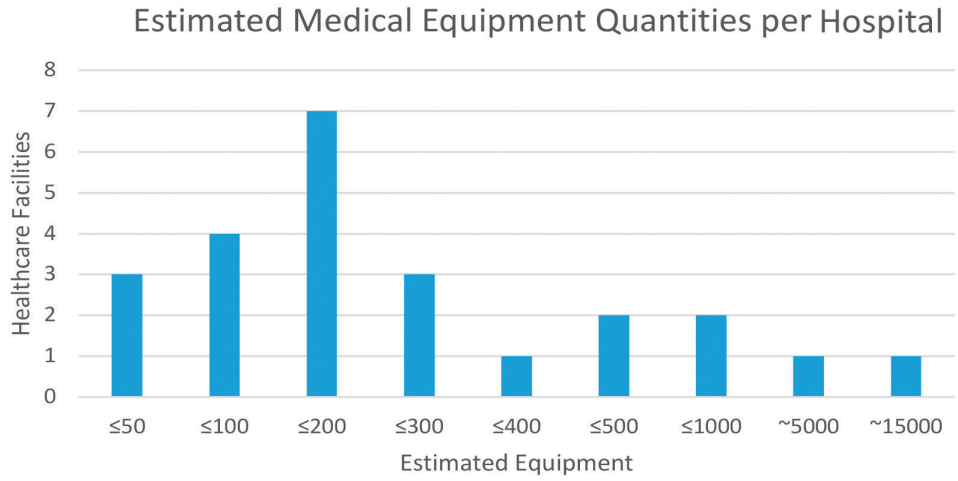
Table 6. Average Confidence in Skillsets by Years of Experience

Years of Experience	Q4-Maintain	Q5-Fix	Q6-Communicate	Q7-Train	Q8-Respect
0-1	7.8	7.8	7.9	7.2	6.3
2-5	8	7.8	8.7	8	7.7
6-10	8.7	7.9	8.9	8.5	8.6
11-15	8	7.8	8.6	8.2	8
16-20	8.3	7.5	8	7.5	6.8
21+	9.3	8.7	8.7	7.7	9.7

Question 9: In your best estimate, how many pieces of medical equipment does your facility have?

Figure 18 shows the estimated quantities of medical equipment per site. Most sites (7) report between 100-200 items of medical equipment. The facility reporting upwards of 15,000 items is a 150-bed charity/ mission hospital in Ethiopia.

Figure 18.



10. In your best guess, what percentage of the equipment on-site is non-operational?

Figure 19 illustrates the participants' estimates of non-operational equipment. Approximately one-third of the sites report that only 0-10% of equipment is non-operational. A definition for "non-operational" was not provided, nor was a list of what equipment should be assessed in this estimation. This will be analysed in greater detail during the equipment audit. The weighted average finds that 26% of equipment is estimated to be non-operational.

Figure 19.

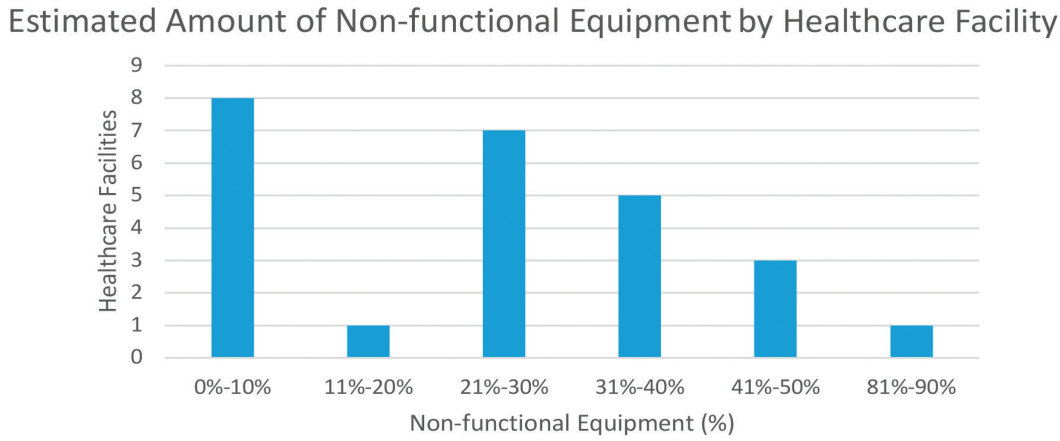


Table 7 demonstrates the estimated percentage of non-operational equipment at each facility. To protect the anonymity of the participating healthcare facilities, each facility was given a random identifying number followed by the 2-letter country code. Healthcare facilities marked with an asterisk are mission/charity-funded facilities.

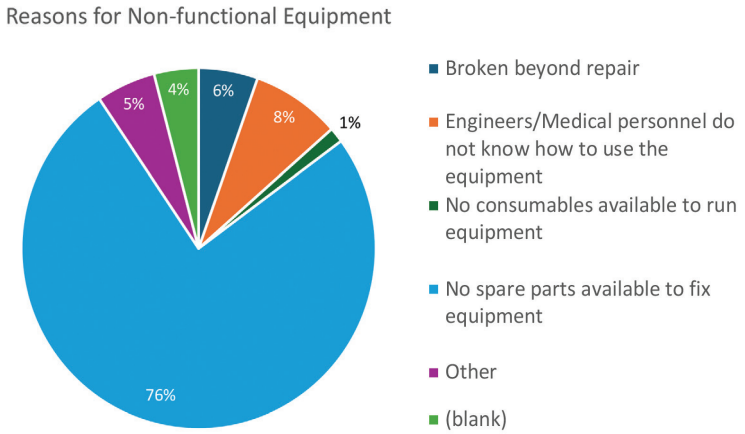
Table 7. Average Percentage of Estimated Non-operational Equipment per Hospital

Hospital	Non-Operational Equipment
04ET	2%
01ZM	31%
13ZW	23%
*09ET	1%
19UG	25%
17GH	17%
*07CD	30%
05SL	10%
24SL	85%
20LR	4%
23MW	40%
14ZM	45%
15MW	33%
25NG	2%
*18NG	22%
21MW	50%
22MW	30%
*11ET	26%
*03UG	10%
10NA	43%
06GH	6%
08GH	30%
02ET	10%

Question 11. In your opinion, what is the number one reason medical equipment at your healthcare facility is non-operational?

The number one cited reason for non-functional medical equipment is the lack of available spare parts (see Figure 20). The second highest reason is user-errors due to staff inability/unfamiliarity to operate medical equipment.

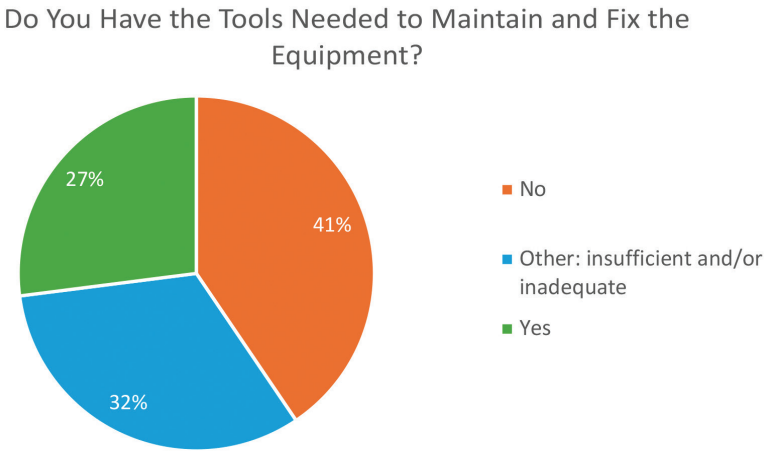
Figure 20.



12. Do you have the tools needed to maintain and fix the equipment?

Only 27% of participants report having the basic tools needed to maintain and fix medical equipment.

Figure 21.



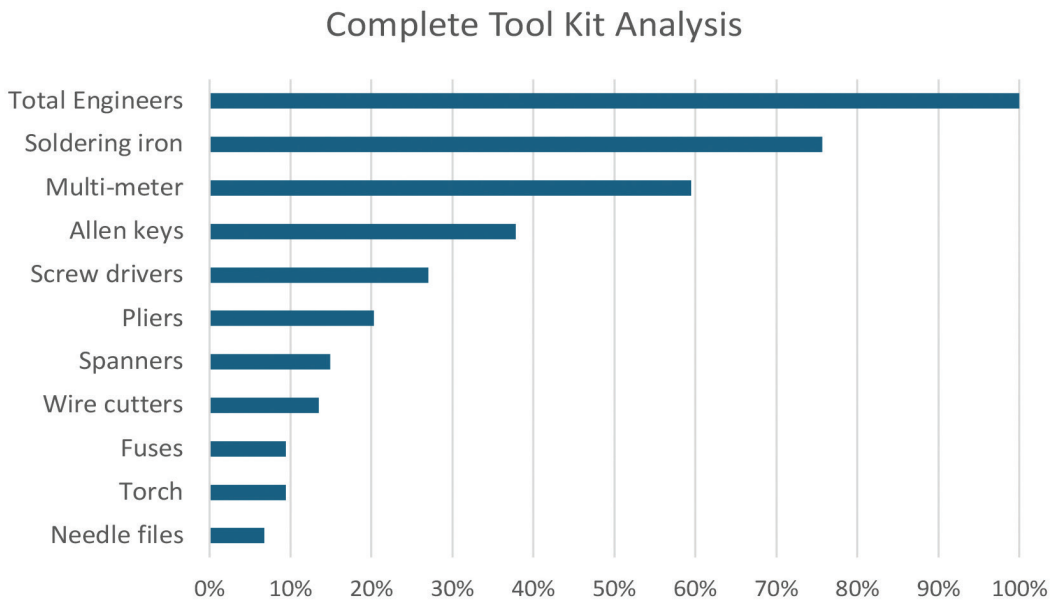
Question 13. Do you have the following tools (select all that apply)?

The ten tools deemed essential to the daily tasks of biomedical engineers were listed for each participant to select which were available to them. The results below list the percentage of the engineers (74) that have access to the listed tools:

- Soldering iron: 76%
- Multi-meter: 70%
- Allen keys: 59%
- Full set of screwdrivers: 53%
- Pliers (combination and long nose): 47%
- Full set of spanners: 43%
- Wire cutters (regular and precise): 42%
- Spare fuses: 24%
- High-quality torch/flashlight: 18%
- Set of needle files: 14%

Figure 22 demonstrates that only 5 engineers (7% of the cohort) have a complete tool kit, with each new bar representing the proportion of engineers who had this tool (and all other items listed above it).

Figure 22.



All of the above items, along with additional resources (see Attachment 1), will be provided to the participants in their professional Medical Aid International toolkits.

Equipment Audit

Background

The objective of the initial audit was to assess the baseline operational function of 30 items of medical equipment prior to the intervention of Medical Aid International's online training. At this time, no universal definition of equipment standards exists amongst this cohort, so interpretations of the question "is this item operational" will likely vary significantly across different individuals, facilities, and countries (as operational standards differ). To address this variability and gain a clear perspective on the operational status of the devices, three simple questions were devised and posed for every item in the equipment audit. The three questions asked for every item were:

1. "Does the equipment perform its job to your satisfaction?"
2. "Do you have any concerns about the safety of this equipment, for either the patient or user?"
3. "When was the last time the equipment was used?"

If an item was deemed satisfactory, safe, and regularly used (defined as used within the past six months), it is classified in this report as locally acceptable for use.

In addition to the three universally asked questions, item-specific questions were raised to gain a more detailed insight into the operational status of certain medical equipment. These questions build upon the initial criteria for determining if an item was locally acceptable for use, and established additional fundamental benchmark standards, which are slightly more stringent. It is important to note that these benchmark standards were derived from the questions posed in the audit, which was designed with the assumption that participants had minimal biomedical training. Consequently, even these benchmark standards do not equate to the quality expectations commonly held in Western healthcare settings.

Definitions

Satisfactory: Medical equipment items that participants have answered "yes" to "does the equipment perform its job to your satisfaction?" Satisfaction is entirely user defined.

Safe: Medical equipment items that participants have indicated have no safety concerns. Safety is entirely user defined.

Regularly used: Equipment that has been used within the past 6 months. Participants are given the following use options:

- Within the past 7 days
- Within the past month
- Within the past 6 months
- Over 6 months ago
- Never
- Unknown

Acceptable: Medical equipment items that have been have been reported by the auditor as satisfactory, safe, and used within the past 6 months.

Benchmark compliant: Medical equipment items that have been marked as satisfactory, safe, used within the past 6 months, and meet item-specific criteria as defined in later sections.

Methods

Participants were asked to audit 30 pre-determined items of medical equipment. The items selected were those posing the greatest contribution to safe surgery and safe recovery. Additionally, a few speciality items were included in the list to ascertain their prevalence in the LMIC healthcare setting. Participants were asked to log every item on the list whether it was in current use, storage, or decommissioned. We have no means of verifying the adherence to these instructions.

The intent of the candidate selection process was to include a cohort representing a variety of healthcare facilities across LMICs. These criteria ensured that the study encompassed data from a wide range of hospitals, with some recording as few as 31 items, and others logging up to 629 items. To prevent any single facility from disproportionately influencing the overall results, each facility was given equal weight in the analysis. This was achieved by calculating weighted averages.

To calculate weighted averages, the data were first processed by hospital. Individual facility analyses were conducted for each of the 23 sites. Then, the averages across these sites were computed, ensuring that each hospital contributes equally to the final average, regardless of the number of items logged. This method ensured a balanced representation of all facilities in the results.

In addition to weighted averages, simple averages are also reported in cases where differences are notable. Simple averages were calculated by summing all the equipment data points and dividing by the total number of data points, treating the data set as a whole without considering individual hospital contributions.

This dual approach provides a comprehensive view, ensuring that the data reflects both the overall trends and the balanced contributions of each facility.

On average, engineers indicate that 72% (simple average: 80%) of hospital equipment has satisfactory performance. When more stringent criteria beyond simple satisfaction are implemented (i.e., equipment must be simultaneously satisfactory, safe, and used within six months), that percentage drops to 56% (simple average: 67%). This percentage drops to 33% (simple average: 42%) with additional minimum benchmark criteria applied (simultaneously satisfactory, safe, used within six months, and unique equipment specific standards), as can be seen later in the report.

Participants report that on average 23% (simple average: 15%) of hospital equipment is unsatisfactory, 27% (simple average: 17%) of equipment is unsafe, and 16% (simple average: 14%) of equipment has sat unused for six months or more. Essential[6] equipment with the highest percentage of dissatisfaction includes autoclaves (38%, 40/106), operating room lights (33%, 32/98), and infant radiant warmers (32%, 25/79). Essential[1] equipment with the highest percentage of safety concerns includes X-ray/C-arms (32%, 18/57), oxygen concentrators (30%, 112/371), and infant radiant warmers (29%, 23/79). Satisfaction and safety charts can be found in Appendix Table 2A.1 and Table 2A.2, respectively.

As mentioned above, only 56% of equipment is simultaneously satisfactory, safe, and used within the past six months (simple average 67%). Neither total years of experience, self-assessed ability to maintain, nor self-assessed ability to fix equipment, were appropriate predictors of acceptable equipment (R^2=0.102). The coefficient of self-assessed ability to fix equipment suggests a negative relationship, indicating that higher self-assessment might lead to lower values of the dependent variable, but it is not statistically significant (See Appendix 2A.3). Similarly, none of the aforementioned variables are appropriate predictors of benchmark compliant equipment (R2=0.038) (see Appendix 2A.4).

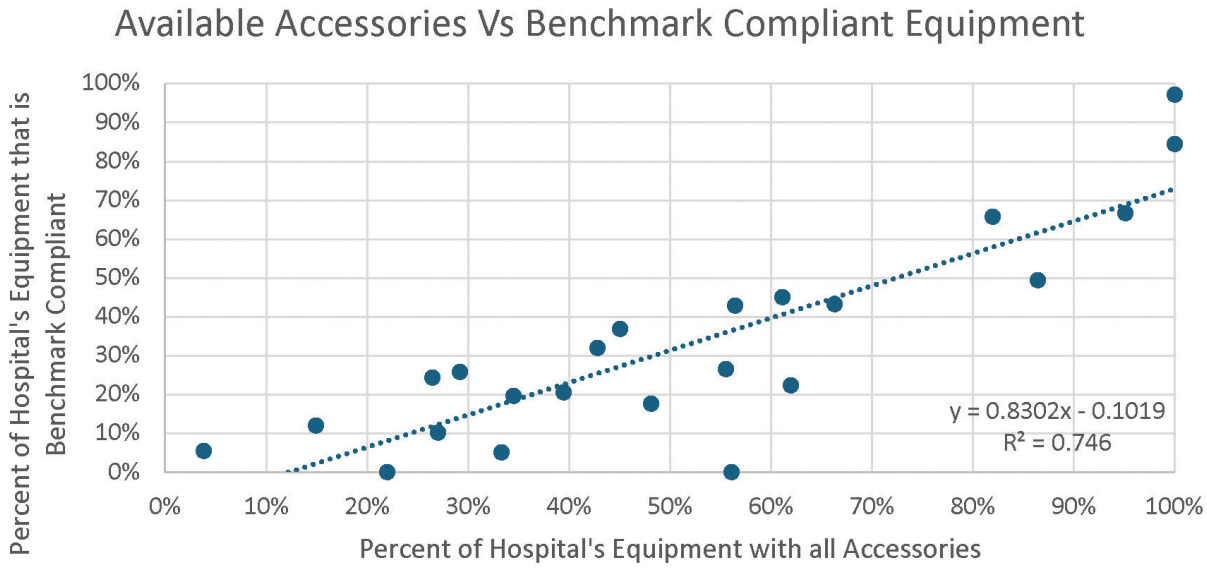
[6]While all equipment is essential, this single analysis excludes dialysis machines, blood gas analyser, laparoscopy, CPAP pipeline, electric bone saw, back-up generator, endoscopy equipment, and operating room traction tables as comparatively very few of these items have been logged. These items are included in all other overall analyses.

Additionally, a multiple regression analysis proved that hospital bed capacity, number of operating rooms, number of engineers at the facility, total years of experience of engineers, percentage of newly purchased equipment, percentage of equipment with user manuals, and percentage of equipment with all accessories are not statistically significant predictors of acceptable equipment levels. The regression model explains 49.1% of the variance in acceptable equipment, but the overall model is not statistically significant (Significance F = 0.112). The variable "Percentage of Newly Purchased Equipment" and "Availability of accessories" show the most substantial (though not significant) positive effect on acceptable equipment levels with coefficients of 0.314 and 0.303 respectively. See Appendix 2A.5 for regression model.

However, when a similar multiple regression test was run, but this time with the dependent variable being percentage of benchmark compliant equipment as opposed to acceptable equipment, the results changed dramatically. The analysis suggests that the availability of accessories has a highly significant positive effect on the benchmark compliant equipment (coefficient 0.787, p-value =0.00025). All other independent variables remain not statistically significant predictors of benchmark compliant equipment (See Appendix 2A.6). A single regression test with availability of accessories as the independent variable and benchmark compliant equipment as the dependent variable yields an R^2 of 0.746 suggesting that approximately 74.6% of the variance in the dependent variable is explained by the independent variable in the model. The model is highly statistically significant (p-value =1.10585E-07) (see Appendix 2A.7).

Figure 23 illustrates the relationship between the availability of accessories and the percentage of benchmark-compliant equipment. The data points represent individual facilities, with the x-axis indicating the availability of accessories and the y-axis showing the percentage of equipment meeting benchmark criteria. The figure clearly demonstrates that facilities with high levels of available accessories have high levels of benchmark compliant equipment.

Figure 23.



Of the audited equipment, only 58% (simple average: 66%) have all accessories, 52% (simple average: 56%) have all consumables, and 16% (simple average: 13%) have all spare parts. Necessary consumables, accessories, and spares were not listed in the audit for participants to crosscheck their knowledge against.

The primary means of equipment acquisition on a hospital basis was via donations (on average 56% of equipment was donated, 31% purchased new). This statistic changes significantly using a simple

average; of the 2,930 items of equipment 46% were donated and 47% were purchased new. The audit did not specify if these donated objects were new or second-hand. Of the 1,966 items of equipment that were deemed acceptable (i.e., assessed to be simultaneously satisfactory, safe, and regularly used) 37% were donated and 59% were purchased new. The remaining 4% are a combination of unknown acquisition (2%), purchased used (1%), and other (1%). Though very weak, there is a positive correlation between the percentage of new equipment and acceptable equipment function (See Appendix 2A.5 for multiple regression analysis). Thus, there is a slight tendency for facilities with a higher percentage of purchased new equipment to have a higher percentage of acceptable equipment. A chi-square test confirms that there is an association between satisfaction and purchase status for at least one equipment type. Individual chi-square tests conclude that defibrillators, infant radiant warmers, infusion pumps, oxygen concentrators, patient monitors, pulse oximeters, autoclaves, and X-rays reject the null hypothesis that there is no association between acquisition type and acceptable function. Accordingly, for the aforementioned devices, this statistical test confirms that acceptable equipment performance is dependent on equipment acquisition type: new or donated (see Appendix 2A.8 for statistical tests).

Figures 24 and 25 provide a visual representation of the satisfaction levels for various types of medical equipment. The equipment is categorised based on user feedback into three groups: Satisfied (blue), Unsatisfied (orange), and Unknown (grey).

Figure 24.

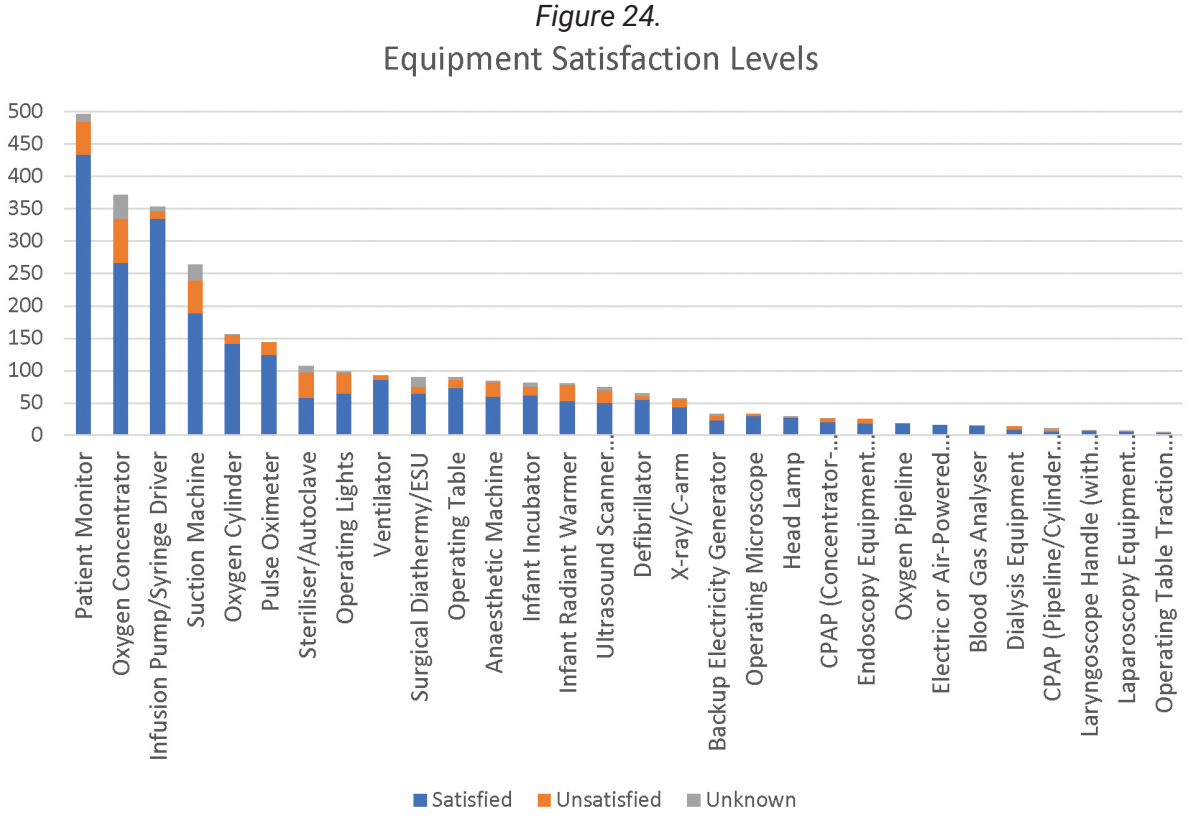
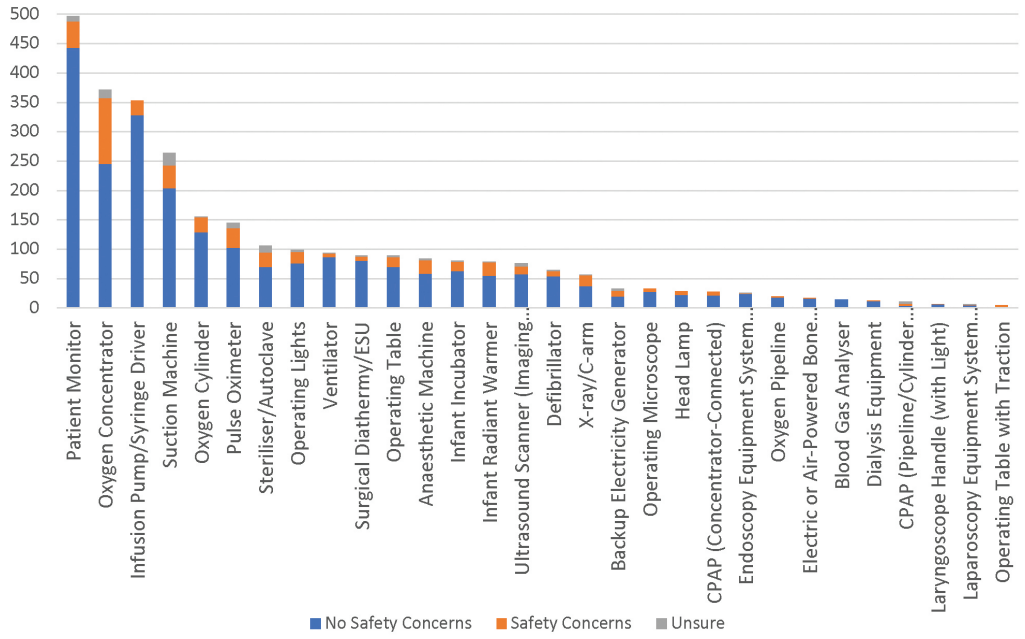


Figure 25.

Equipment Safety Levels



Site Overview

A profile of the healthcare facilities included in this study is provided below in Table 8 for context.

Table 8. Healthcare Facility Profiles

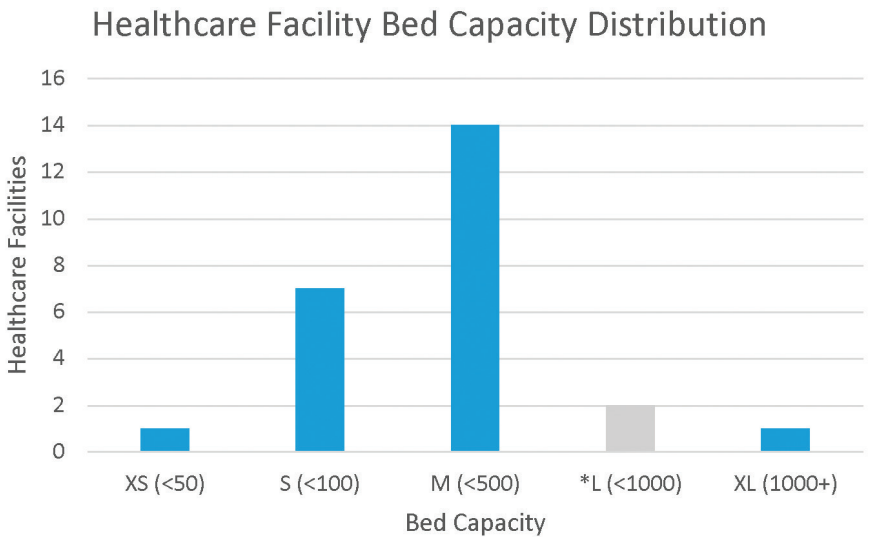
Hospital Code	Funding Source	Location	Items Logged	Bed Est.	OR s	Partic-ipating Engineers	Total Years of Experience	Percent Purchase New	Percent with Manuals	Satisfactory Equipment	Acceptable Equipment	Benchmark Equipment
02ET	Government/State	City	75	40	1	1	0.5	0%	35%	28%	0%	0%
04ET	Government/State	Capital	106	206	4	2	12	22%	65%	91%	82%	37%
09ET	Charity/Mission	Capital	165	70	1	1	4.67	80%	100%	100%	99%	97%
11ET	Charity/Mission	City	191	150	8	6	43	58%	98%	87%	71%	66%
07CD	Charity/Mission	Metropolitan City	271	300	8	3	27	48%	38%	83%	80%	20%
06GH	Government/State	Capital	629	1000	11	8	56	98%	68%	99%	93%	66%
08GH	Government/State	City	73	210	1	2	9	11%	62%	58%	51%	21%
17GH	Government/State	Unknown	49	55	1	1	5	39%	84%	71%	65%	27%
20LR	Government/State	Small City	95	95	1	2	7	0%	37%	74%	60%	32%
15MW	Government/State	Town	99	320	2	2	11	1%	36%	72%	55%	10%
21MW	Government/State	Town	175	250	1	1	3	20%	33%	62%	57%	43%
22MW	Government/State	Small City	160	250	2	2	7	0%	29%	57%	49%	24%
23MW	Government/State	Rural	31	60	2	1	5	0%	39%	74%	65%	26%
10NA	Government/State	Town	102	90	3	3	33	90%	58%	69%	63%	12%
18NG	Charity/Mission	Unknown	39	120	1	9	71	56%	33%	38%	10%	5%
25NG	Government/State	Metropolitan City	32	200	2	1	13	34%	91%	91%	91%	84%
05SL	Government/State	Metropolitan City	90	200	2	1	17	0%	28%	63%	41%	22%
24SL	Government/State	City	105	350	2	1	8	0%	88%	82%	0%	0%
03UG	Charity/Mission	Town	87	250	2	1	0.67	17%	25%	76%	72%	45%
19UG	Private	City	40	85	2	2	4	50%	5%	53%	28%	18%
01ZM	Government/State	City	139	250	3	5	15	11%	62%	83%	76%	43%
14ZM	Government/State	Small City	37	60	2	1	2	0%	3%	51%	35%	5%
13ZW	Government/State	Metropolitan City	140	120	2	6	56.75	86%	89%	89%	55%	49%

Rural: <10,000 Small City: 25,000-100,000 Metropolitan City or Capital: 500,000+

Town: 10,000-25,000 City: 100,000-500,000

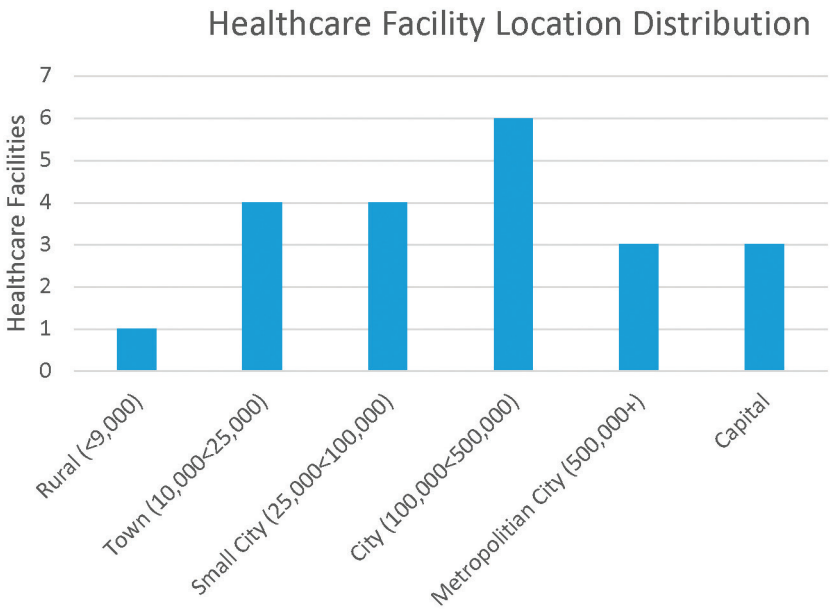
Hospital bed capacity estimates show a mean of approximately 206 beds. The median capacity is 200 beds, and the most frequently occurring hospital size is a 250 bed facility. The data exhibit significant variability, from a minimum of 40 to a maximum of 1000 beds. Figure 26 illustrates the bucketed bed capacity distribution. Figure 27 illustrates the distribution of healthcare facilities across various location types. The most healthcare facilities in this study exist in cities: arbitrarily classified as regions with 100,000-500,000 inhabitants. Population was determined via web search utilising the addresses of the facilities.

Figure 26.



**Audits from these sites have not been completed; accordingly, the current data set does not represent these two large healthcare facilities.*

Figure 27. Locale Distribution



Healthcare Facility Equipment Overview

The following section analyses equipment satisfaction, safety, and use at every participating facility as a percentage of total equipment at that facility. On average 56% of the equipment at each hospital is perceived by the engineers to be satisfactory, safe, and regularly used. Equipment meeting these three minimum criteria will hereby be referred to as “acceptable”. Only these three criteria are evaluated in the following analysis as only these three criteria apply to every item. Benchmark criteria, which change for each item, are assessed in the equipment section rather than in the facility overview.

Included in the synopsis is the original estimate of operational equipment reported by the engineers in the onboarding survey. On average, the engineers’ estimates do not accurately predict acceptable equipment functionality. However, the estimates for operational equipment were reasonably accurate assumptions of satisfactory equipment (see Appendix 2A.9 for t-test). Seventeen sites (74%) overestimated the capabilities of their equipment.

These cascading graphs suggest that simply asking if equipment performance is satisfactory does not accurately reflect the operational functionality of the item. It also suggests that equipment known to be unsafe is still used. Of the total equipment used within the past six months (2,461 items), 14% have recorded safety concerns.

Satisfaction and safety are obvious indicators of equipment performance. However, regular use, categorised as used within the past six months, is slightly more nuanced. If the item under consideration has sat unused for over six months, the assumption is that it is in some way lacking; perhaps it is the incorrect voltage, excessively worn, or inappropriate for use in some way. Regardless, it is sitting unused and therefore not benefiting patient care.

The request to estimate operational equipment was given after the sites had been accepted and admitted into the project. Accordingly, these estimates were not likely an attempt to bias us towards selecting their application. However, it is highly likely that these individuals succumbed to the social desirability bias and overestimated the quality of their equipment to appear in a more favourable light. Additionally, it is important to remember that the equipment estimate request from the onboarding survey did not specify equipment type, whereas the audit specified 30 items.

Ethiopia

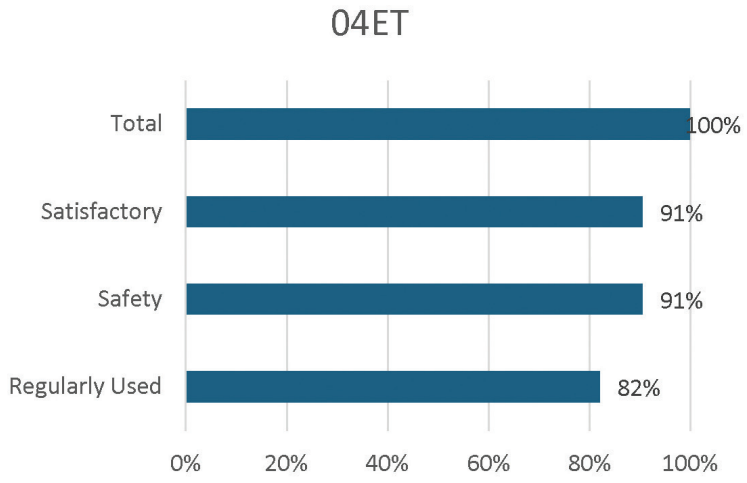
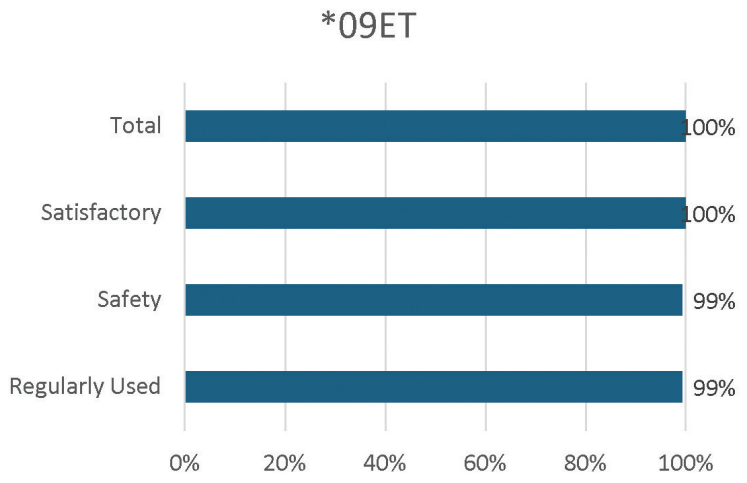
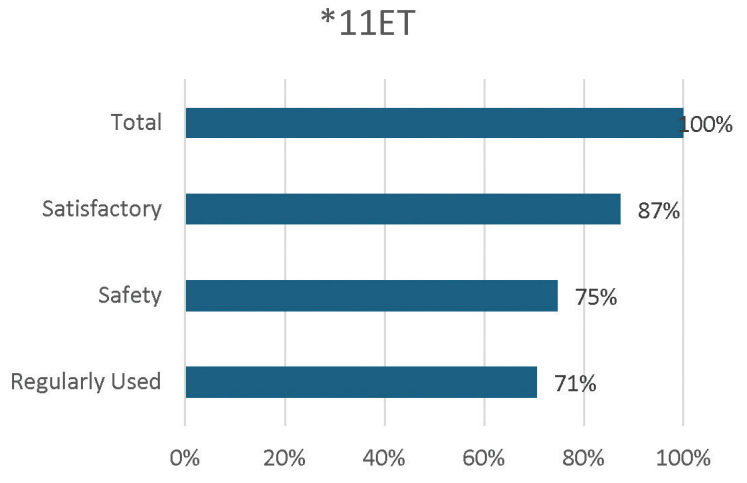
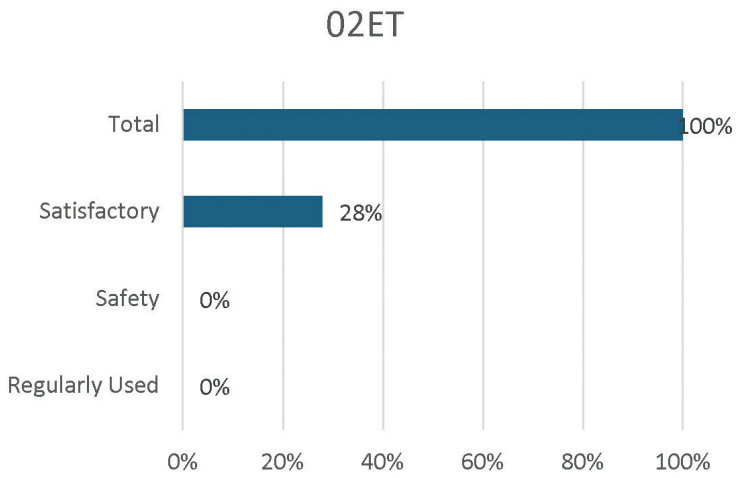
Figure 28a. 	04ET, a 206-bed government-run trauma hospital in Ethiopia, reports satisfaction with 91% of their 106 logged items. Ninety-one percent (91%) of the equipment is simultaneously satisfactory and safe. However, only 82% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=2) estimated percentage of operational equipment was 99%.
Figure 28b. 	09ET, a 70-bed mission/charity run-children's speciality hospital in Ethiopia, reports satisfaction with 100% of their 165 logged items. One hundred percent (100%) of the equipment is simultaneously satisfactory and safe, while 99% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer (n=1) accurately estimated the percentage of operational equipment was 99%.
Figure 28c. 	11ET, a 150-bed mission/charity hospital in Ethiopia, reports satisfaction with 87% of their 191 logged items. Seventy-five percent (75%) of the equipment is simultaneously satisfactory and safe. While 71% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=6) estimated percentage of operational equipment was 74%.

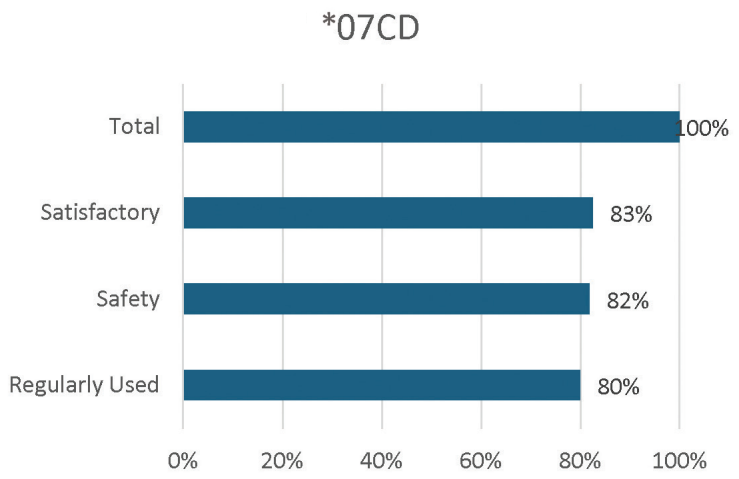
Figure 28d.



02ET, a 40-bed government hospital in Ethiopia, reports satisfaction with 28% of their 75 logged items. None of the items that were satisfactory were also reported as being safe (having no safety concerns). In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 90%.

The Democratic Republic of Congo

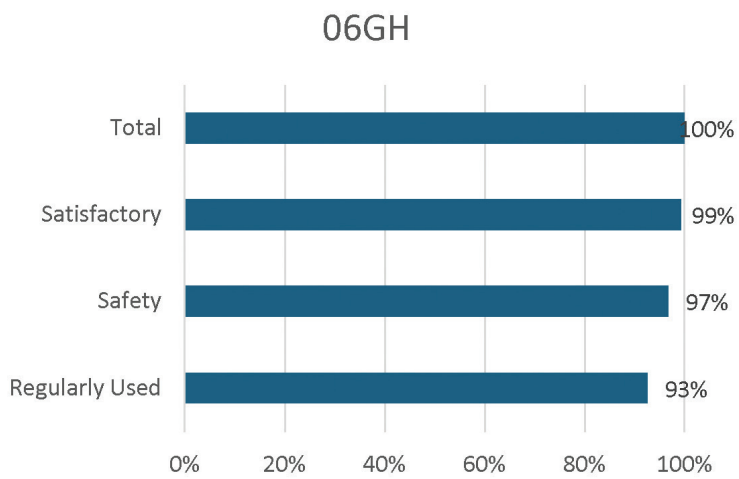
Figure 28e.



07CD, a 300-bed mission/charity hospital in the Democratic Republic of Congo, reports satisfaction with 83% of their 271 logged items. Eighty-two percent (82%) of the equipment is simultaneously satisfactory and safe. While 80% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=3) estimated percentage of operational equipment was 70%.

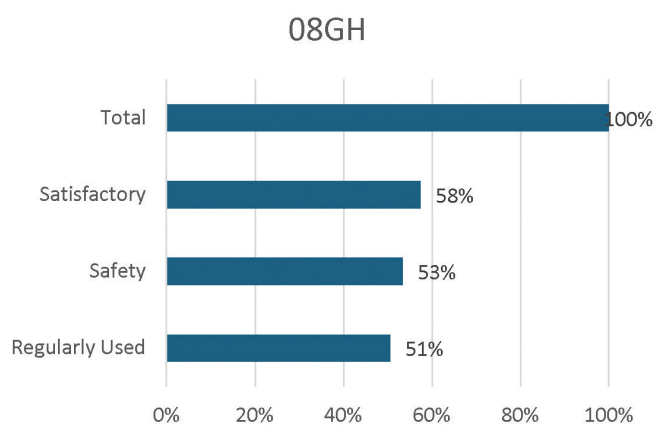
Ghana

Figure 28f.



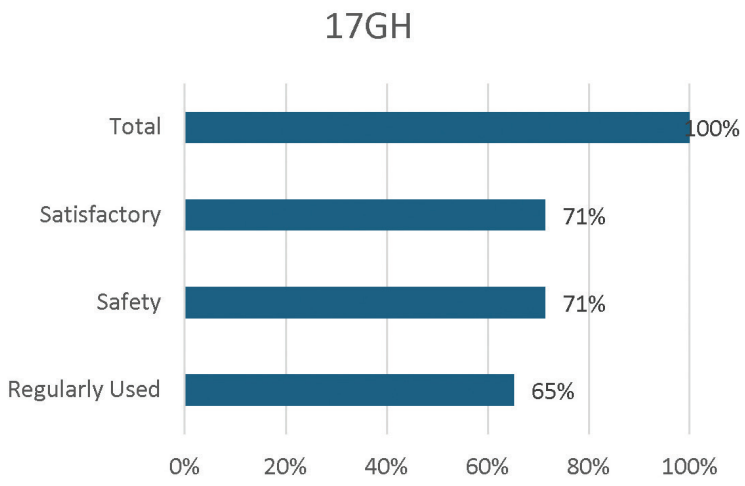
06GH, a 1000-bed government run university teaching hospital in Ghana, reports satisfaction with 99% of their 629 logged items. Ninety-seven (97%) percent of the equipment is simultaneously satisfactory and safe. While 93% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=8) estimated percentage of operational equipment was 95%.

Figure 28g.



08GH, a 210-bed government hospital in Ghana, reports satisfaction with 58% of their 73 logged items. Fifty-three percent (53%) of the equipment is simultaneously satisfactory and safe, while 51% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=2) estimated percentage of operational equipment was 70%.

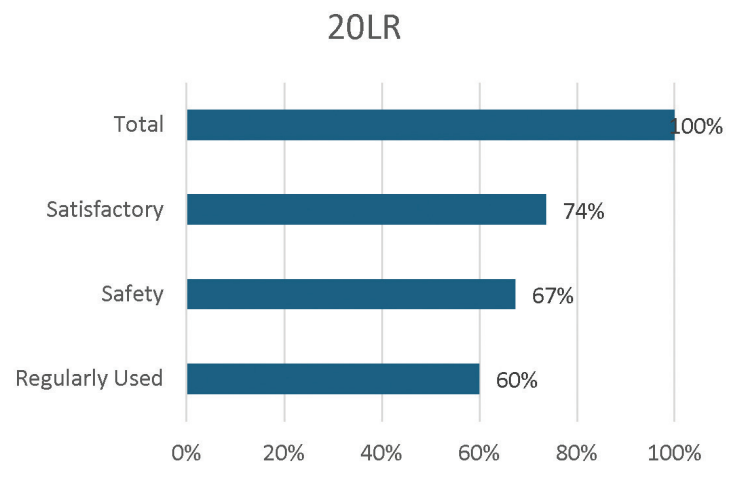
Figure 28h.



17GH, a 55-bed government hospital in Ghana, reports satisfaction with 71% of their 49 logged items. Seventy-one percent of the equipment is simultaneously satisfactory and safe, while 65% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 83%.

Liberia

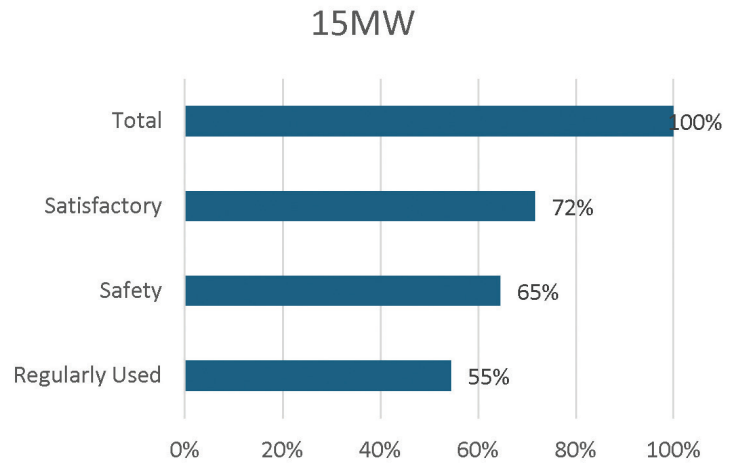
Figure 28i.



20LR, a 95-bed government hospital in Liberia, reports satisfaction with 74% of their 95 logged items. Sixty-seven percent (67%) of the equipment is simultaneously satisfactory and safe, while 60% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=2) estimated percentage of operational equipment was 96%.

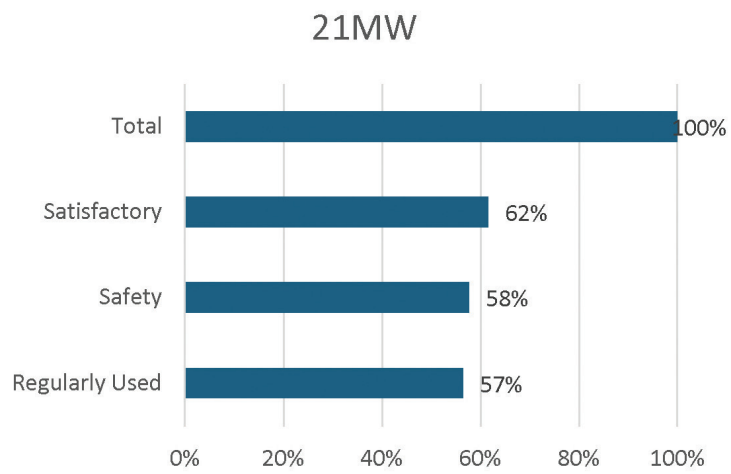
Malawi

Figure 28j.



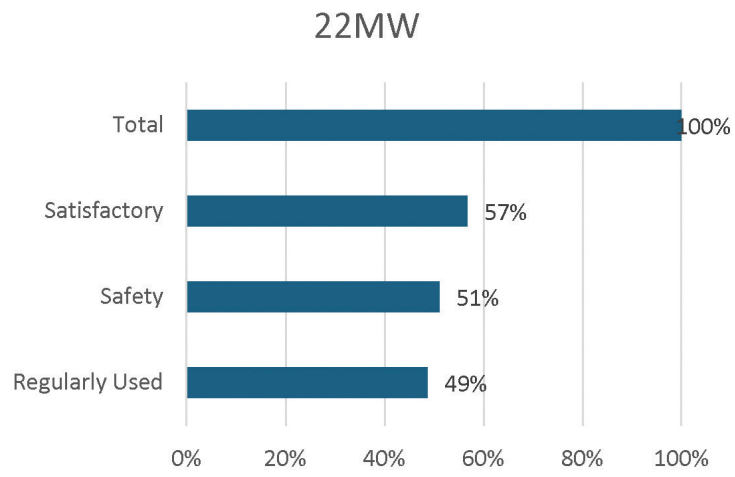
15MW, a 320-bed government hospital in Malawi, reports satisfaction with 72% of their 99 logged items. Sixty-five percent (65%) of the equipment is simultaneously satisfactory and safe, while 55% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=2) estimated percentage of operational equipment was 68%.

Figure 28k.



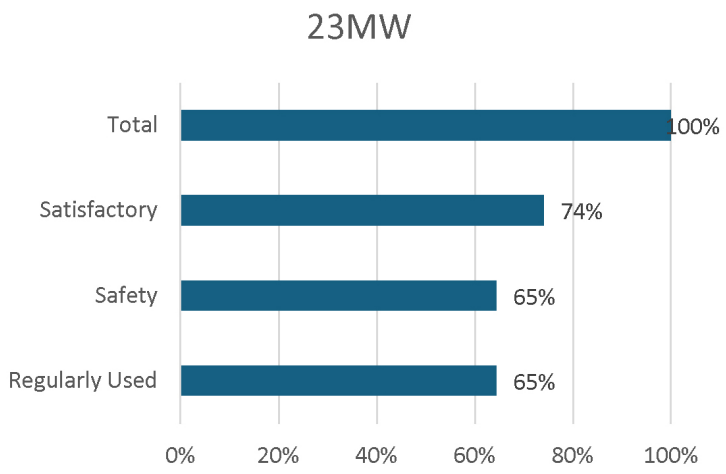
21MW, a 250-bed government hospital in Malawi, reports satisfaction with 62% of their 175 logged items. Fifty-eight percent (58%) of the equipment is simultaneously satisfactory and safe, while 57% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 50%.

Figure 28l.



22MW, a 250-bed government hospital in Malawi, reports satisfaction with 57% of their 160 logged items. Fifty-one percent (51%) of the equipment is simultaneously satisfactory and safe. While only 49% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=2) estimated percentage of operational equipment was 70%.

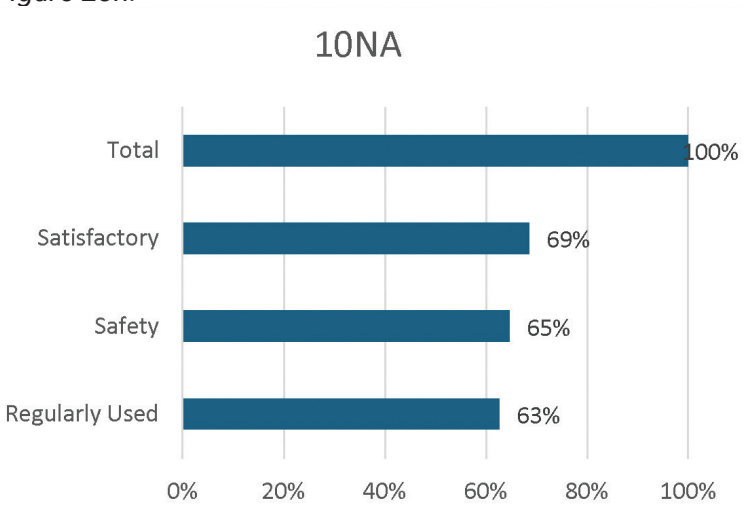
Figure 28m



23MW, a 60-bed government hospital in Malawi, reports satisfaction with 74% of their 31 logged items. Sixty-five percent (65%) of the equipment is simultaneously satisfactory and safe, and 65% of the equipment is also reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 60%.

Namibia

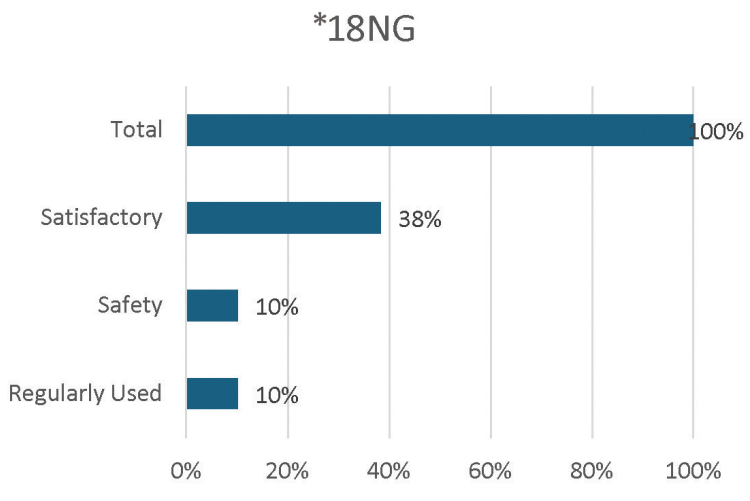
Figure 28n.



10NA, a 90-bed government hospital in Namibia, reports satisfaction with 69% of their 102 logged items. Sixty-five percent (65%) of the equipment is simultaneously satisfactory and safe. While only 63% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=3) estimated percentage of operational equipment was 58%.

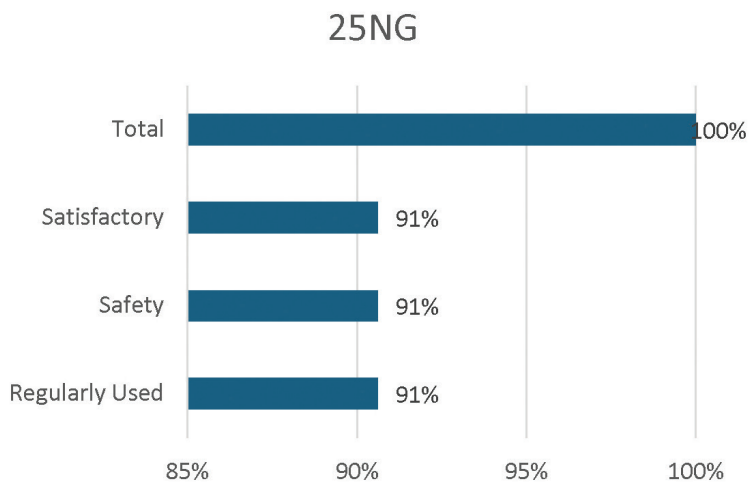
Nigeria

Figure 28o.



18NG, is a 120-bed mission/charity hospital in Nigeria, reports satisfaction with 38% of their 39 logged items. Ten percent (10%) of the equipment is simultaneously satisfactory and safe; 10% of the equipment is also reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=9) estimated percentage of operational equipment was 78%.

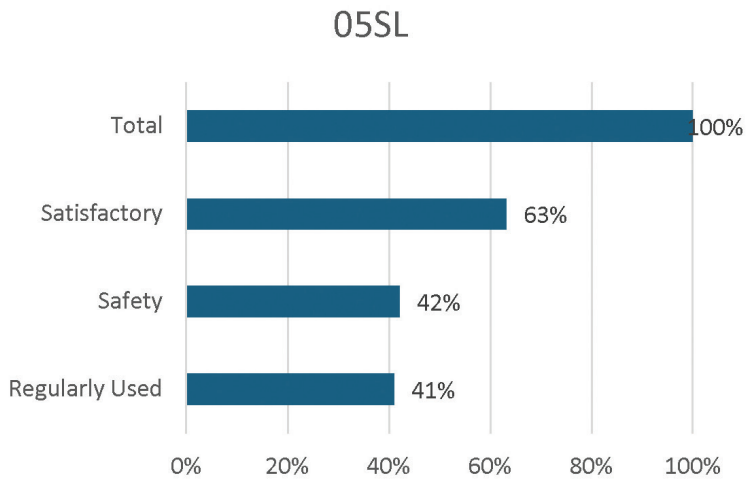
Figure 28p.



25NG, a 200-bed government fistula hospital in Nigeria, reports satisfaction with 91% of their 32 logged items. They originally reported all equipment had safety concerns. Due to the stark contrast in satisfaction rate and safety rate, an email was sent to confirm this response. The engineer responded that he misinterpreted the question; no equipment had safety concerns. The data was updated to reflect this correction. Accordingly, 91% of logged equipment is satisfactory, safe, and regularly used. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 98%.

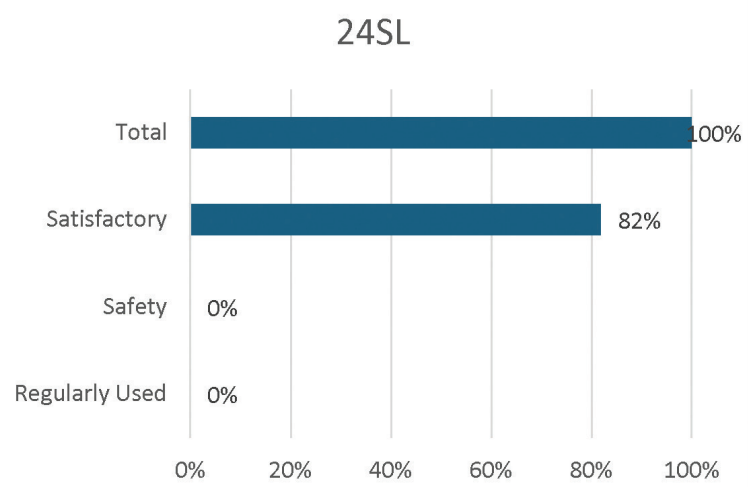
Sierra Leone

Figure 28q.



05SL, a 200-bed government hospital in Sierra Leone, reports satisfaction with 63% of their 90 logged items. Forty-two percent (42%) of the equipment is simultaneously satisfactory and safe. While only 41% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 91%.

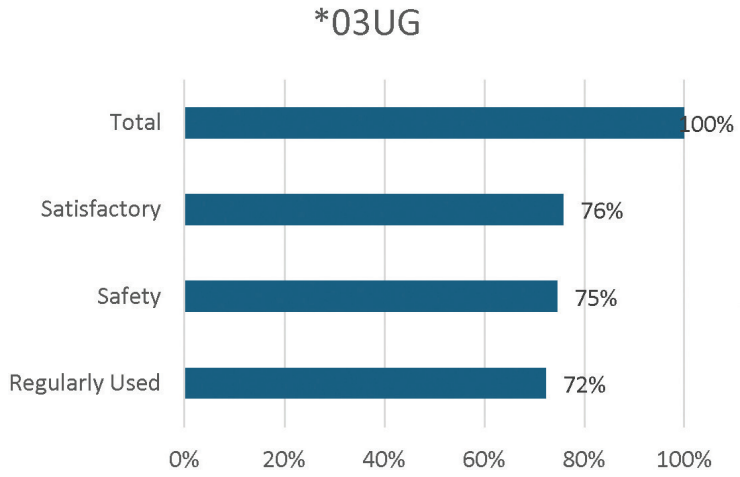
Figure 28r.



24SL, a 350-bed government hospital in Sierra Leone, reports satisfaction with 82% of their 105 logged items. They report all equipment has safety concerns. Due to the stark contrast in satisfaction rate and safety rate, an email was sent to confirm response. The response was confirmed, 0% of the satisfactory equipment has been deemed safe. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 15%.

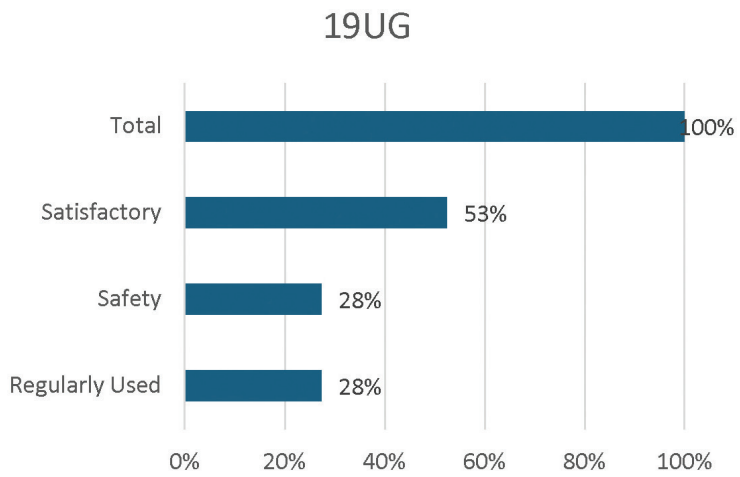
Uganda

Figure 28s.



03UG, a 250-bed mission/charity hospital in Uganda, reports satisfaction with 76% of their 87 logged items. Seventy-five percent (75%) of the equipment is simultaneously satisfactory and safe. While only 72% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 90%.

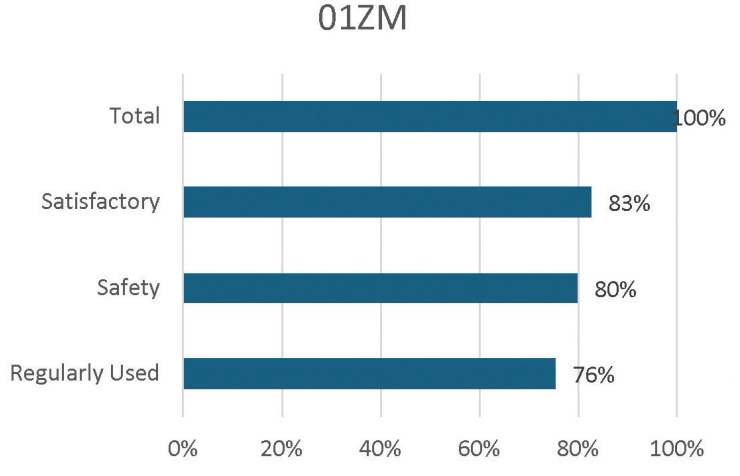
Figure 28t



19UG, an 85-bed private hospital in Uganda reports satisfaction with 53% of their 40 logged items. Twenty-eight percent (28%) of the equipment is simultaneously satisfactory and safe; 28% of the equipment is also reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=2) estimated percentage of operational equipment was 75%.

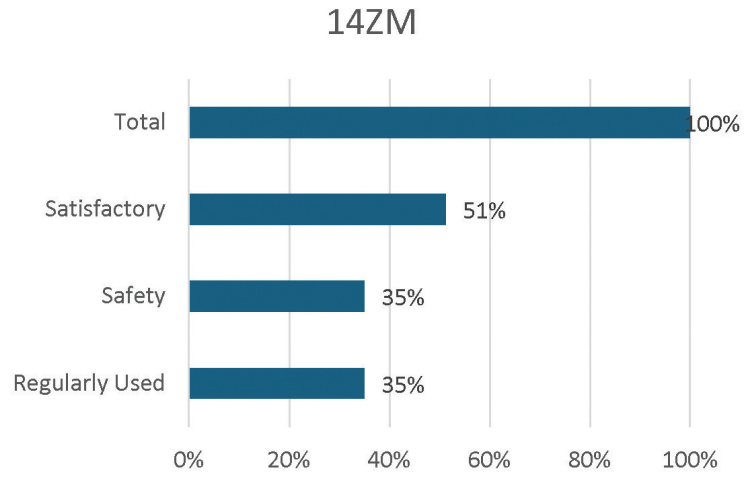
Zambia

Figure 28u



01ZM, a 250-bed government children's hospital in Zambia, reports satisfaction with 83% of their 139 logged items. Eighty percent (80%) of the equipment is simultaneously satisfactory and safe. While only 76% of the equipment is reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineers' (n=5) estimated percentage of operational equipment was 69%.

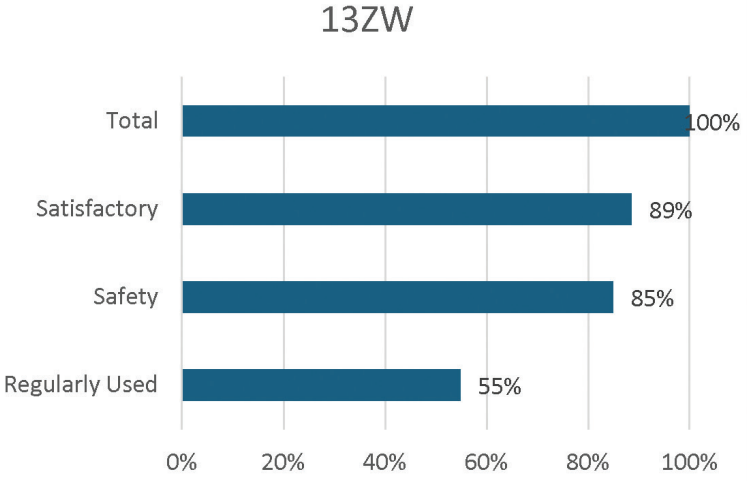
Figure 28v.



14ZM, a 60-bed government hospital in Zambia, reports satisfaction with 51% of their 37 logged items. Thirty-five percent of the equipment is simultaneously satisfactory and safe; 35% of the equipment is also reported as being satisfactory, safe, and has been used within six months. In the onboarding survey, the engineer's (n=1) estimated percentage of operational equipment was 55%.

Zimbabwe

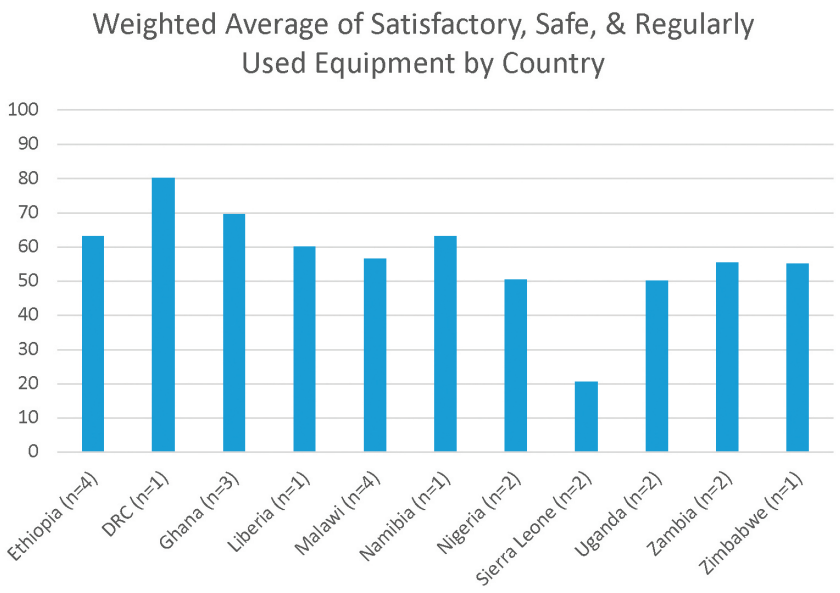
Figure 28w.



13ZW, a 120-bed government hospital in Zimbabwe, reports satisfaction with 89% of their 140 logged items. Eighty-five percent of the equipment is simultaneously satisfactory and safe. While only 55% of the equipment is reported as being satisfactory, safe, and has been used within six months. However, analysis of the comment section of the audit reveals that 30 items cited as never used are sitting new and unused in storage. In the onboarding survey, the engineers' (n=6) estimated percentage of operational equipment was 77%.

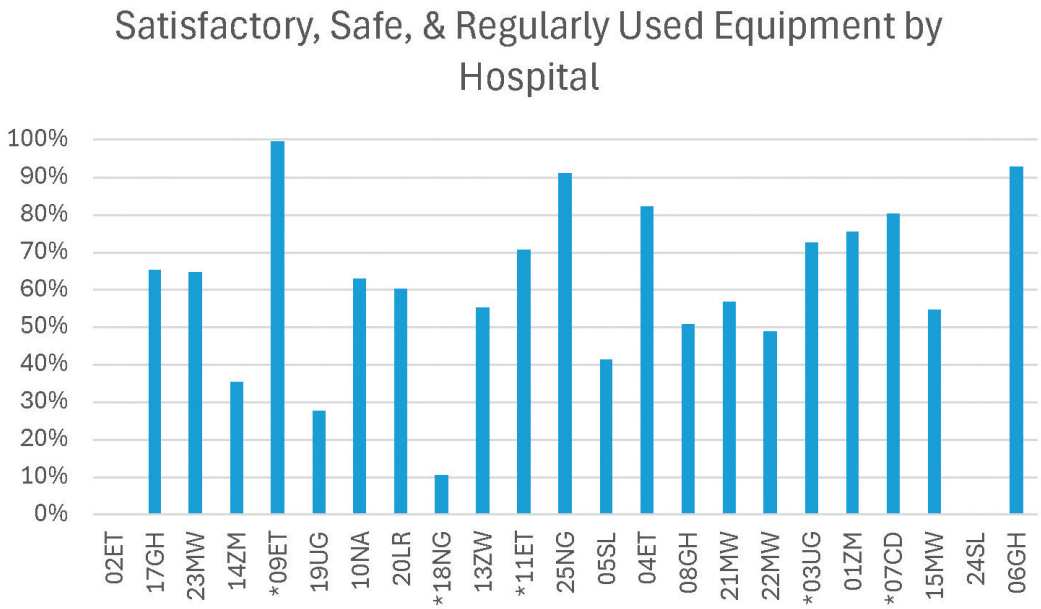
The next few graphs evaluate the overall functionality (satisfactory + safe + use) on a per country basis (Figure 29) and compare results across all healthcare facilities. In Figure 30, and all other figures unless specified otherwise, the hospitals are organised in order of increasing bed capacity. Mission/charity hospitals are noted with an asterisk throughout the report.

Figure 29.



n= number of healthcare facilities within each country

Figure 30.



** Mission/charity hospital*

Equipment Overview

This data set covers 2,930 items which were assessed across 23[7] healthcare facilities. The top five most frequently recorded items were patient monitors (496), oxygen concentrators (371), infusion pump/syringe drivers (352), suction machines (263), and oxygen cylinders (156). Table 9 lists all logged equipment quantities. Detailed analysis will be provided for the top half of the equipment as those items are reported in the highest quantities.

[7]While all equipment is essential, this single analysis excludes dialysis machines, blood gas analyser, laparoscopy, CPAP pipeline, electric bone saw, back-up generator, endoscopy equipment, and operating room traction tables as comparatively very few of these items have been logged. These items are included in all other overall analyses.

Table 9. Equipment Overview

Equipment	Total Quantity	Acceptable	Benchmark Compliant
Patient Monitor	496	80%	23%
Oxygen Concentrator	371	51%	29%
Infusion Pump/Syringe Driver	352	80%	80%
Suction Machine	263	64%	43%
Oxygen Cylinder	156	75%	42%
Pulse Oximeter	144	60%	35%
Steriliser/Autoclave	106	42%	41%
Operating Lights	98	57%	1%
Ventilator	93	83%	58%
Surgical Diathermy/ESU	89	63%	46%
Operating Table	89	70%	44%
Anaesthetic Machine	84	58%	39%
Infant Incubator	80	63%	63%
Infant Radiant Warmer	79	47%	46%
Ultrasound Scanner (Imaging Machine)	75	60%	44%
Defibrillator	64	66%	48%
X-ray/C-arm	57	58%	46%
Operating Microscope	32	75%	69%
Backup Electricity Generator	32	56%	38%
Head Lamp	29	72%	72%
CPAP (Concentrator-Connected)	27	70%	44%
Endoscopy Equipment System	25	48%	28%
Oxygen Pipeline	19	74%	37%
Electric or Air-Powered Bone Drill/Saw	16	94%	81%
Blood Gas Analyser	14	79%	71%
Dialysis Equipment	13	62%	54%
CPAP (Pipeline/Cylinder Oxygen-Connected)	10	30%	20%
Laryngoscope Handle (with Light)	7	86%	57%
Laparoscopy Equipment System	6	67%	50%
Operating Table Traction Device	4	0%	0%

Equipment Evaluation Method

This section provides an in-depth analysis of selected items from the audit. Each item underwent a structured evaluation process involving participant responses to three universally asked questions:

1. **Performance Satisfaction:** Participants were queried about their satisfaction with the equipment's performance in fulfilling its intended function.
2. **Safety Concerns:** Participants were asked to identify if there were any safety concerns regarding the equipment, pertaining to both patient and user safety.
3. **Utilisation Frequency:** Information regarding usage of the equipment was collected to gauge its regularity of use within the facility. Participants could select one of the following responses: within the past seven days, within the past month, within the past six months, longer than six months, never.

These questions, supplemented by item-specific inquiries, formed the basis of the cascading evaluation process aimed at determining the equipment's overall functionality, as deemed by Medical Aid International. This systematic approach was an attempt to ensure that only equipment meeting, at minimum, all three of the criteria — satisfactory, safe, and regularly used — was deemed acceptable. For example, this process eliminates equipment that was regularly used but deemed unsafe (14% of all equipment). However, no method is error-proof, and equipment that may not meet benchmark standards may still be categorised as benchmark compliant. An example is item #0096, an autoclave from 04ET. The engineers responded that this item performed its job to their satisfaction, had no safety concerns, and was used in the past 7 days. It switched on, generated the required temperature and pressure, and had all needed accessories and consumables. However, in the optional notes and comments section the engineer wrote "The machine is not work b/c the gasket is broken and h[ea]ter is no work."

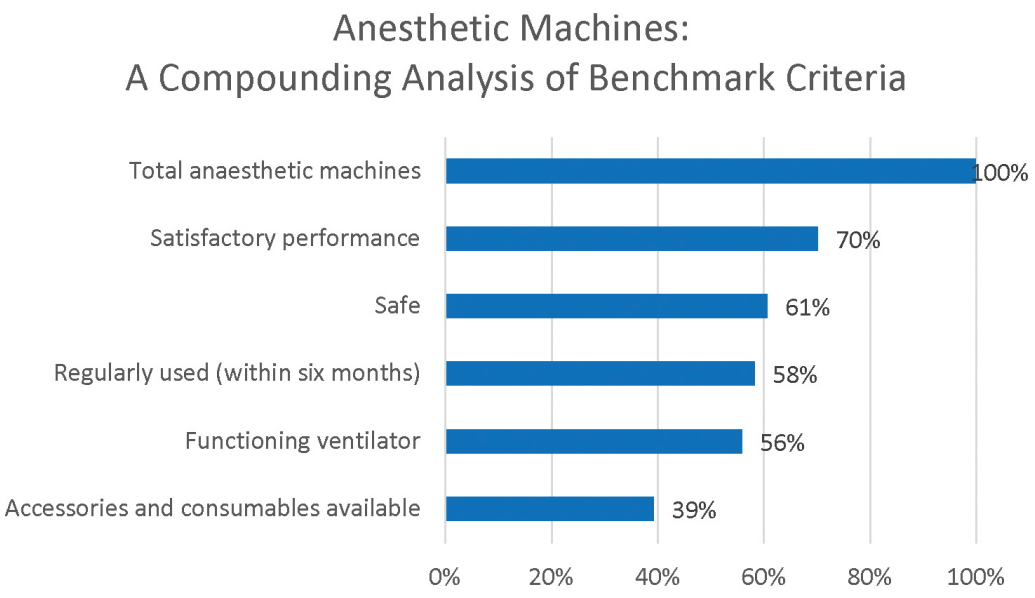
Each equipment segment will conclude with an images section. Participants were required to submit photos of the equipment audited. Images of completely non-operational equipment rusting in LMIC "equipment graveyards" have become ubiquitous online. While attention grabbing, and pertinent for discussion regarding appropriate disposal and decommissioning, the equipment in those images is not in use. The following images were intentionally selected to provide insight into the equipment that is regularly used. All equipment in the forthcoming images has been used within six months. These images capture the wide variety of equipment, from extremely high-tech, top-of-the-line items to antiquated equipment well beyond its life expectancy.

Anaesthetic Machines

- Total: 84
- Acceptable (satisfactory, safe, regularly used): 58%
- Benchmark Standards:
    - Acceptable
    - Has a functioning ventilator
    - Has all necessary accessories and consumables
- Benchmark compliant: 39%
- Donated: 54%
- Without equipment manuals: 33%
- Percent of all equipment with all consumables: 61%
- Percent of all equipment with all accessories: 54%
- Percent of all equipment with available spare parts: 17%

In addition to the standard questions regarding satisfactory performance, safety, and regular use, the anaesthetic machine benchmark standards include the presence of a functioning ventilator, and availability of all necessary accessories and consumables. Figure 31 illustrates the cascading nature of applying compounding acceptance criteria to the 84 anaesthetic machines surveyed. The analysis shows 70% of anaesthetic machines demonstrated satisfactory performance; 61% were both satisfactory and safe; 58% were deemed satisfactory, safe, and regularly used; 56% were satisfactory, safe, regularly used and had a working ventilator; and finally, only 39% were simultaneously satisfactory, safe, regularly used, had a working ventilator and all necessary accessories and consumables. Accordingly, only 39% (33 of 84) of the machines meet benchmark standards.

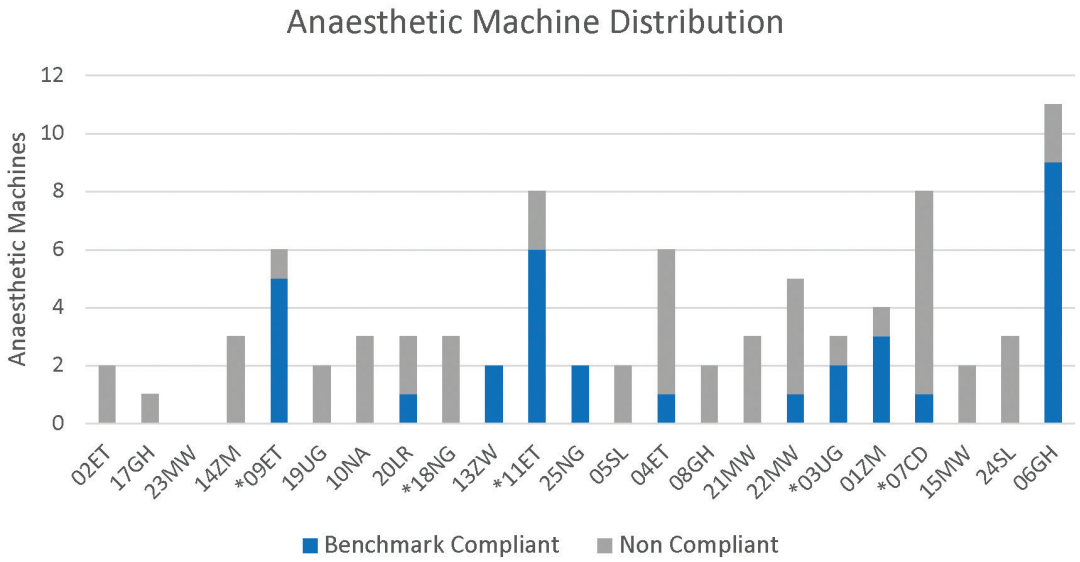
Figure 31.



The criteria for determining the benchmark compliant equipment does not include considerations such as whether the machine has undergone servicing, if the soda lime has been recently replenished, or if anaesthetic agent monitoring and carbon dioxide (CO_2) monitoring are utilised.

The 33 benchmark compliant anaesthetic machines (highlighted blue in Figure 32) are distributed across only 11 healthcare facilities. Fifty-five percent (55%) of these compliant machines are Drager (18/33). Fifty-eight percent (58%) (19/33) of compliant machines were purchased new, as opposed to 36% which were donated. Figure 32 shows the distribution of benchmark compliant anaesthetic machines across all healthcare facilities (organized from left to right by increasing bed capacity).

Figure 32.



** Mission/charity hospital*

Eighty percent (80%) of the mission hospitals have at least one benchmark compliant anaesthetic machine compared to only 41% of the government hospitals.

Table 10 demonstrates the country of manufacture of all 84 anaesthetic machines along with the percentage from each country meet benchmark criteria.

Table 10. Anaesthetic Machine Country of Manufacture

Country	Frequency	Percent Meeting Benchmark Criteria
China	23	26% (6/23)
Germany	23	83% (19/23)
Japan	1	0% (0/1)
UK	14	36% (5/14)
Unknown	9	11% (1/9)
US	13	15% (2/13)
India	1	0% 0/1

The top six manufacturers are: Drager (21), Mindray (11), Ohmeda (11), Diamedica (8), Aeonmed (7), and UAM (4).

While 84 anaesthetic machines have been logged, only 7 laryngoscopes across 6 facilities have been reported. The working hypothesis, from anecdotal evidence, is that anaesthetic providers carry their own personal laryngoscopes with them, and they are not property of the hospital.

Summary of Optional Notes and Comments

Analysis of the notes and comments section of the audit provides insight into the functional status, maintenance needs, and usage and performance of all the recorded anaesthetic machines. There are multiple mentions of the need for accessories to ensure the functionality of the machine and needed replacements of ventilators, monitors, oxygen sensors, power supply, and soda lime.

Discussion and Insights

From the manufacturer name, model number, and submitted images it was possible to determine that 64 of the machines were closed circuit, and 20 were open circuit machines.

There are two primary types of anaesthetic machines: closed circuit and open circuit machines. Closed circuit machines are standard level of care in high-income countries. However, these machines are more often than not inappropriate for LMICs. While closed circuit machines are often seen as financially beneficial, as the machine is designed to recycle medical gases and anaesthetic agents, the complexity of this feature and extensive patient monitoring required make it incredibly dangerous in low resource settings. Closed circuit machines require a continuous supply of soda lime to absorb expired CO_2. If the soda lime is not changed at regular intervals, its ability to effectively absorb CO_2 is compromised. This can lead to inadequate CO_2 removal from the patient leading to hypercapnia. Accordingly, when closed circuit anaesthetic machines are used, they must be paired with CO_2 monitoring (capnography) to ensure patient safety. Additionally, in closed circuit machines anaesthetic agent monitoring must also occur to ensure the patient remains appropriately anaesthetised during the procedure. Basic patient monitors do not typically come with capnography or anaesthetic agent monitoring capabilities; this is often an additional feature which must be purchased separately. Closed circuit machines also require regular specialised servicing.

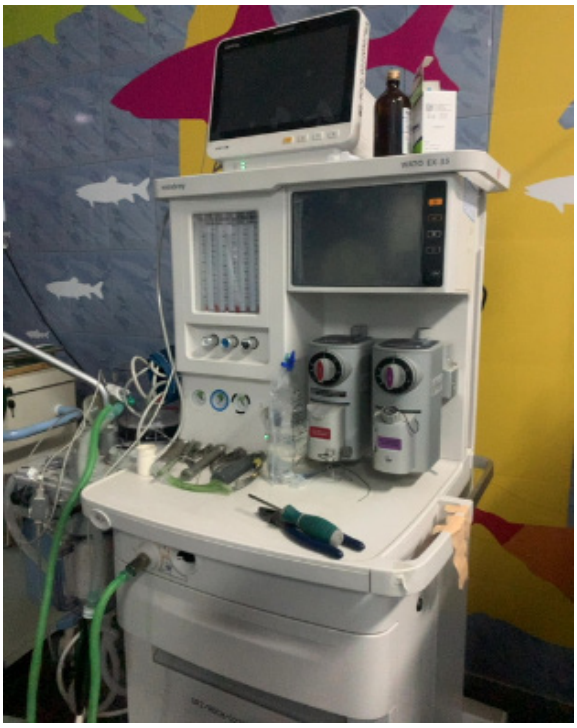
Open circuit machines do not require CO_2 monitoring nor anaesthetic agent monitoring as exhaled gases are vented into the atmosphere as opposed to being recirculated. Likewise, open circuit machines do not require soda lime nor medical gases, as oxygen is siphoned from room air via built-in oxygen concentrators. Open circuit machines are easier to operate, require fewer consumables and less patient monitoring. Additionally, open circuit machines do not require annual servicing from the manufacturer.

While closed circuit machines are not in and of themselves dangerous, they can quickly become dangerous if consumables run out, if advanced monitoring is unavailable, and if servicing lapses. It is for these reasons that open circuit machines are best suited to low resource environments.

Figure 33.
Anaesthetic Machine Images from Audit

*11ET, #064
Benchmark compliant closed circuit anaesthetic machine that was purchased new.

20LR, #039
Donated benchmark compliant open circuit anaesthetic machine purpose built for LMICs.



01ZM, #104
Benchmark compliant donated WATO-35.

*07CD, #015
Acceptable (but not benchmark compliant) closed circuit anaesthetic machine. Does not have required consumables.

*18NG, #063
Draw-over anaesthetic machine with listed safety concerns used in the past 7 days.

19UG, #011
Closed circuit anaesthetic machine with listed safety concerns used in the past 7 days.

08GH, #016
Anaethetic machine deemed unsatisfactory and unsafe but used within the past 7 days.

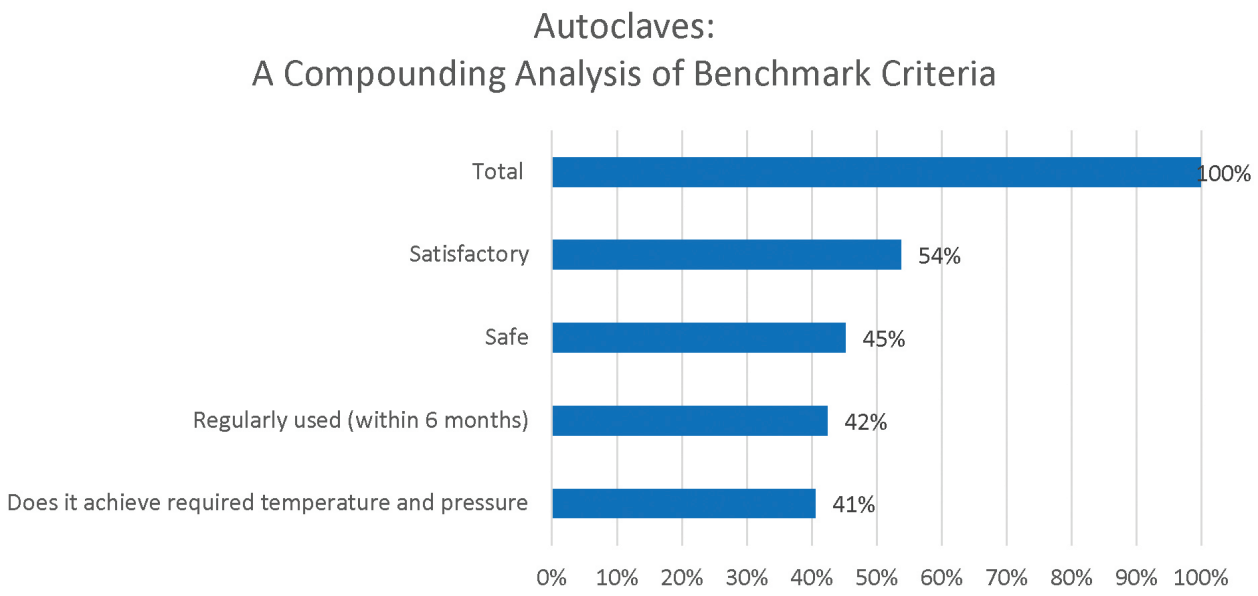
10NA, #050
Listed as safe, satisfactory, and used within 7 days. However, has no soda lime, vaporiser, nor required accessories and consumables.

Autoclaves

- Total: 106
- Acceptable: 42%
- Benchmark standards:
    - Acceptable
    - Achieves required temperature and pressure
- Benchmark compliant: 41%
- Donated: 58%
- Without equipment manuals: 49%
- Percent of all equipment with all consumables: 40%
- Percent of all equipment with all accessories: 42%
- Percent of all equipment with available spare parts: 10%

Figure 34 demonstrates the cascading impact of adding additional benchmark criteria: does it achieve required temperature and pressure. Availability of accessories and consumables were not factored into the benchmark criteria as these are considered beneficial but not always essential for sterilisation (i.e. indicator tape, reverse osmosis water).

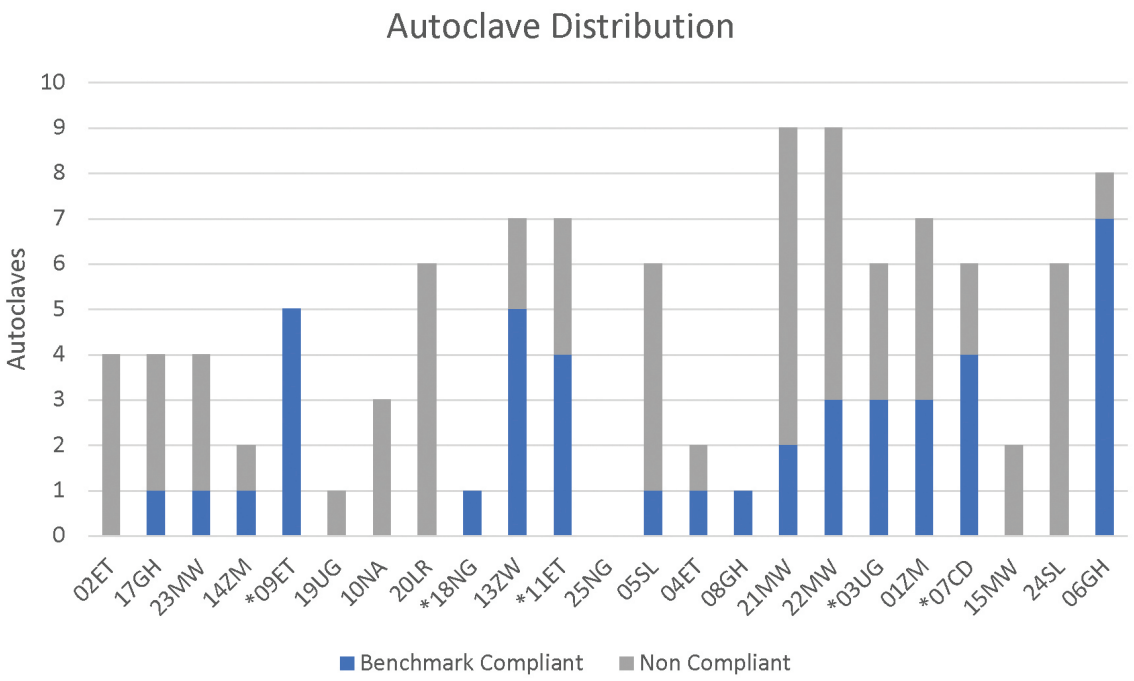
Figure 34.



A total of 106 autoclaves were logged from 55 different manufacturers. The three most frequently recorded manufacturers are Tuttnauer (19), Titanox (5), and Reimers (5). Of the 106 autoclaves, 43 (41%) were determined to be benchmark compliant (i.e. had a satisfactory performance, had no safety concerns, were used within the past six months, and achieved required temperature and pressure for sterilisation).

The distribution of the autoclaves is demonstrated below in Figure 35. The autoclaves that meet all of the benchmark criteria are in blue.

Figure 35.



** Mission/charity hospital*

The essential and fundamental burden of sterilisation is predominantly carried by tabletop autoclaves: 51% of all autoclaves recorded are tabletop, 55% of all acceptable autoclaves are tabletop machines. Tabletop machines typically have a volume of 25L or less and are intended for small clinics.

Seven healthcare facilities are operating without a single compliant autoclave. Another seven healthcare facilities have only one compliant autoclave; these autoclaves are shown below in Figure 36.

Optional Notes and Comments Summary

Analysis of the notes and comments section of the audit provides insight into the functional status, maintenance needs, and usage and performance of autoclaves. Multiple autoclaves are reported as faulty due to issues such as boiler failure, broken door gaskets, burnt heating elements, faulty valves, software errors, and leaks.

Discussion and Insights

Operational and context-appropriate autoclaves are a prerequisite for every healthcare facility. It is imperative that every healthcare facility possess at least one fully operational autoclave before commencing any patient care activities. Sterilisation is a binary process; it either occurs (and the item is sterile), or does not occur (and the item is unsafe for use). A steam autoclave that does not generate at minimum 121°C and 15psi is non-operational. While this audit did ask if the temperature and pressure were met, it did not verify that the engineers had the appropriate tools and calibration equipment to ensure accurate measures of these fundamental sterilisation elements. Medical Aid International's recommendations on LMIC appropriate autoclaves can be found in the LMIC Operating Room Equipment Survey.

Figure 36.
Autoclave Images from the Audit

13ZW, #092
Benchmark compliant table-top autoclave.

23MW, #012
The only benchmark compliant autoclave at this facility is a dry heat steriliser.

14ZM, #008
Benchmark compliant table-top autoclave.

13ZW, #0069
Benchmark compliant industrial autoclave.

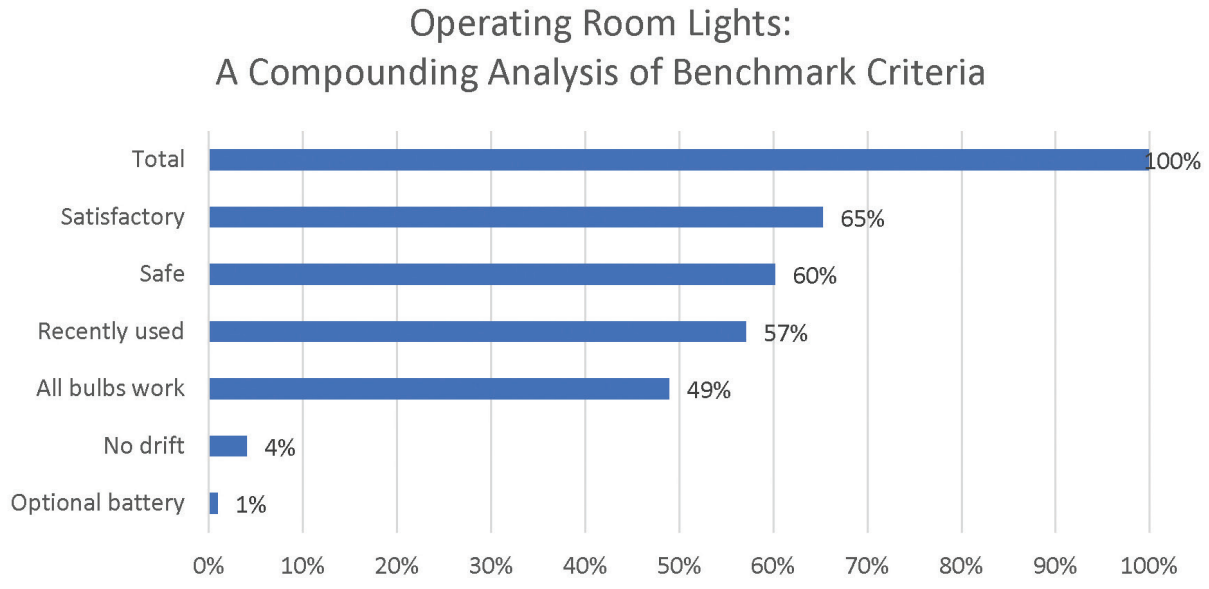
	
17GH, #046. Benchmark compliant pressure-cooker autoclave, purchased new.	03UG, #005. Acceptable, used within the past 7 days, no safety concerns, satisfactory performance. However, the device does not reach designated temperature and pressure.
	
22MW, #002 Used in the last 7 days even though deemed unsafe and unsatisfactory.	04ET, #123 Although engineers reported this autocalve met all of the benchmark compliant criteria, they noted in the comment section that this machine does not heat. Accordingly, this 4 OR tauma care hospital in the capital is operating withouth a suitable autoclave.

Operating Room Lights

- Total: 98
- Acceptable: 57%
- Benchmark standards:
    - Acceptable
    - All bulbs work
    - No drift
    - Optional battery capabilities
- Benchmark compliant: 1%
- Donated: 58%
- Without equipment manuals: 57%
- Percent of all equipment with all consumables: Not asked[8]
- Percent of all equipment with all accessories: Not asked[8]
- Percent of all equipment with available spare parts: Not asked[8]

A total of 98 OR lights were recorded. Only 1% of all lights are deemed compliant (i.e. had a satisfactory performance, had no safety concerns, were used within the past six months, had all working lightbulbs, did not drift, and had a working battery backup). This compounding analysis can be seen in Figure 37.

Figure 37.



** Mission/charity hospital*

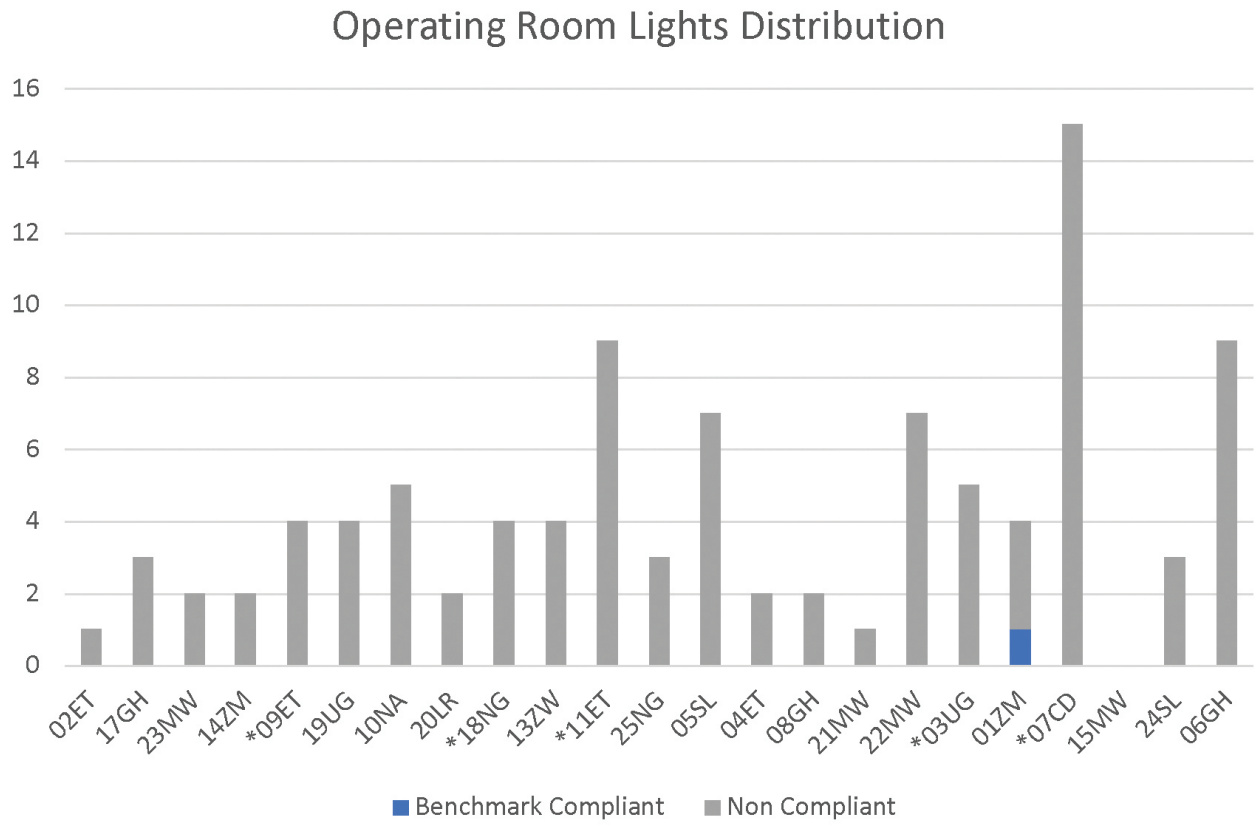
There may be confusion regarding the term "drift" as this was not defined. The intention behind the question "does the light drift" was to ascertain the negative, unwanted movement of the light after it has been set (rather than the ability for the light to be deliberately repositioned).

The five most common brands are Drager (9, across 2 facilities), Chosen (7, across 1 facility), Hanaulux (4, across 4 facilities), Daray (4, across 1 facility), and Castle (4, across 2 facilities).

[8]Questions regarding consumables, accessories and spares were not asked as a separate question regarding light bulbs and their function status was asked instead.

Figure 38 demonstrates the distribution of benchmark compliant equipment.

Figure 38.



** Mission/charity hospital*

Optional Notes and Comments Summary

Analysis of the notes and comments section of the audit provides insight into the functional status and maintenance needs of operating room lights. The number one comment is broken and blown bulbs and the subsequent challenges of procuring replacements. Lack of batteries and broken bulb holders are also mentioned.

Discussion and Insights

A well-lit operating room is paramount to safe and successful surgery. Sufficient lighting must be provided uninterrupted throughout the entire operation. Thus, it is essential that in environments that suffer power fluctuations and failures, the lights have battery back-up options. Only 16% of all surveyed lights had battery power capability.

Although participants were not asked to document if the lights were ceiling mounted or mobile, analysis of the 91 images indicates a near equal divide, with 54% of lights being mobile and 46% being ceiling mounted. Ceiling mounted lights can pose additional safety risks as the infrastructure must be able to support the weight. Image 14ZM, #006 and 22MW, #0083 demonstrate instances where mobile lights may be more appropriate, as the infrastructure appears incompatible with mounted lights.

Figure 39.
OR Light Images from Audit

01ZM, #106
This is the only benchmark compliant OR light across all 98 lights audited.

11ET, #134
This ceiling mounted operating room light is deemed satisfactory and is regularly used even though there are safety concerns regarding its use.

03UG, #057
Example of a regularly used OR light that does not perform to the satisfaction of the engineer.

07CD, #014
Another example of a regularly used (albeit unsatisfactory) light that drifts and does not have all bulbs working.

19UG, #0028
Acceptable (satisfactory, safe, used within 7 days) light with all bulbs functional and no unwanted drift. However, light does not have battery backup feature.

10NA, #105
Acceptable (satisfactory, safe, used within 7 days) light. However, light drifts and does not have all bulbs functioning. Battery backup feature exists but status of battery is unkown.

14ZM, #006
Ceiling mounted light used within the past 7 days, with no safety concerns. The equipment is unsatisfactory and all the lights do not work.

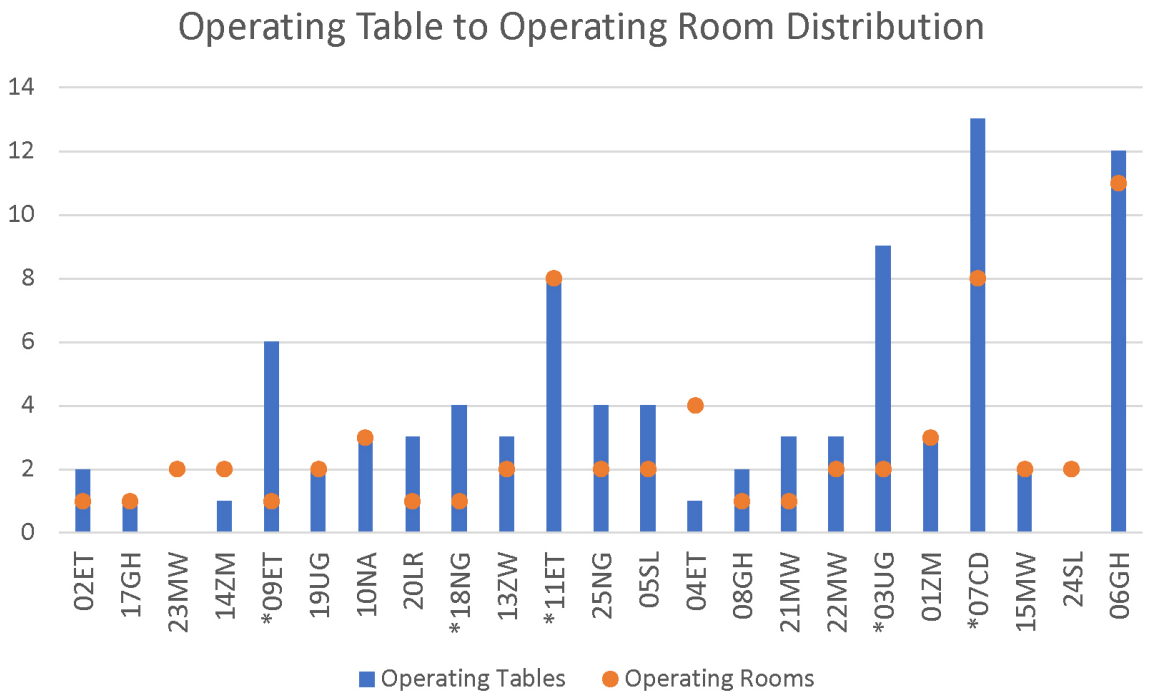
22MW, #083
Ceiling mounted light not used in over 6 months, light does not switch on and safety concerns exist.

Operating Room Tables

- Total: 89
- Acceptable: 70%
- Benchmark standards:
    - Acceptable
    - Height adjustable
    - All necessary accessories available
- Benchmark compliant:44%
- Donated: 58%
- Without equipment manuals: 43%
- Percent of all equipment with all consumables: Not asked
- Percent of all equipment with all accessories: 49%
- Percent of all equipment with available spare parts: 20%

In all, 89 operating room tables were recorded across 64 operating rooms. Figure 40 highlights a significant mismatch between the number of operating tables and operating rooms across the surveyed facilities. In many instances, the number of operating room tables exceeds the number of operating rooms. This discrepancy, along with comments from participants, suggests that some facilities possess multiple tables per room to accommodate different surgical needs. Conversely, facilities with fewer tables than rooms might face scheduling and operational challenges, potentially leading to delays in surgical procedures and reduced overall efficiency. This imbalance underscores the need for proper resource allocation and planning to ensure that each operating room is adequately equipped to handle its surgical workload.

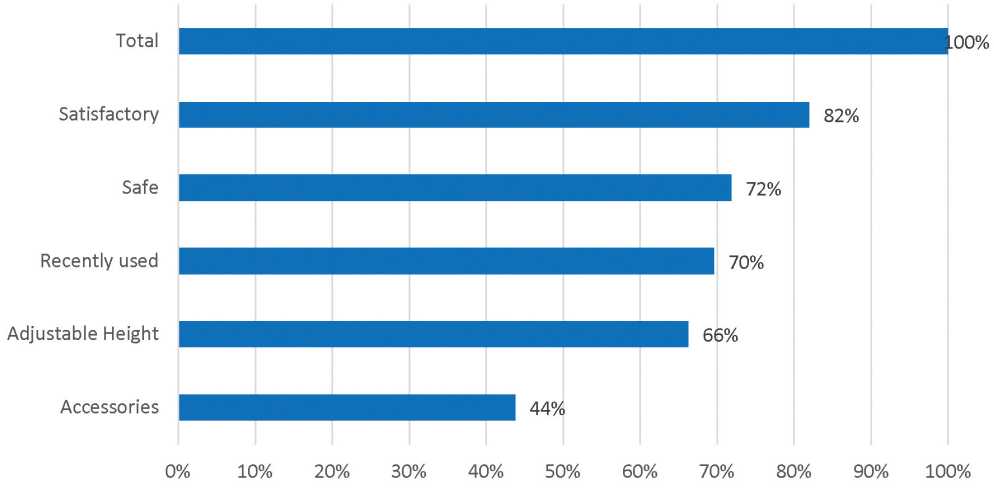
Figure 40.



** Mission/charity hospital*

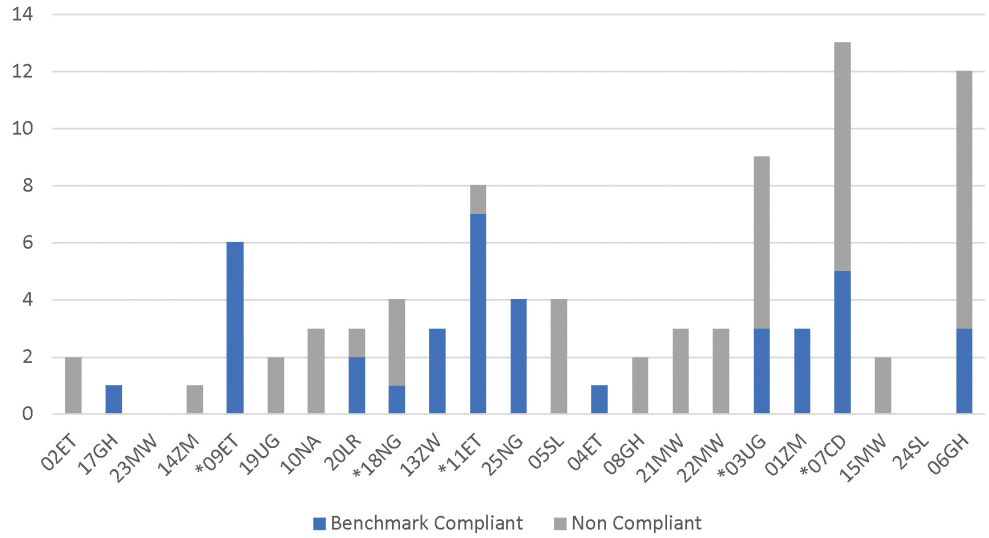
Of the 89 tables, only 59 (66%) were simultaneously satisfactory, safe, regularly used, and height adjustable, while only 44% had all necessary accessories (see Figure 41). Common operating table accessories include lithotomy poles, arm boards, IV tables, etc. Of these 39 benchmark compliant tables, 56% were donated and 44% purchased new.

Figure 41.
Operating Room Tables:
A Compounding Analysis of Benchmark Criteria



Operating room table distribution across the 23 surveyed facilities is illustrated in Figure 42.

Figure 42.
Operating Room Table Distribution



** Mission/charity hospital*

The most common OR table brands are Mindray (12 tables across 2 facilities), Skytron (9, across 3 facilities), AMSCO (4, across 2 facilities). The tables are split almost equally between manual (48%) and electric (47%). Fifty-eight percent (58%) of the tables were donated and 37% were new purchases.

Although 44% of tables are currently deemed benchmark compliant, this percentage would drop to 19% during a power outage as only 17 tables are satisfactory, safe, regularly used, height adjustable, have all accessories and are manually operated – see the Discussion and Insights section below.

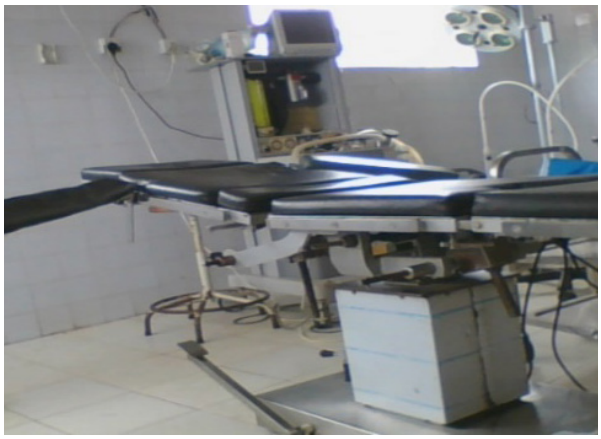
Discussion and Insights

Electric operating room tables are perfectly acceptable for environments with a stable power grid, and sites with trained staff, appropriate disinfectant protocols, backup battery availability, and routine safety and battery checks. These are assumptions that cannot be taken for granted in LMICs. More often than not, facilities struggle with power failures. In such instances, electric tables (unless equipped with functional backup batteries) cease to perform their function. Additionally, electric operating tables can instantaneously be rendered useless if cross continent voltage discrepancies are not accommodated.

Figure 43.
OR Table Images from Audit

	
21MW, #0032 Used in the last week but has safety concerns and does not perform to satisfaction.	22MW, #001 Used in the 6 months but has safety concerns and does not perform to satisfaction.

15MW, #010
Satisfactory and used within 7 days, albeit unsafe and missing accessories.



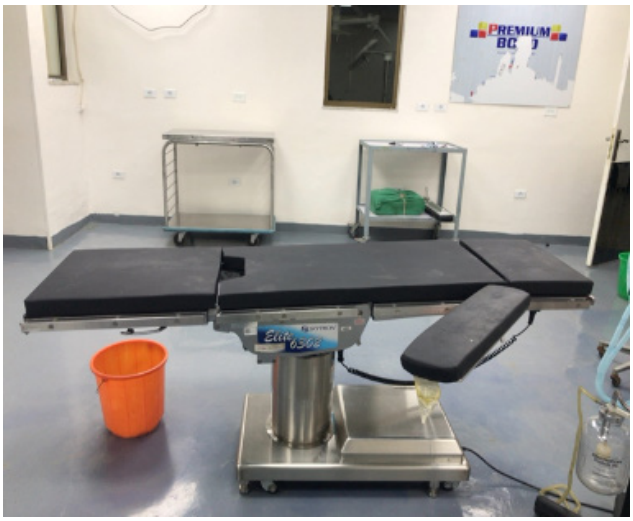
05SL, #029
Used in the last week and performs to satisfaction but has noted safety concerns.

07CD, #0018
Used in the last week and performs to satisfaction but has noted safety concerns.

10NA, #0047.
Used in the last week but has safety concerns and does not perform to satisfaction.

07CD, #024
Benchmark compliant table used within the week.

13ZW, #018
Benchmark compliant table used within the past month.



11ET, #076
Benchmark compliant table.

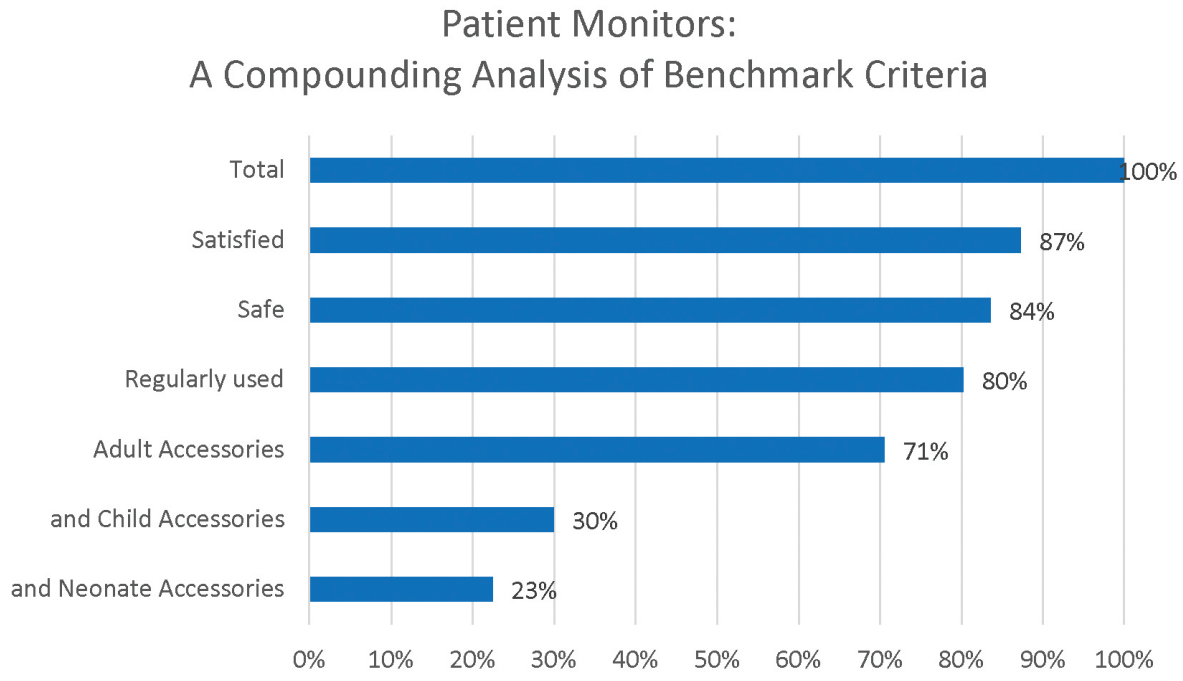
07CD, #159
Acceptable, but not height adjustable.

Patient Monitors

- Total: 496
- Acceptable: 80%
- Benchmark standards:
    - Acceptable
    - All adult accessories available
    - All paediatric accessories available
    - All neonatal accessories available
- Benchmark compliant: 23%
- Donated: 32%
- Without equipment manuals: 32%
- Percent of all equipment with all consumables: 70%
- Percent of all equipment with all accessories: 25%
- Percent of all equipment with available spare parts: 15%

A total of 496 patient monitors have been logged; 80% of these monitors are simultaneously satisfactory, safe, and regularly used. However, the percentage of acceptable machines falls dramatically when asked whether they have adult, child, and neonatal accessories available. Only 23% (112) of the recorded monitors can accommodate all patients (see Figure 44).

Figure 44.



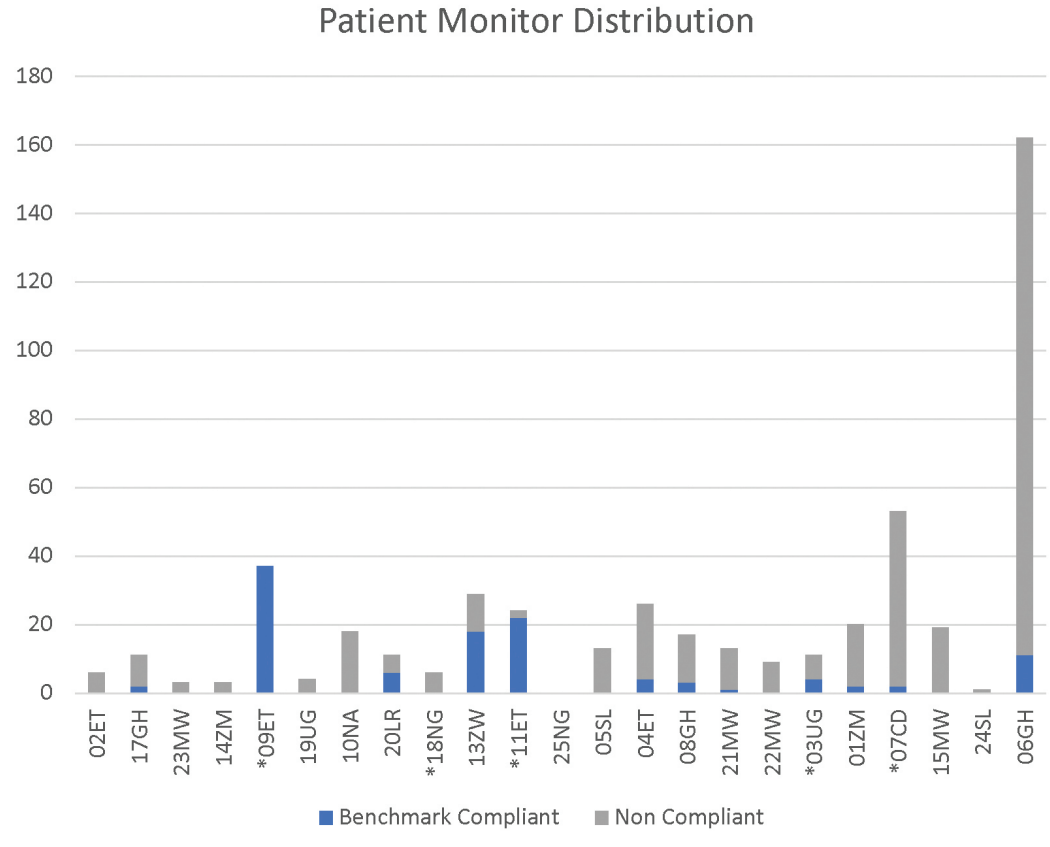
The 496 recorded patient monitors are from at least 60 different manufacturers. Those with the highest quantities are in Table 11. Phillips and GE have 100% satisfaction and very low levels of donations (6% and 5%, respectively).

Table 11. Patient Monitor Data

Brand	Country of Manufacture	Quantities	Satisfaction	% Donated
Philips	Netherlands	86	100%	6%
Contec	China	44	93%	14%
Drager	Germany	42	74%	12%
Comen	China	39	97%	3%
Edan	China	34	91%	29%
BioLight	China	33	70%	58%
Mindray	China	28	96%	75%
GE Health Care	USA	22	100%	5%
Welch Allyn	USA	21	71%	48%

The inequitable distribution of patient monitors is evident in Figure 45.

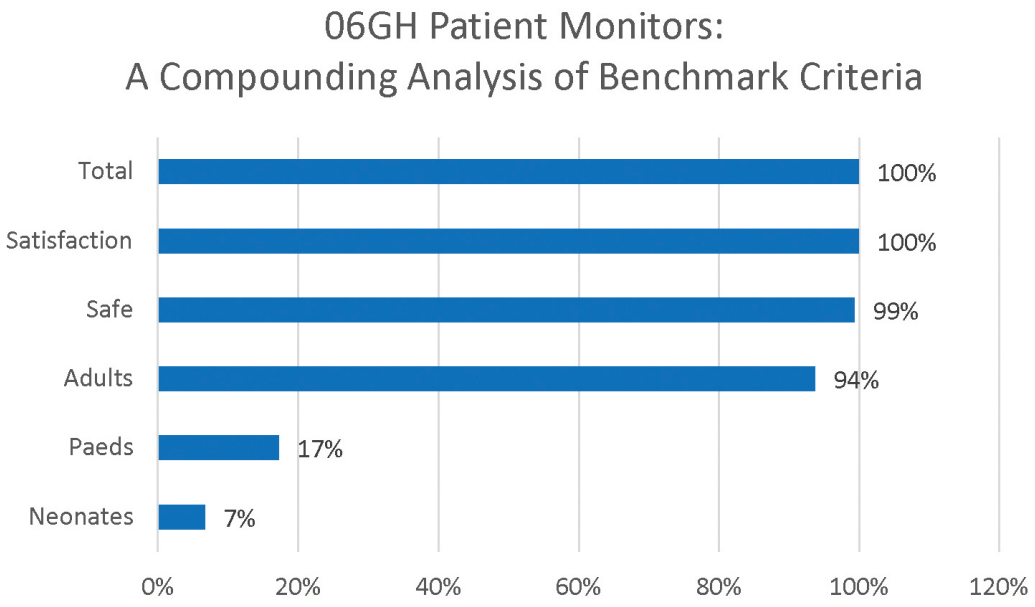
Figure 45.



** Mission/Charity Hospitals*

Figure 45 shows extremely high quantities of patient monitors at 06GH. However, they had relatively low (7%) benchmark compliance. This is not due to an influx of inappropriate donations as 97% of their patient monitors were purchased new. Implementing a cascading analysis of compounding acceptance criteria on only the patient monitors from 06GH, demonstrates that these items fall short of being benchmark compliant due to the lack of paediatric and neonatal accessories (see Figure 46). Comparatively to adults, there is limited equipment availability for use in paediatric and neonatal care. We are unable to identify if this is appropriate, and representative of patient need, or represents a gap in patient care.

Figure 46.



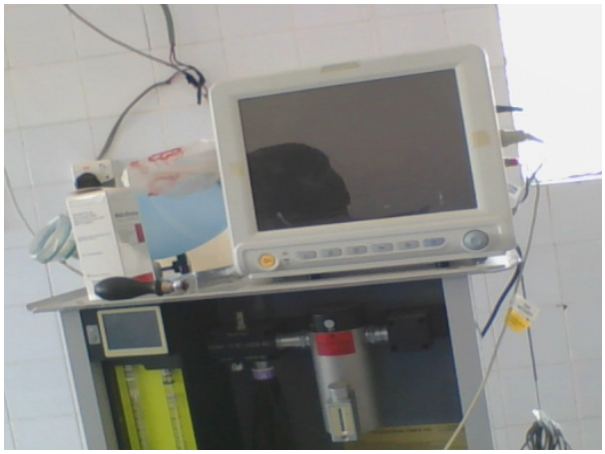
Summary of Optional Notes/Comments

Analysis of the notes and comments section of the audit provides insight into the functional status, maintenance needs, and usage and performance of patient monitors. Several monitors have been described as fully functional yet lack necessary accessories such as probes, cuffs, or power cables. Others have been reported to have issue due to display screens, battery failures, or spoiled probes. A few units are condemned for disposal due to irreparable damage or outdated technology. Accessories and spare parts are frequently mentioned as essential for maintaining functionality, and the lack of these components often results in the equipment not being used or performing sub-optimally.

Figure 47.
Patient Monitor Images from Audit

07CD, #103
Benchmark compliant monitor.

20LR, #016
Benchmark compliant monitor.



05SL, #027
Patient monitor has been used in the past 7 days, satisfactory performance, noted safety concerns.

14ZM, #033
Patient monitor has been used in the past 7 days, satisfactory performance, noted safety concerns.

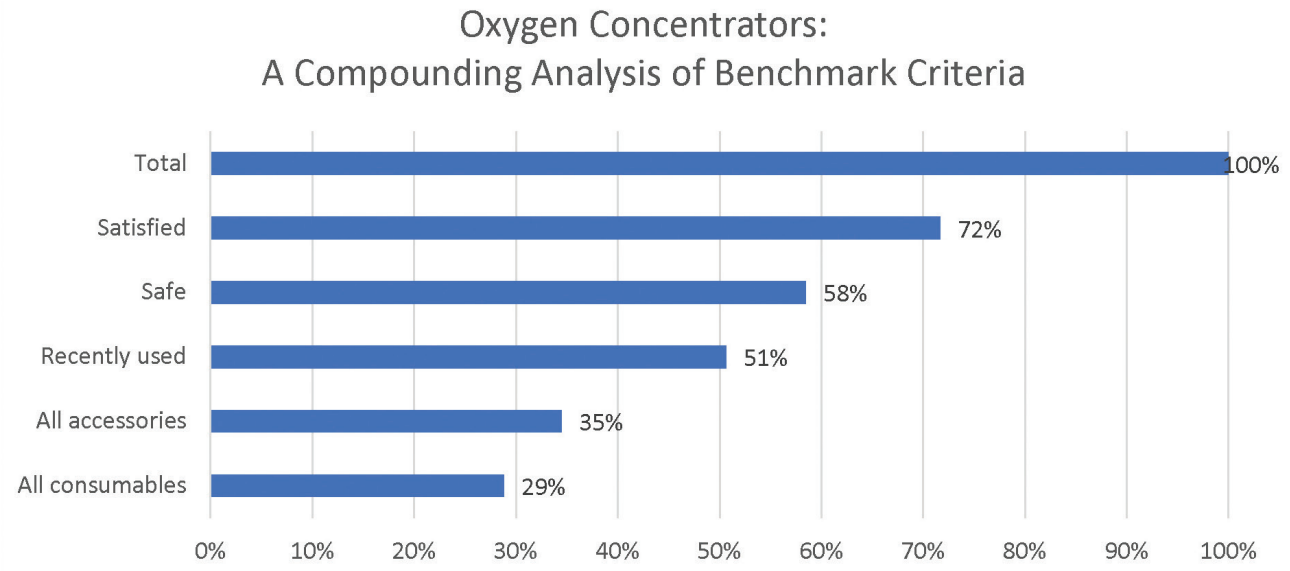
	
11ET, #026 Benchmark compliant monitor.	04ET, #036 Benchmark compliant monitor.

Oxygen Concentrators

- Total: 371
- Acceptable: 51%
- Benchmark standards:
    - Acceptable
    - All necessary accessories available
- Benchmark compliant: 29%
- Donated: 76%
- Without equipment manuals: 32%
- Percent of all equipment with all consumables: 55%
- Percent of all equipment with all accessories: 56%
- Percent of all equipment with available spare parts: 13%

371 oxygen concentrators were recorded. Only 29% of these were simultaneously satisfactory, safe, recently used, and had all accessories and consumables (see Figure 48).

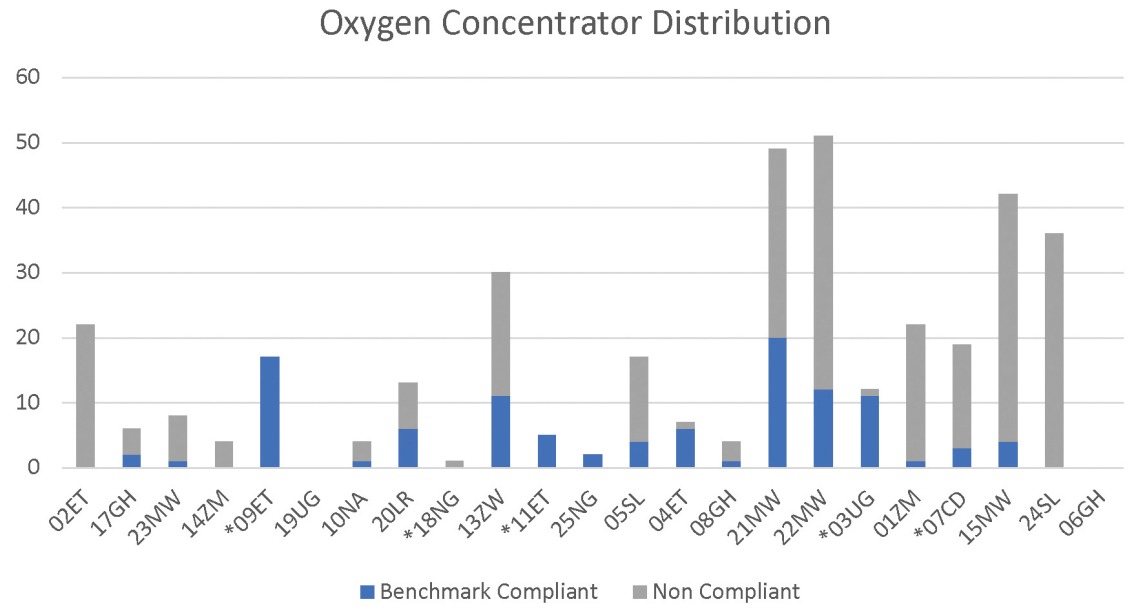
Figure 48.



Accessories for oxygen concentrators include humidifier bottles, nasal cannulas, oxygen masks, tubing, and filters. Filters, nasal cannulas, and masks may also be considered consumables as they need frequent replacement. All these elements, whether accessories or consumables, are essential for optimal oxygen concentrator function.

Distribution of oxygen concentrators is illustrated in Figure 49. Of significant note is that 06GH, 13ZW, 22MW, 03UG, 21MW, 24SL, and 11ET have oxygen pipelines.

Figure 49.



** Mission/charity hospital*

Seventy-six (76%) of all concentrators were donated. Oxygen concentrators make up the highest percentage of donated equipment. Table 12 shows the top seven manufacturers of oxygen concentrators. Of these seven most frequent brands, the USA manufactured Airsep machines have the highest satisfaction rates (at 80%), with Chinese Dynmed having the lowest at 53% satisfaction.

Table 12. Oxygen Concentrator Data

Manufacturer	Origin	Quantity	Percent Donated	Percent Satisfied
Airsep/NewLife	USA	60	73%	80%
Longfian	China	55	42%	78%
Canta Medical	China	48	90%	75%
Jiangsu Yuyue Medical	Japan	31	87%	74%
OXY-LIFE	India	31	94%	77%
Dynmed	China	30	100%	53%
DeVilbiss	USA	28	64%	71%

Summary of Optional Notes/Comments

Analysis of the notes and comments section of the audit provides insight into the functional status, maintenance needs, and usage and performance of the oxygen concentrators. Comments were recorded for 265 of the 371 items. Many units are described as not functional or out of work due to issues such as low oxygen purity (26), broken humidifier bottles (11), faulty flowmeters (4), and loud unusual noises (4). An additional 26 machines need accessories and spares ranging from filters to power cables.

Discussions and Implications

The data indicate that not only are oxygen concentrators the most donated item, with 283 units donated, but they also have the highest percentage of donations relative to the total number of units available, at 76%. This reflects both a high volume and a high proportion of donations for oxygen concentrators compared to other medical equipment. The working theory for this high volume of donated oxygen concentrators is they are the surplus generated in response to the increase demand in Western countries during the Covid-19 pandemic. This assumption cannot be verified as we do not have pre-pandemic numbers for these facilities.

This audit did not ask participants to measure oxygen purity levels, although the notes and comment sections indicated that some participants did utilise oxygen analysers in their equipment assessment. As oxygen analysers are provided as part of the Medical Aid International resource package, future audits will incorporate the use of these analysers to record oxygen purity levels.

Figure 50.
Oxygen Concentrator Images from Audit

11ET, #010
Benchmark compliant oxygen concentrator.

01ZM, #014
Benchmark compliant oxygen concentrator.

05SL, #120
Benchmark compliant oxygen concentrator.

14ZM, #028
Acceptable oxygen concentrator: satisfactory, safe, used within the past 7 days but lacking accessories.

	
07CD, #140 Acceptable oxygen concentrator: satisfactory, safe, used within the past 7 days but lacking accessories. Notes and comments section reads “the machine is working properly but filters needed.”	10NA, #101 Used within 7 days, no safety concerns, but does not perform to satisfaction.

Suction Machines

- Total: 263
- Acceptable: 64%
- Benchmark standards:
    - Acceptable
    - Generates Suction
    - All necessary accessories available
- Benchmark compliant: 43%
- Donated: 44%
- Without equipment manuals: 41%
- Percent of all equipment with all consumables: 54%
- Percent of all equipment with all accessories: 54%
- Percent of all equipment with available spare parts: 11%

263 suction machines were logged; 43% of these were deemed benchmark compliant as they were reported to be satisfactory, safe, regularly used (within 6 months), generated suction, and had all accessories available. Figure 51 shows the cascading effect of applying compounding acceptance criteria to the suction machines surveyed. Forty-four percent (44%) of suction machines were donated with 41% purchased new.

Figure 51.

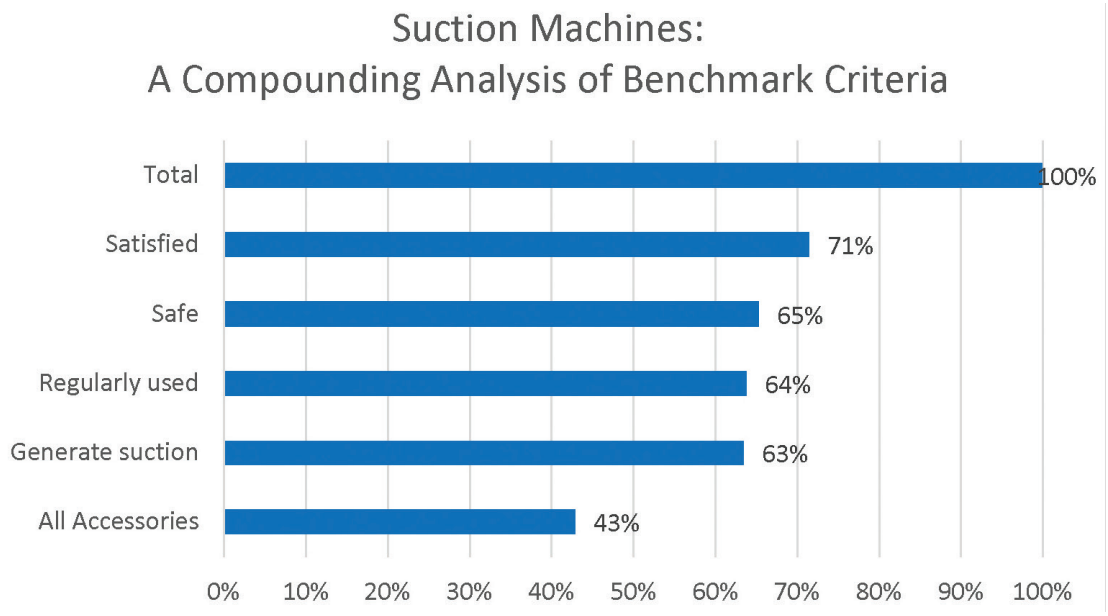
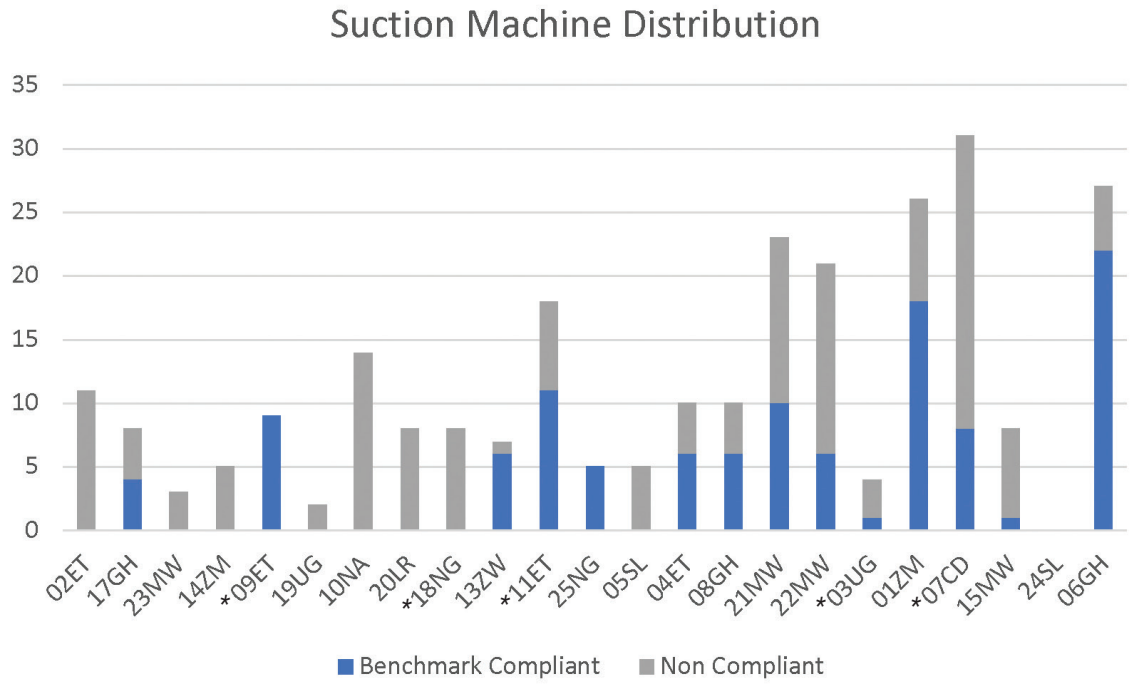


Figure 52 illustrates the distribution of suction machines. Critically, 24SL reports 0 suction machines.

Figure 52.



** Mission/charity hospital*

Summary of Optional Notes/Comments

The comments on suction machines reveal several recurring themes. Many machines are reported to be in good working condition and performing their intended functions. However, a significant number of machines are non-functional due to issues such as faulty motors, low suction pressure, and inability to create suction. A common problem is the lack of accessories, consumables, and spare parts, including suction bottles, filters, vacuum bottles, tubing, and power cables, which severely impacts machine usability. Battery problems and power issues frequently affect functionality, particularly during power outages.

Discussion and Implications

Suction machines are critical in the operating room because they ensure a clear surgical field by removing blood, bodily fluids, and other secretions, enabling the surgeon to maintain visibility and perform precise operations. For anaesthetic providers, suction machines are essential for maintaining airway patency and preventing aspiration, which is crucial for patient safety during anaesthesia. In the recovery phase, these machines help manage postoperative secretions, reducing the risk of complications and promoting a smoother recovery process.

Figure 53.
Suction Machine Images from Audit

	
15MW, #037 Benchmark compliant suction machine.	03UG, #048 This is the only benchmark compliant suction machine at the facility.

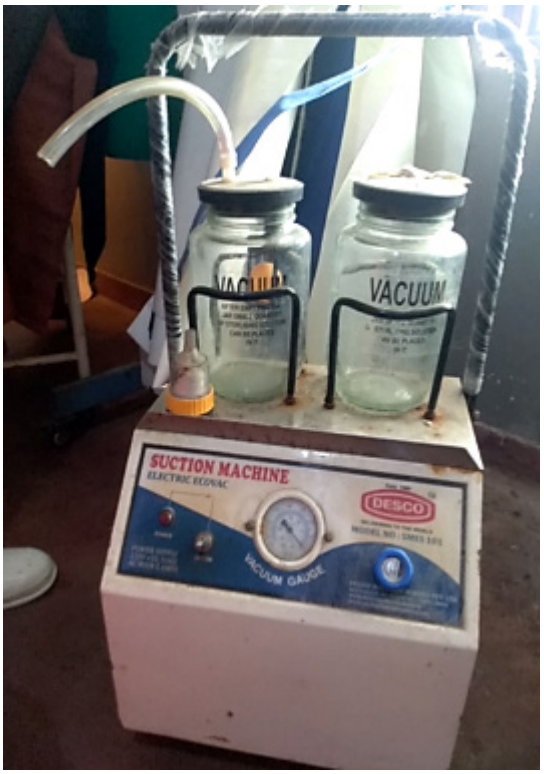
08GH, #065
Benchmark compliant suction machine.

06GH, #326
Benchmark compliant suction machine.

11ET, #053
Benchmark compliant suction machine.

11ET, #096
Suction machine has been used within 7 days; its performance is satisfactory but deemed unsafe.

05SL, #011
Used in past 7 days, is satisfactory but has safety concerns.



21MW, #078
Used in the past month but is marked as unsafe and unsatisfactory.

08GH, #008
Machine has been used in the past 7 days but is not safe nor satisfactory.

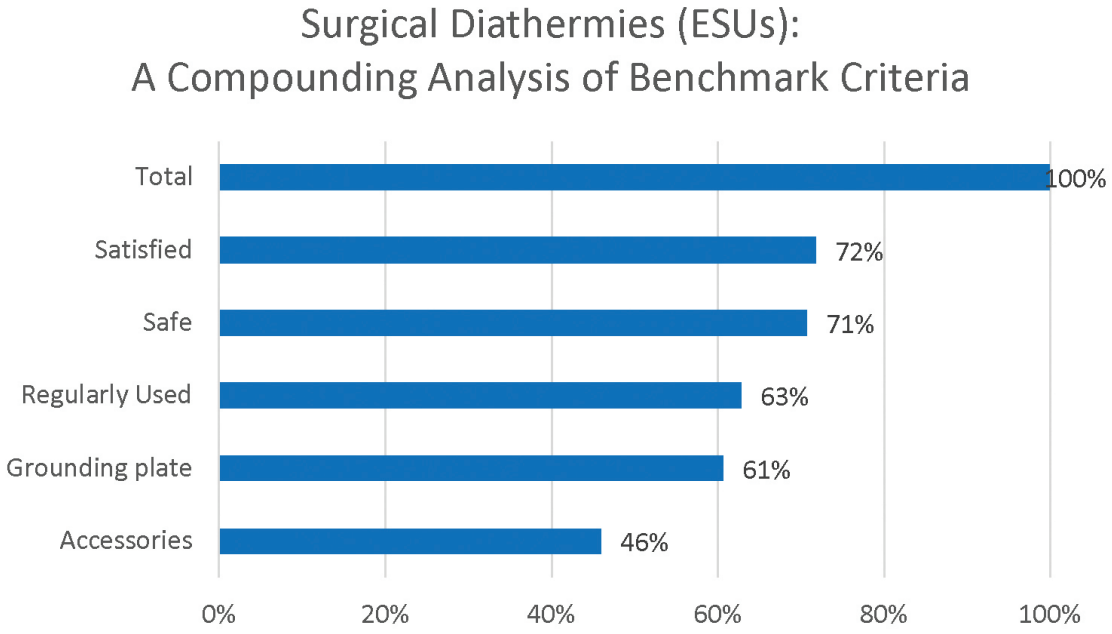
14ZM, #019
Used in the past month, maintains satisfactory performance but has safety concerns.

Electrosurgical Units (ESU)/Diathermies

- Total: 89
- Acceptable: 63%
- Benchmark standards:
    - Acceptable
    - Available grounding plate
    - All necessary accessories available
- Benchmark compliant: 46%
- Donated: 47%
- Without equipment manuals: 28%
- Percent of all equipment with all consumables: Not asked[9]
- Percent of all equipment with all accessories: 63%
- Percent of all equipment with available spare parts: 19%

Eighty-nine (89) electrosurgical units (ESUs) were recorded. In addition to being satisfactory, safe, and regularly used, the benchmark criteria for ESUs include the necessity for a grounding plate, and all other accessories (see Figure 54). ESUs generally require many accessories including mono- and bi-polar electrodes, foot switches, and electrodes.

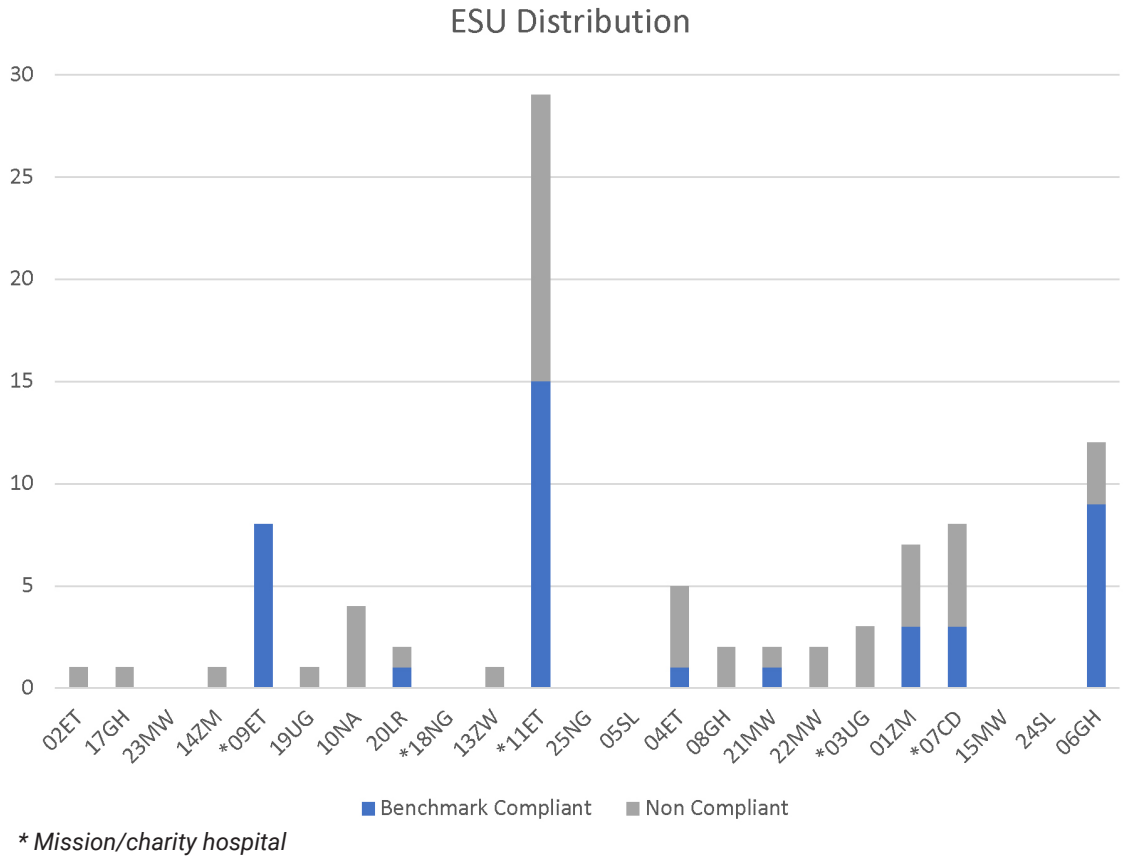
Figure 54.



The distribution of ESUs is highly skewed towards mission hospitals. The 5 mission hospitals have 54% (48) of the ESUs, while the remaining 18 government and private hospitals have only 46% (41). A singular mission hospital in Ethiopia has 29 ESUs, 16 of which were purchased new. Overall, 49% were new purchases with 47% donated. The top three brands are German made ERBE (n=20), and American made ValleyLab (n=19), and ConMed (n=14). Six facilities have no ESUs. Figure 55 shows ESU distribution.

[9]Assumption is all single-use electrodes (i.e., consumables) will be reused. Accordingly, only asked about accessories.

Figure 55.

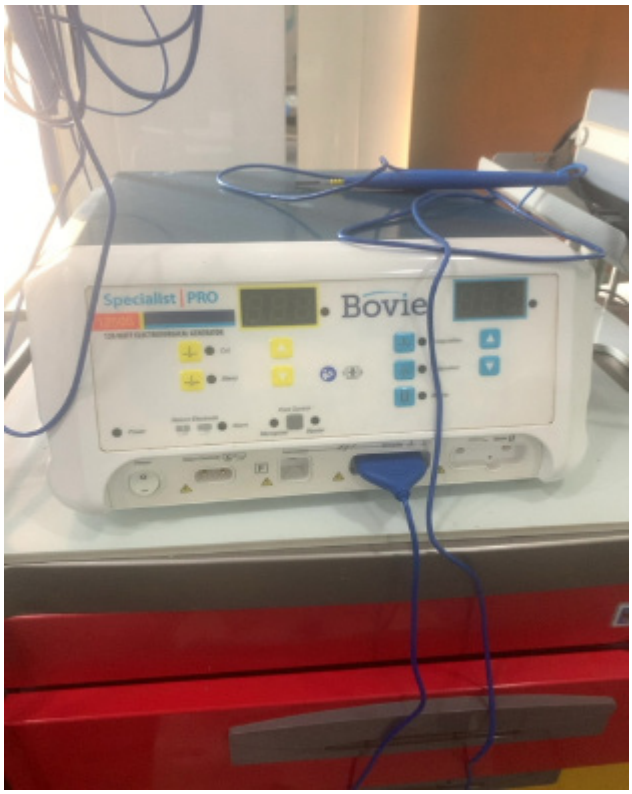


** Mission/charity hospital*

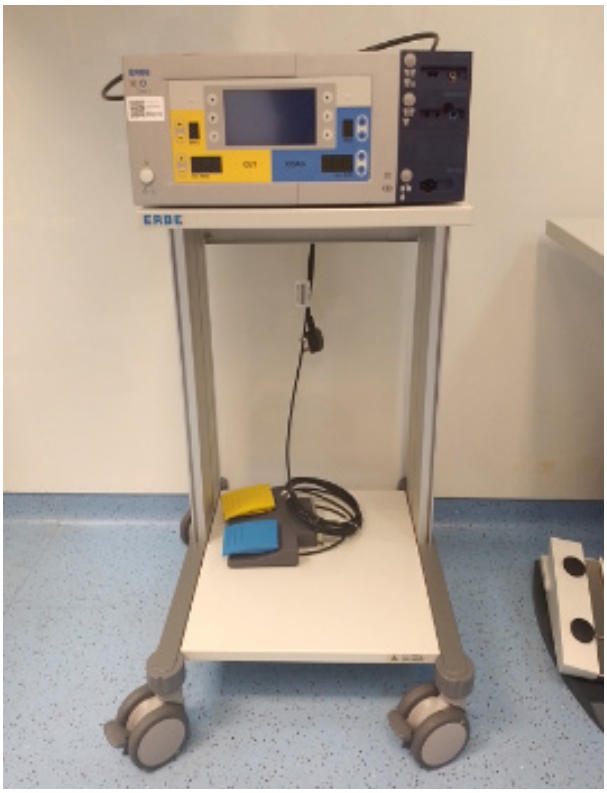
Summary of Optional Notes/Comments

The optional notes and comment section expound on the lack of critical accessories. Missing accessories include grounding plates and cutting and coagulation pencils. While the device may switch on, they cannot be used without these essential accessories.

Figure 56.
ESU Images from Audit



01ZM, #005
Benchmark compliant ESU.



06GH, #022
Benchmark compliant ESU.

11ET, #150
Benchmark compliant ESU.

20LR, #036
Benchmark compliant ESU.

	
08GH, #002 Used within 7 days but has safety concerns and a faulty grounding plate.	04ET, #078 Used within 7 days but deemed unsafe.

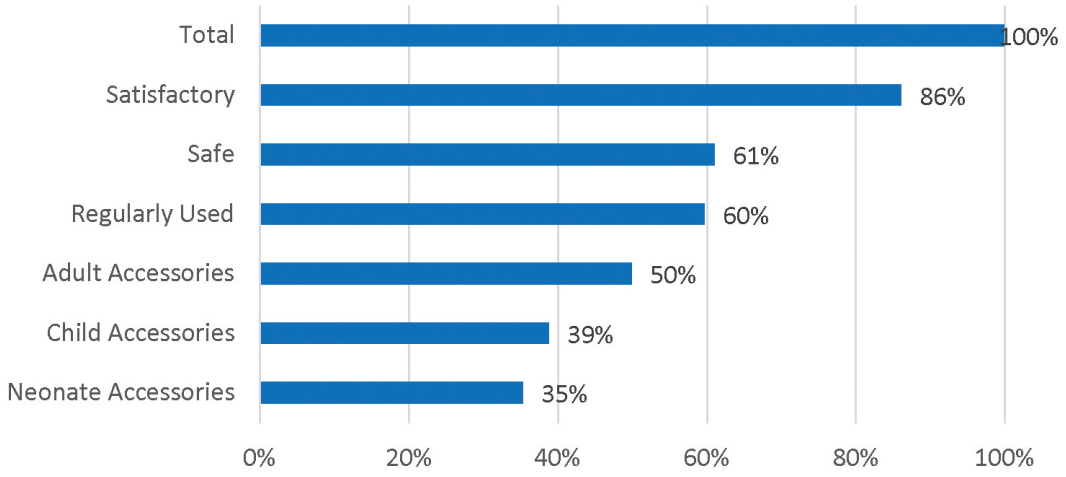
Pulse Oximeters

- Total: 144
- Acceptable: 60%
- Benchmark standards:
    - Acceptable
    - All adult accessories available
    - All paediatric accessories available
    - All neonatal accessories available
- Benchmark compliant: 35%
- Donated: 58%
- Without equipment manuals: 17%
- Percent of all equipment with all consumables: 76%
- Percent of all equipment with all accessories: 38%
- Percent of all equipment with available spare parts: 30%

A total of 144 pulse oximeters were recorded. Equipment was deemed benchmark compliant if, in addition to being acceptable, it had accessories available for all patient types. Similarly to patient monitors, very few facilities have accessories to appropriately monitor paediatric and neonatal cases (see Figure 57).

Figure 57.

Pulse Oximeters:
A Compounding Analysis of Benchmark Criteria

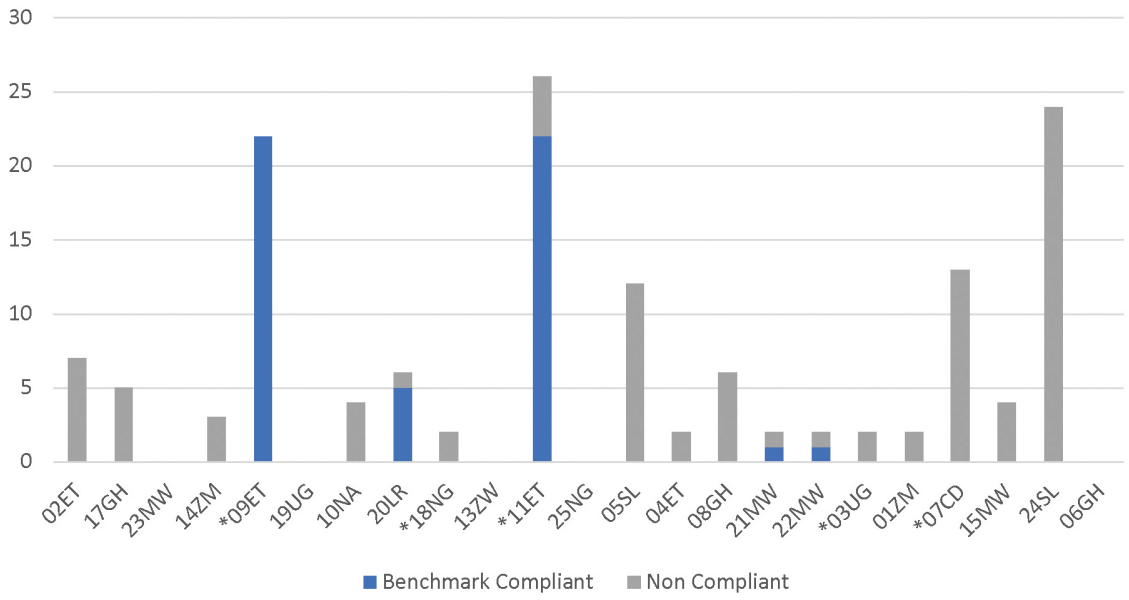


45 pulse oximeters were manufactured by Acare Technology (Taiwan); 25 of those were the Life Box AH-M1 model. LifeBox pulse oximeters can be found across six healthcare facilities. All Acare pulse oximeters were reported to perform to the engineer's satisfaction. The other most notable manufactures were Masimo (20, USA), Nellcor (15, USA), and GE (11, USA).

Figure 58 illustrates the pulse oximeter distribution. Five hospitals report no pulse oximeters (albeit 06GH likely has patient monitors with pulse oximeter capabilities).

Figure 58.

Pulse Oximeter Distribution



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Summary of Optional Notes/Comments

Overall, while a good portion of pulse oximeters are operational, there is a recurring need for accessories, spare parts and battery replacements to ensure all devices are fully functional and meet the needs of different patient groups.

Figure 59.
Pulse Oximeter Images from Audit

<table>
<tr><td> 
</td><td> 
</td></tr>
<tr><td>21MW, #013
Benchmark compliant Lifebox pulse oximeter.</td><td>11ET, #028
Benchmark compliant SPO_2 monitoring device.</td></tr>
<tr><td> 
</td><td>  </td></tr>
<tr><td>20LR, #022
Benchmark compliant pulse oximeter.</td><td>22MW, #032
Benchmark compliant pulse oximeter at the hospital. This is the only pulse oximeter at the facility.</td></tr>
</table>

	
24SL, #037 Monitor has been used within the past 7 days, has satisfactory performance but has noted safety concerns.	05SL, #050 Pulse oximeter has been used within the past 7 days, has satisfactory performance but has noted safety concerns.

Infant Incubators

- Total: 80
- Acceptable: 63%
- Benchmark standards:
    - Acceptable
    - Warm
- Benchmark compliant: 63%
- Donated: 49%
- Without equipment manuals: 31%
- Percent of all equipment with all consumables: Not asked
- Percent of all equipment with all accessories: 50%
- Percent of all equipment with available spare parts: 15%

Eighty (80) infant incubators were logged in the audit, 63% of which meet the benchmark standards: satisfactory, safe, regularly used, and warm. Figure 60 shows the cascading effect of applying compounding acceptance criteria to the 80 infant incubators surveyed.

Figure 60.

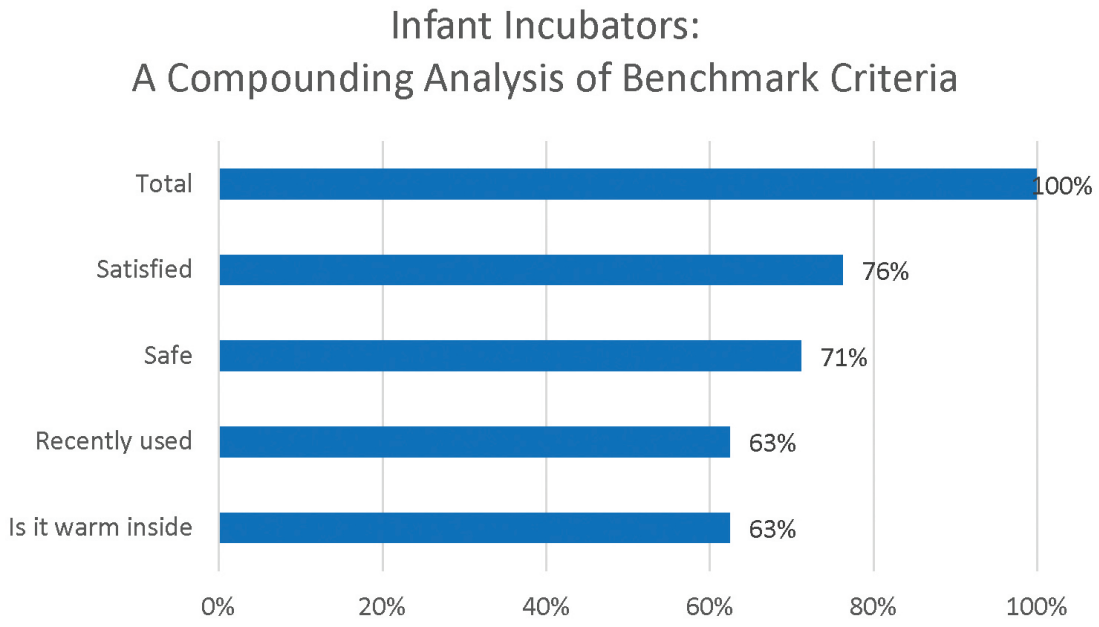

Figure 61 illustrates the distribution of compliant and non-compliant incubators across different healthcare facilities.

Figure 61.

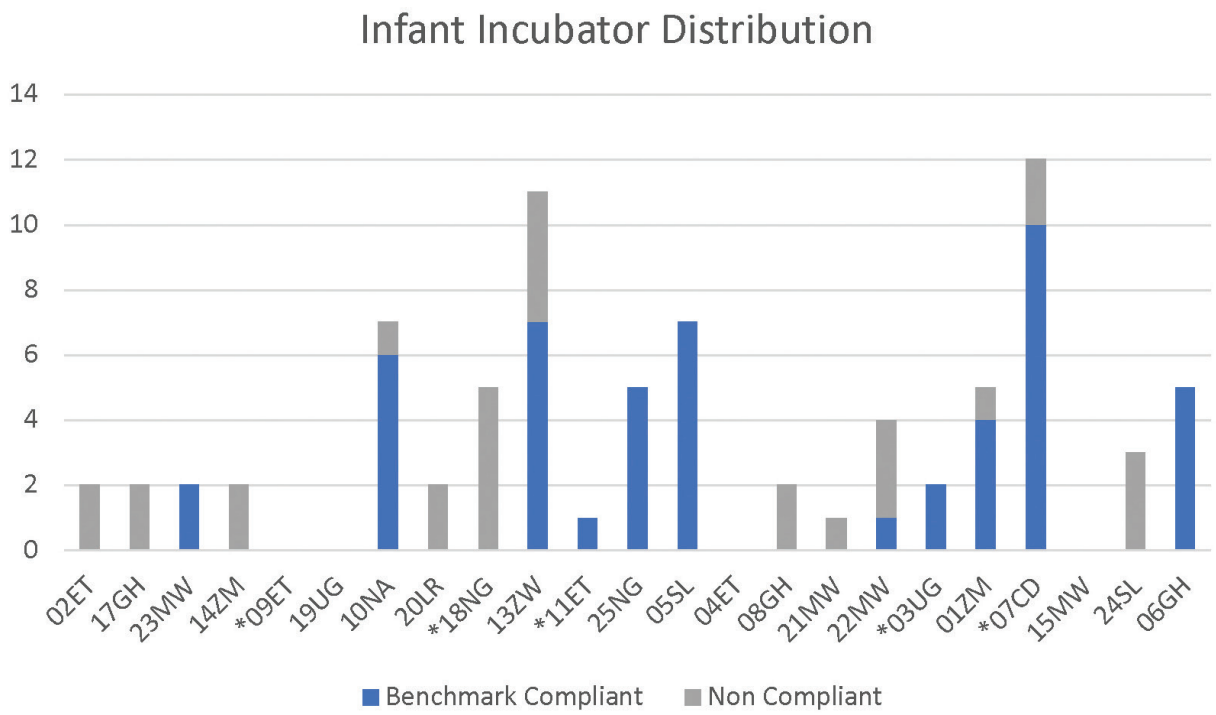

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Table 13 breaks down the percentage of compliant incubators by country of manufacture. Eliminating the UK and Italy, as they only have 1 and 2 incubators respectively, the country of manufacture with highest compliance rates are China (86%) and Germany (81%). The country of manufacture with the least compliance are those from unknown origins (31%) and Brazil (50%).

Table 13. Benchmark Complaint Assessment by Country of Manufacture

Manufacturer	Total	Benchmark Compliant
UK	1	100%
China	14	86%
Germany	16	81%
Japan	6	67%
Hungary	8	63%
USA	13	62%
Brazil	4	50%
Unknown	16	31%
Italy	2	0%

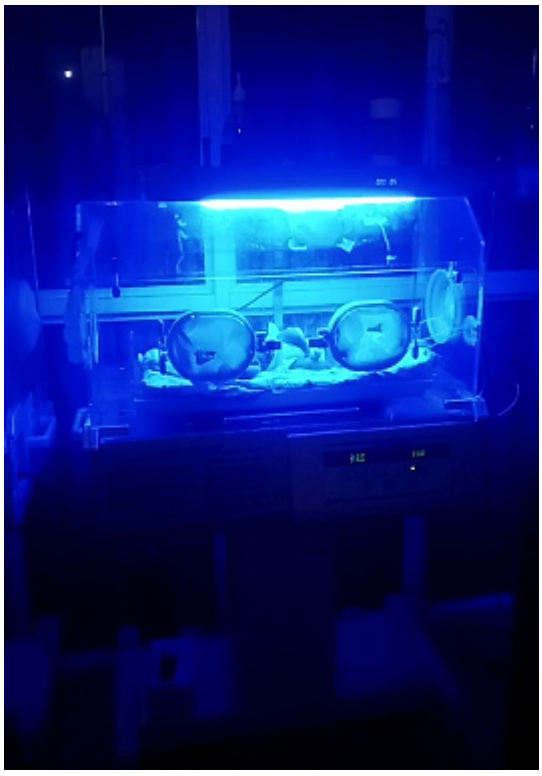
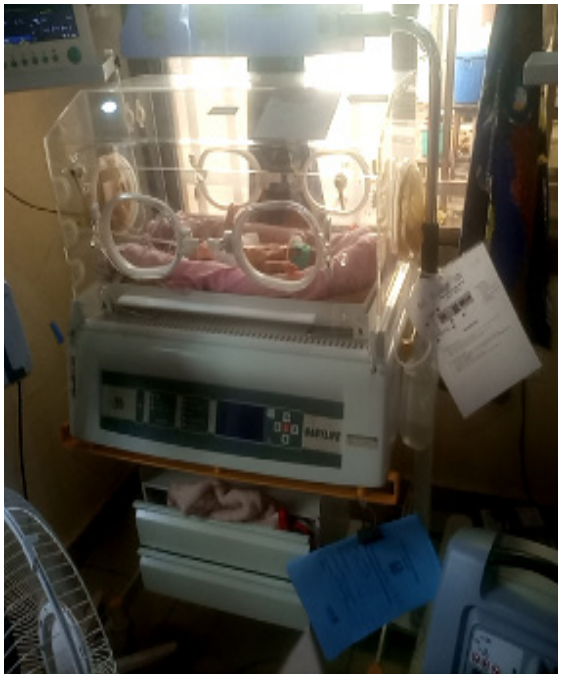
Summary of Optional Notes/Comments

Analysis of the notes and comments section of the audit provides insight into the functional status, maintenance needs, and usage and performance of infant incubators. Many machines are currently under repair or non-operational due to maintenance needs requiring components such batteries, door gaskets, and heating elements. Lack of accessories, consumables, and spare parts are noted as barriers to optimal performance.

Figure 62.
Infant Incubator Images from Audit

11ET, #022
Benchmark compliant infant incubator.

07CD, #049
Benchmark compliant infant incubator.

	
13ZW, #028 Benchmark compliant infant incubator.	25NG, #010 Benchmark compliant infant incubator.
	
24SL, #029 Used within 7 days, known safety concerns.	08GH, #046 Used within 7 days, known safety concerns.

Infant Radiant Warmers

- Total: 79
- Acceptable: 47%
- Benchmark standards:
    - Acceptable
    - Warms
- Benchmark compliant:46%
- Donated: 61%
- Without equipment manuals: 44%
- Percent of all equipment with all consumables: Not asked
- Percent of all equipment with all accessories: 51%
- Percent of all equipment with available spare parts: 9%

Infant radiant warmers are benchmark compliant if they are acceptable (satisfactory, safe, used within six months) and provide warmth. Figure 63 shows the cascading effect of applying compounding acceptance criteria to the infant radiant warmers surveyed.

Figure 63.

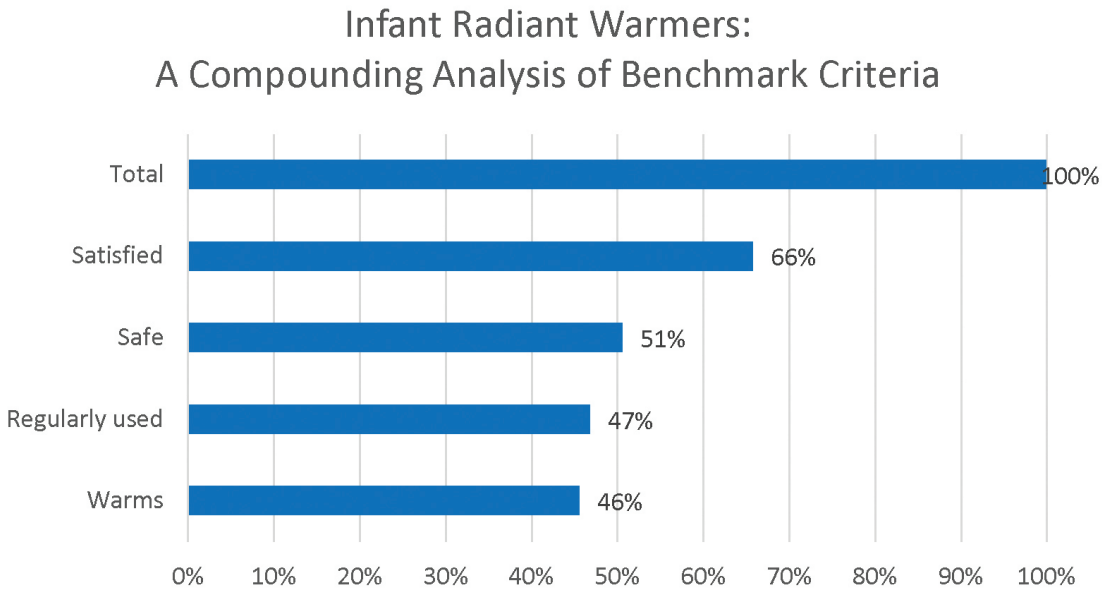
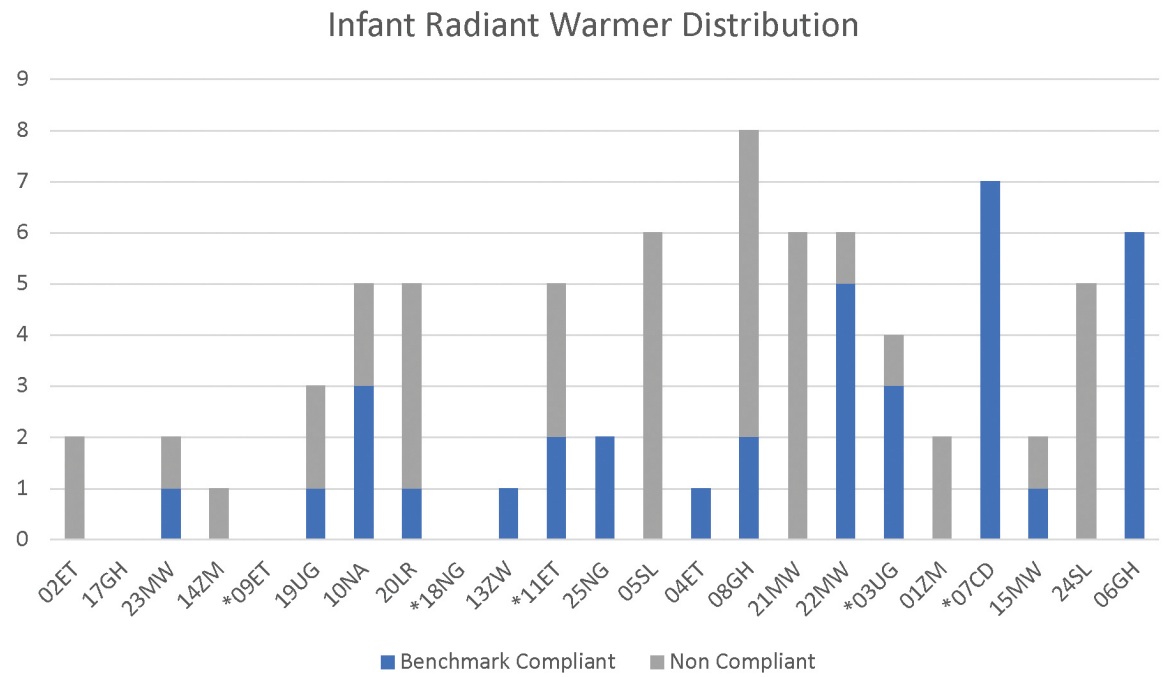


Figure 64 illustrates the distribution of infant radiant warmers.

Figure 64.



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Summary of Optional Comments/Notes

Many comments simply state that the infant radiant warmers are in good working order. However, a significant number of warmers require accessories or spare parts, such as temperature sensors, power cords, and tables. Some warmers are described as needing maintenance or having specific faults, such as damaged keypads, power supply faults, error messages on the display, and issues with warming. There are also mentions of equipment being outdated and no longer serviceable, leading to the need for decommissioning.

Figure 65.
Infant Radiant Warmer Images from Audit

11ET, #023
Benchmark compliant infant radiant warmer.

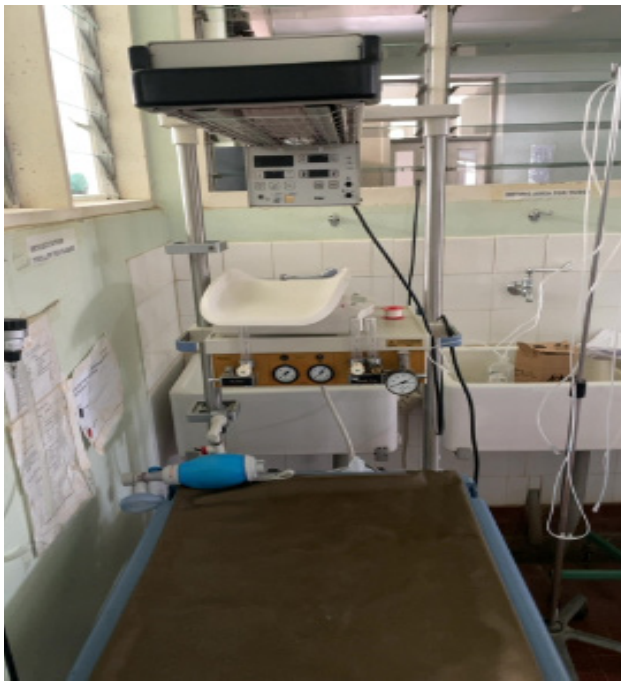
25NG, #011
Benchmark compliant infant radiant warmer.

04ET, #043
This item is logged as an infant radiant warmer and does meet the benchmark compliant criteria. This example demonstrates that there are instances where equipment gets misidentified or logged incorrectly.

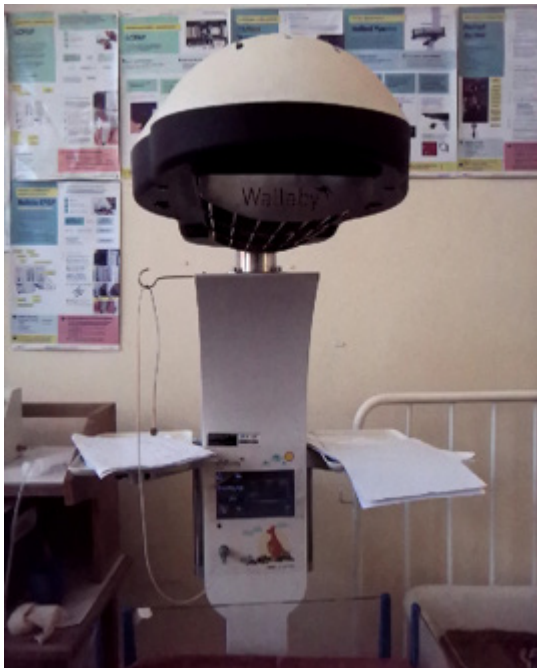
07CD, #060
Benchmark compliant infant radiant warmer.

10NA, #046
Benchmark compliant infant radiant warmer.

06GH, #459
Benchmark compliant infant radiant warmer.



03UG, #007
Benchmark compliant infant radiant warmer.



22MW, #038
Benchmark compliant infant radiant warmer.

08GH, #027
Although used in the past 7 days (and in current use), the machines does not perform to satisfaction and has noted safety concerns. Notes from the comment section state "the power comes on, but the writings do not show on the screen, this make users unable to change settings and also know the current readings on the screen."

19UG, #024
Although used in the past 7 days, the item does not perform satisfactory and safety concerns exist. Additionally, it is noted that the bottom lamps are faulty.

21MW, #136
In current use although engineers have expressed safety concerns and machine does not switch on.

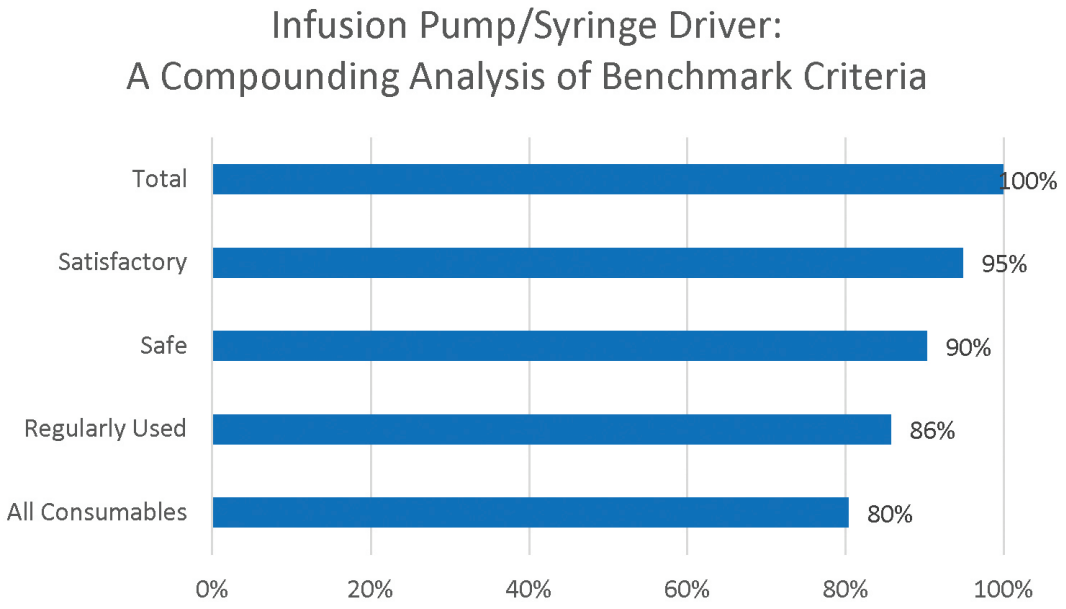
02ET, #082
Used within 7 days, unsafe, but satisfactory performance.

Infusion Pumps/Syringe Drivers

- Total: 352
- Acceptable: 80%
- Benchmark standards:
    - Acceptable
    - All consumables available
- Benchmark compliant: 80%
- Donated: 15%
- Without equipment manuals: 27%
- Percent of all equipment with all consumables: 90%
- Percent of all equipment with all accessories: Not asked
- Percent with available spare parts: 4%

In addition to being satisfactory, safe, and used within six months, infusion pumps/syringe drivers must also have all required consumables to be deemed benchmark compliant. Figure 66 illustrates these compounding acceptance criteria when applied to the 352 recorded pumps/syringe drivers.

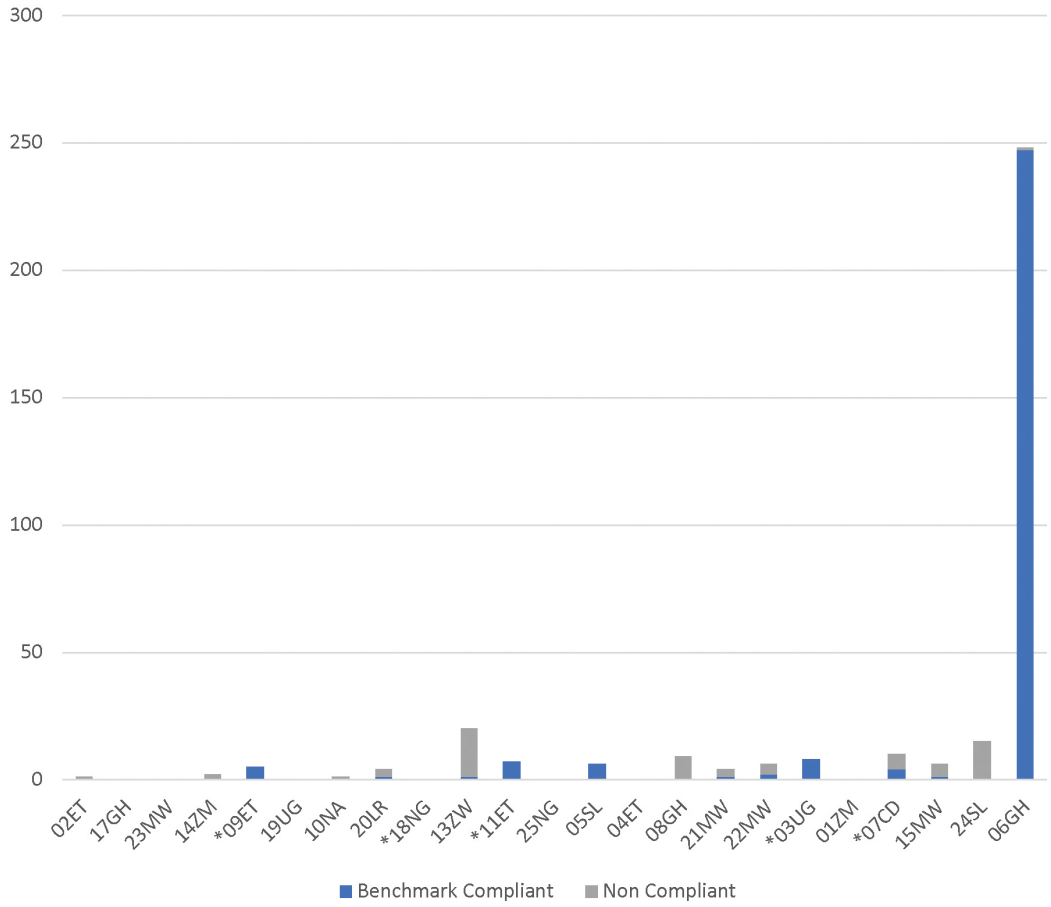
Figure 66.



Overall, an exceptionally high percentage of devices (80%) are satisfactory, safe, regularly used, and supplied with all consumables. Excluding the infusion pumps/syringe from 06GH, benchmark compliance drops to 35%. All but two of 06GH pumps were purchased new, bringing the overall donation rate to 15% (excluding 06GH, 50% of pumps were donated).

Figure 67 poignantly illustrates that seventy percent (70%) of these devices are located at a single hospital.

Figure 67.
Infusion Pump/Syringe Driver Distribution



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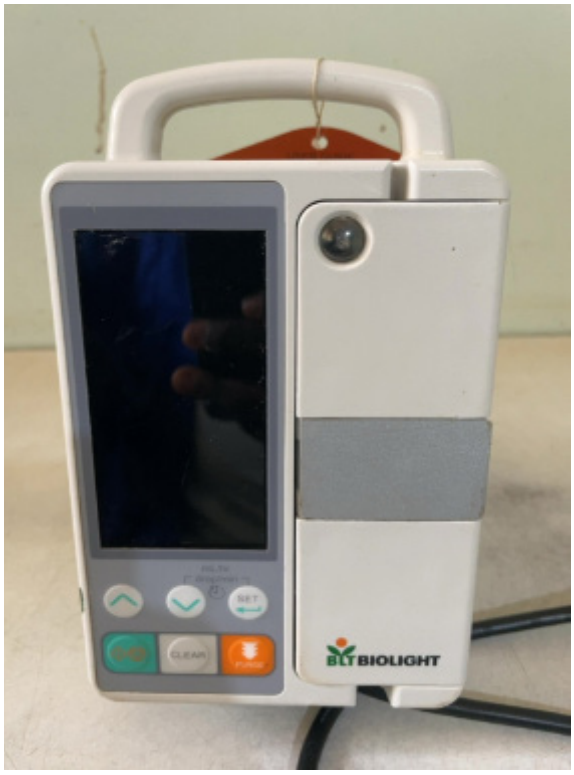
The two major manufacturers of the infusion pumps/syringe drivers are Mindray (195) and Braun (84).

Figure 68.
Infusion Pump/Syringe Driver Images from Audit

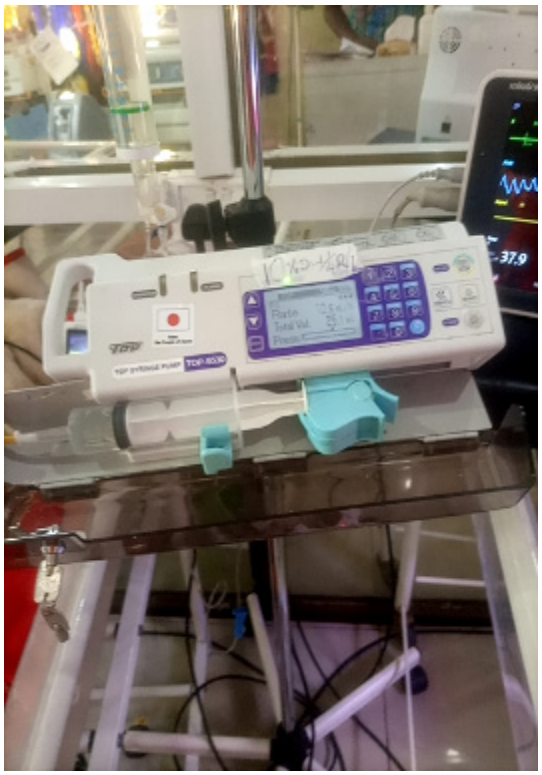
11ET, #128
Benchmark compliant device, purchase new.

07CD, #105
Benchmark compliant device, purchase new.

06UG, #489
Benchmark compliant device, purchased new.



03UG, #018
Benchmark compliant device, purchased new.

	
24SL, #061 Unsafe syringe driver with satisfactory performance used within the past 7 days.	14ZM, #034 Unsafe syringe driver, with unsatisfactory performance used within the past 6 months.

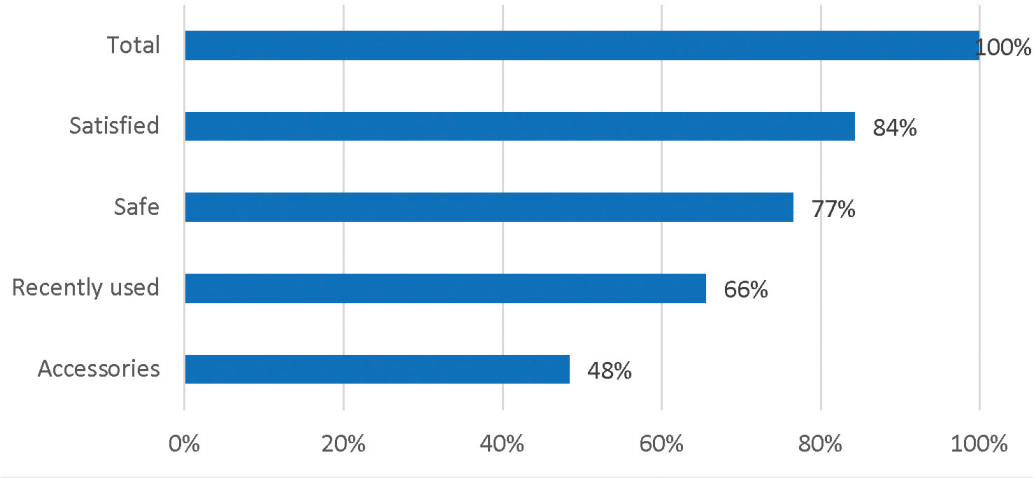
Defibrillators

- Total: 64
- Acceptable: 66%
- Benchmark standards:
    - Acceptable
    - All necessary accessories available
- Benchmark compliant: 48%
- Donated: 52%
- Without equipment manuals: 27%
- Percent of all equipment with all consumables: 72%
- Percent of all equipment with all accessories: 64%
- Percent of all equipment with available spare parts: 9%

A total of 64 defibrillators were recorded at only 12 sites. In addition to the standard acceptable criteria, benchmark compliant equipment must have all accessories available. Figure 69 shows the cascading effect of applying compounding acceptance criteria to the defibrillators surveyed. Recent use may not be the best indicator for this item, but for continuity of the data analysis method, it remains included in the acceptable criteria.

Figure 69.

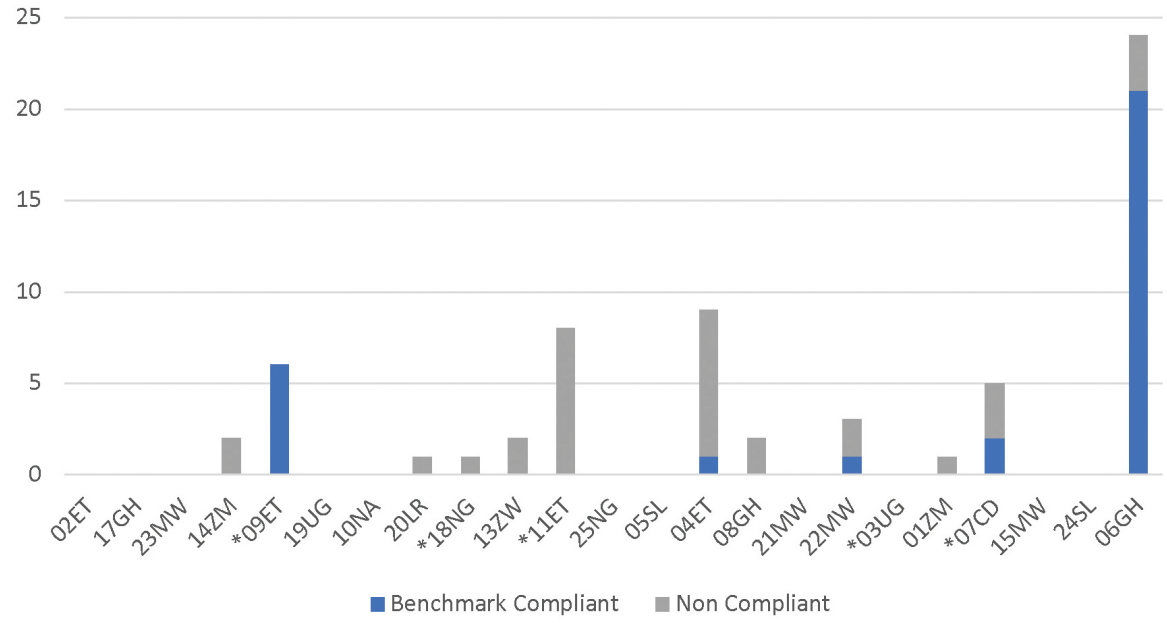
Defibrillators:
A Compounding Analysis of Benchmark Criteria



Defibrillator distribution is shown in Figure 70. Fifty-two percent (52%) of defibrillators were donated and 42% were purchased new.

Figure 70.

Defibrillator Distribution



** Mission/charity hospital*

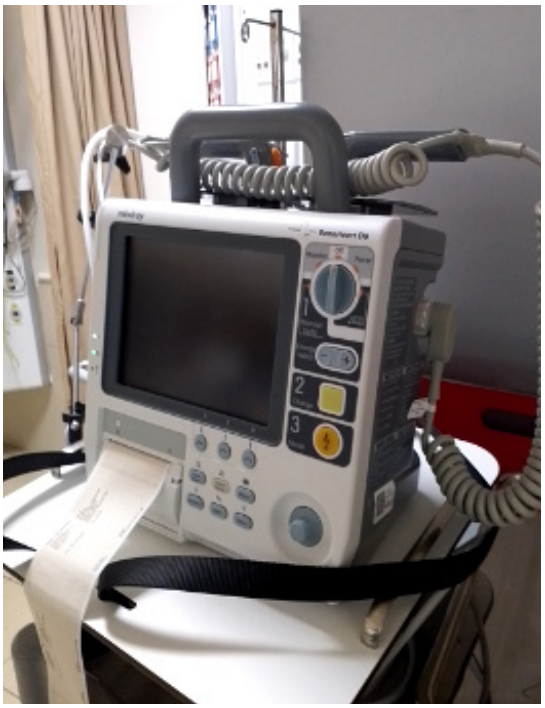
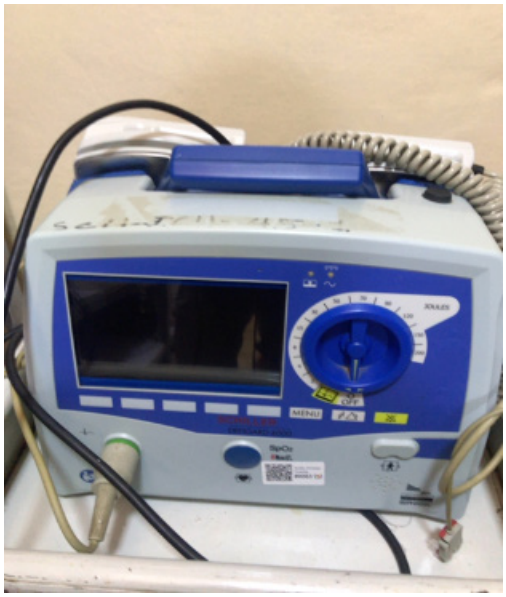
Summary of Optional Notes/Comments

The relatively few comments provided for defibrillators predominately highlight the lack of accessories, consumables, and batteries.

Discussion and Implications

Eleven (11) healthcare facilities report no defibrillators. While ubiquitous across the West, defibrillators are often less prevalent in LMICs. The effective use of a manual defibrillator requires a functional ECG with all accessories and consumables, as well as staff trained to recognise shockable cardiac arrhythmias. These compounding variables decrease the probability of appropriate defibrillator use.

Figure 71.
Defibrillator Images from Audit

	
07CD, #012 Benchmark compliant defibrillator.	06GH, #095 Benchmark compliant defibrillator.
	
11ET, #063 Used within past week but deemed unsafe.	11ET, #177 Example of an inappropriate donation that has never been used. Defibrillator is likely 40-60 years old.

	
22MW, #021 Defibrillator has not been used in over 6 months but is safe and satisfactory.	04ET, #019 Defibrillator is regularly used, satisfactory, safe, but does not have all accessories.

Ultrasounds

- Total: 75
- Acceptable: 60%
- Benchmark standards:
    - Acceptable
    - Available transducers
    - All accessories available
- Benchmark Compliant: 44%
- Donated: 40%
- Without equipment manuals: 36%
- Percent of all equipment with all consumables: 61%
- Percent of all equipment with all accessories: 57%
- Percent of all equipment with available spare parts: 11%

Figure 72 shows the cascading effect of applying compounding acceptance criteria to the 75 ultrasounds recorded. Benchmark compliant ultrasounds are simultaneously satisfactory, safe, used within six months, have required transducers available, along with all other necessary accessories.

Figure 72.

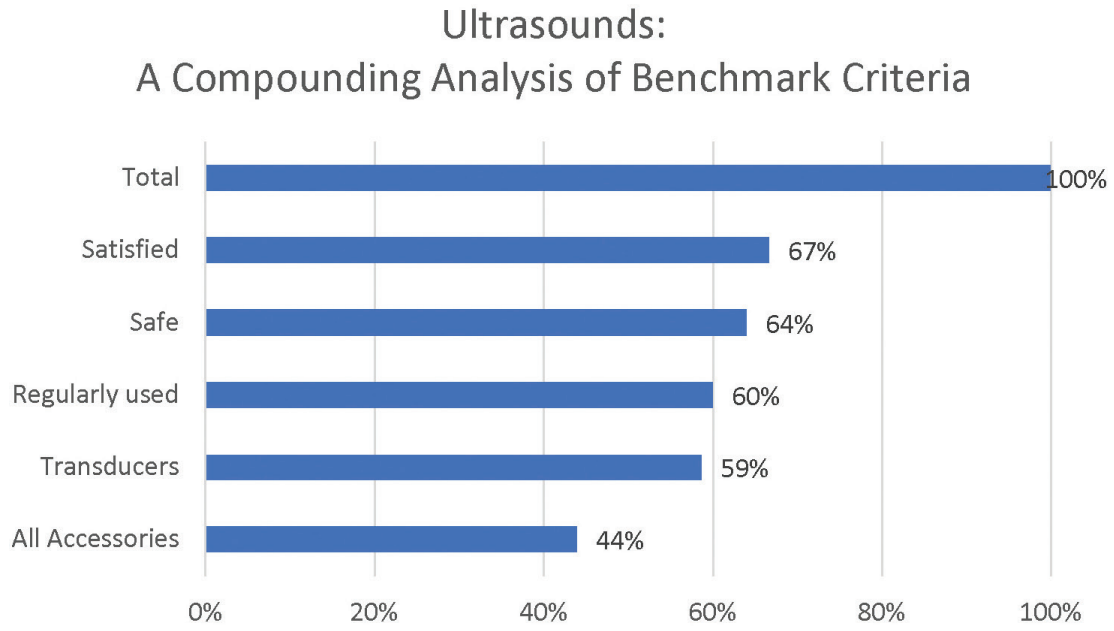
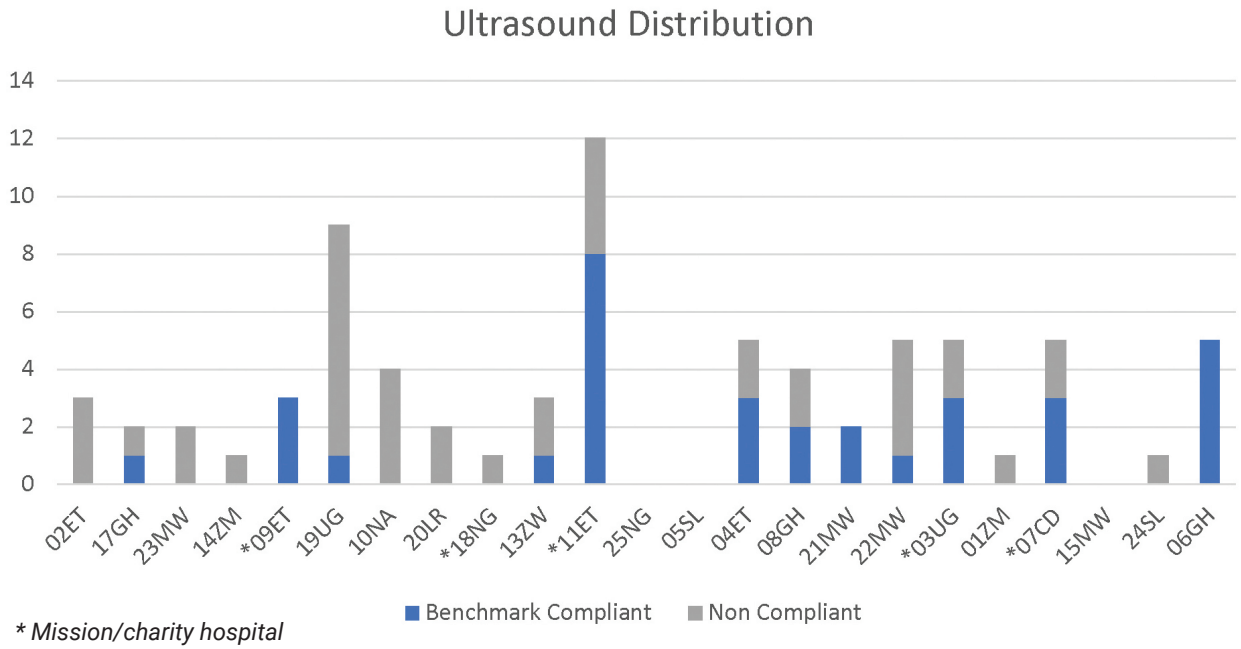


Figure 73 demonstrates ultrasound distribution. Three facilities report no ultrasounds, one of which is an obstetric fistula centre. Another eight facilities have no ultrasounds meeting benchmark criteria. Edan (n=11), Mindray (n=9), and GE (n=8) were the three most common brands.

Figure 73.

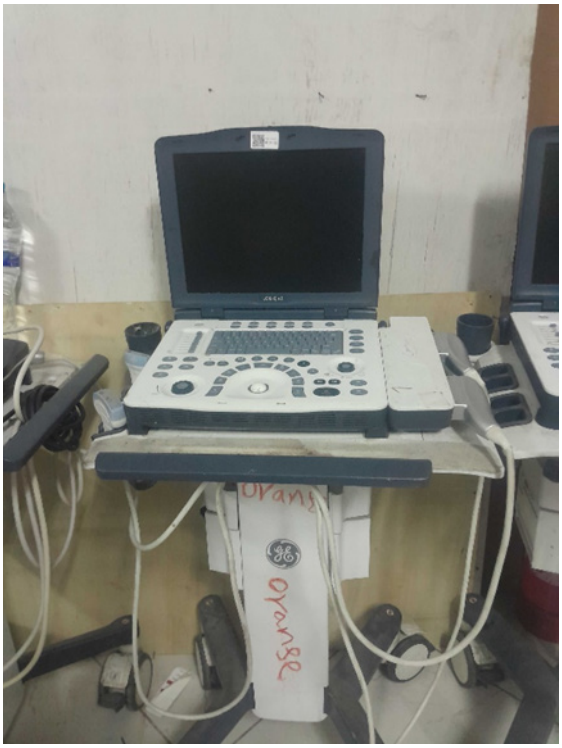


** Mission/charity hospital*

Summary of Optional Comments/Notes

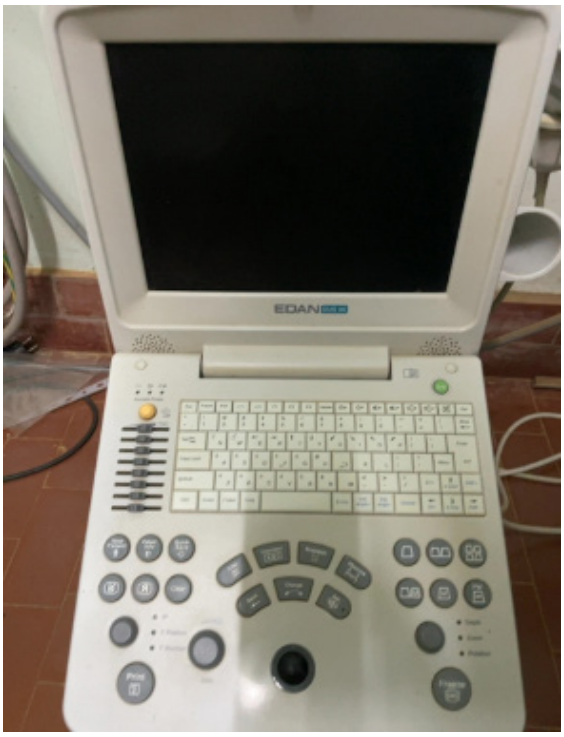
The comments about the ultrasound machines highlight several recurring issues and general themes. Many machines are in good working condition or functional but require various repairs, spare parts, and maintenance to stay operational. There are multiple mentions of non-working transducers and outdated models that are no longer serviceable due to a lack of available parts. Equipment is often old and outdated making the challenge of acquiring spare parts even more difficult.

Figure 74.
Ultrasound Images from Autoclave

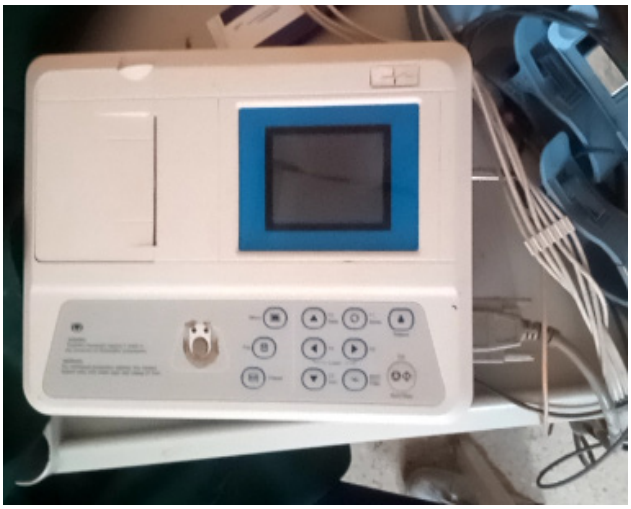


04ET, #111
Benchmark compliant ultrasound that was purchased new.

11ET, #005
Purchased benchmark compliant ultrasound.

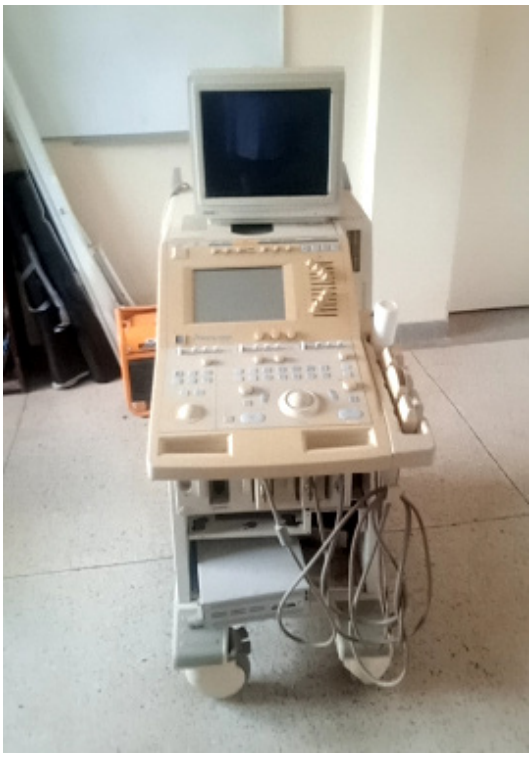


03UG, #062
Donated benchmark compliant ultrasound.

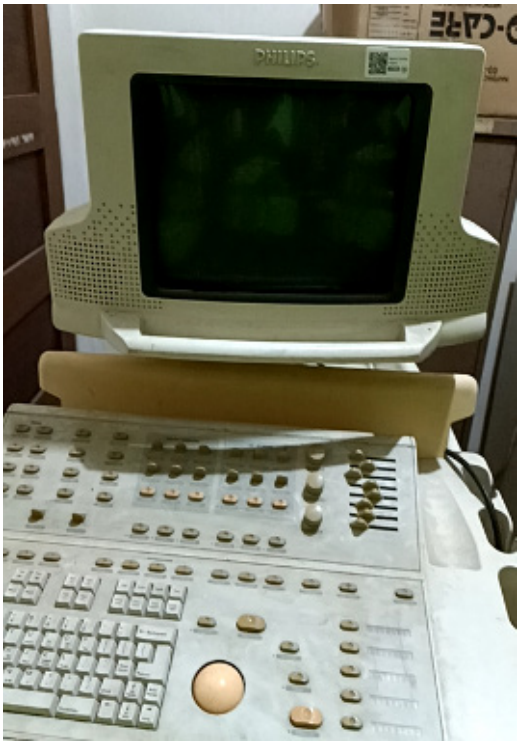


19UG, #008
Acceptable ultrasound (satisfactory, safe, used within 7 days) but missing necessary accessories.

24SL #163
Donated ultrasound machine used within the last month. Machine is satisfactory but has safety concerns. This is the only ultrasound at the hospital



UG19, #034
Engineers are unsure when this machine was last used. They indicated it was unsafe and did not perform to satisfaction.



18NG, #025
This is the only ultrasound at the hospital, it has not been used in over 6 months, has safety concerns and unsatisfactory performance.

23MW, #007
This donated ultrasound was used in the last month. It does not perform to satisfaction, and its safety is unknown.

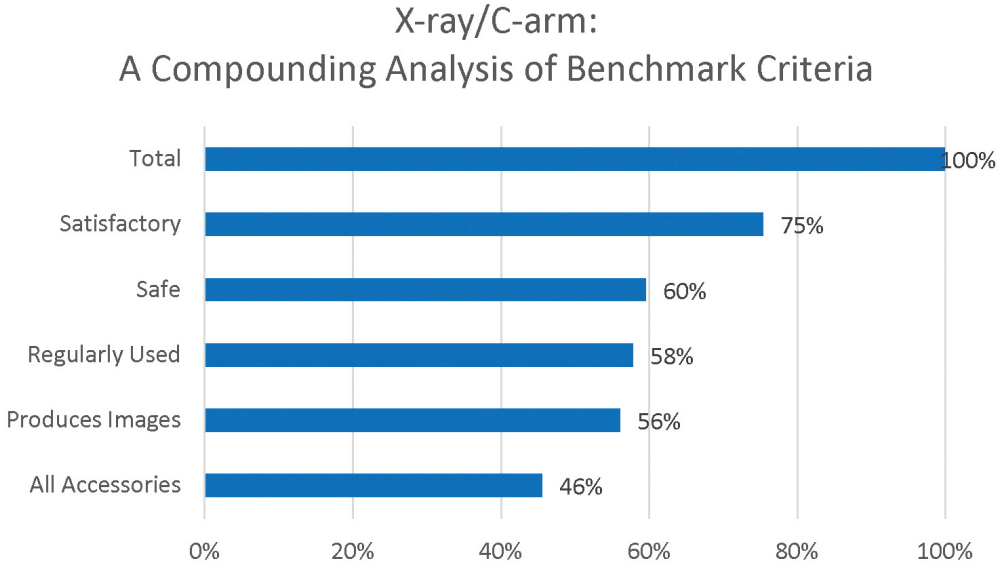
X-Ray/C-arm

- Total: 57
- Acceptable: 58%
- Benchmark standards:
    - Acceptable
    - Produces images
    - All accessories available
- Benchmark compliant: 46%
- Donated: 40%
- Without equipment manuals: 28%
- Percent of all equipment with all consumables: Not asked
- Percent of all equipment with all accessories: 58%
- Percent of all equipment with available spare parts: 11%

Fifty-seven (57) X-rays and C-arms were reported. AI analysis of the make and model determined 13 of the items to be C-arms and 44 to be X-rays. Sixty-one percent (61%) of the X-rays are analogue.

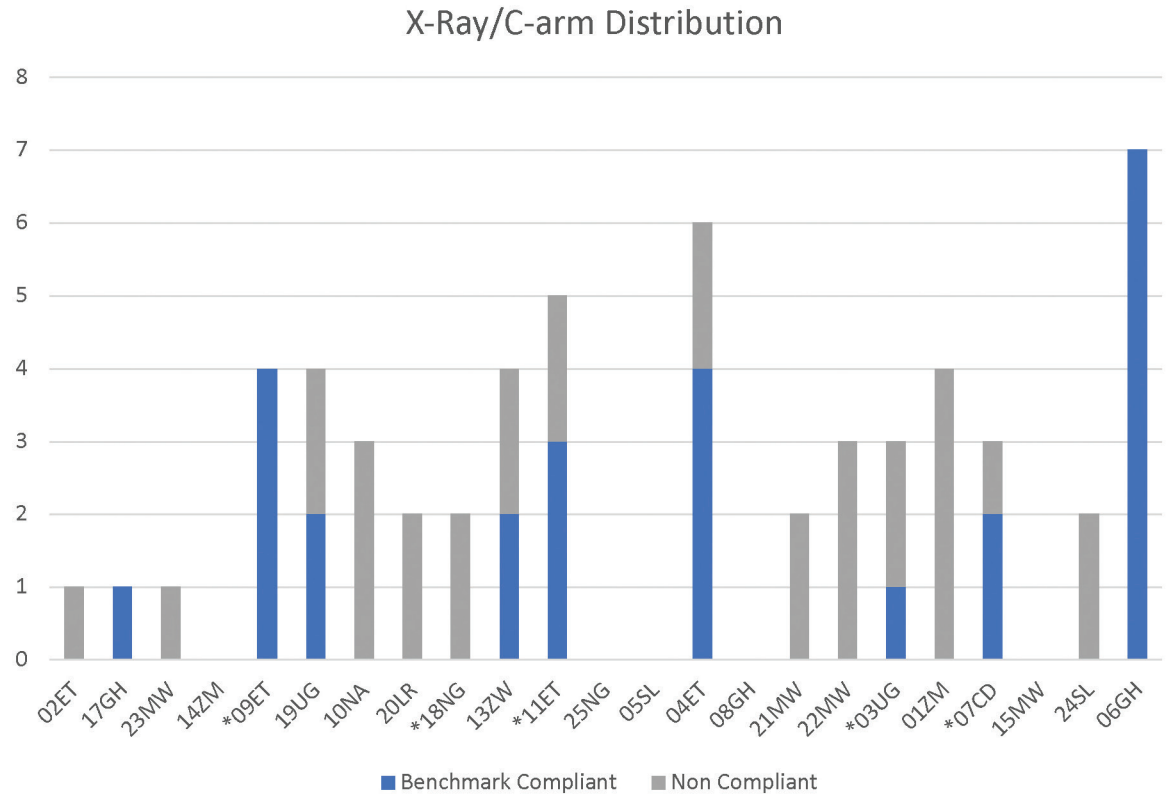
Benchmark compliant X-rays/C-arms must be acceptable, produce images, and have all accessories available (see Figure 75).

Figure 75.



X-ray/C-arm distribution is illustrated in Figure 76. Five facilities have no X-rays nor C-arms. Notably, three of these five facilities also reported no ultrasounds, highlighting a significant gap in their imaging capabilities. The primary manufacturers of the equipment are Phillips (13) followed by GE (10). Forty-six percent (46%) of all X-ray/C-arms were purchased new, 40% were donated.

Figure 76.



** Mission/Charity Hospitals*

Summary of Optional Comments/Notes Section

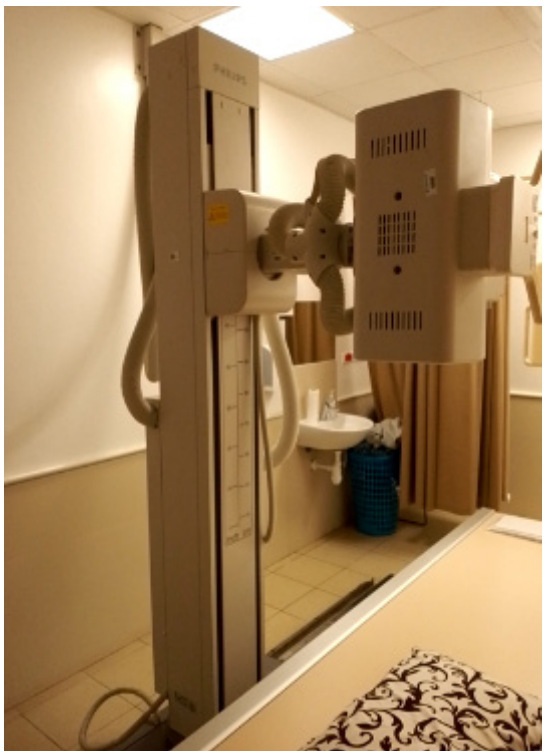
The comments about the X-ray machines reveal several general themes. Firstly, a common issue is the lack of spare parts and consumables, which hampers the functionality of otherwise well-performing equipment. Items missing include X-ray film, lead aprons, and signal processing units. Maintenance needs are a recurring theme, with several machines requiring regular upkeep, replacement parts, and specific repairs such as collimator replacements to ensure patient safety from scatter radiation.

There are also significant concerns about the age and technology of the machines, with older analogue machines producing blurred images and being less effective compared to newer digital models. Some machines are out of use due to faults or radiation leakage, highlighting safety issues that need addressing.

Figure 77.
X-ray/C-arm Images from Audit

13ZW, #093
Benchmark compliant X-ray that was purchased new.

03UG, #061
Benchmark compliant donated X-ray.



06UG, #123
Benchmark compliant X-ray.

23MW, #022
Donated analogue X-ray used within the past 7 days, unsafe but satisfactory.

04ET, #056
Acceptable (satisfactory, safe, used within 7 days) X-ray that produces images but does not have all accessories.

07CD, #207
Benchmark compliant C-arm.

24SL, #099
X-ray has been used in the past 7 days, is satisfactory but unsafe.

Ventilators

- Total: 93
- Acceptable: 83%
- Benchmark standards:
    - Acceptable
    - Working battery
    - All accessories available
- Benchmark compliant: 58%
- Donated: 67%
- Without equipment manuals: 12%
- Percent of all equipment with all consumables: 83%
- Percent of all equipment with all accessories: 73%
- Percent with available spare parts: 10%

To satisfy benchmark criteria, ventilators must be acceptable for use (satisfactory, safe, used within six months) and have a working battery, and all accessories. Figure 78 illustrates these compounding acceptance criteria when applied to the 93 recorded ventilators.

Figure 78.

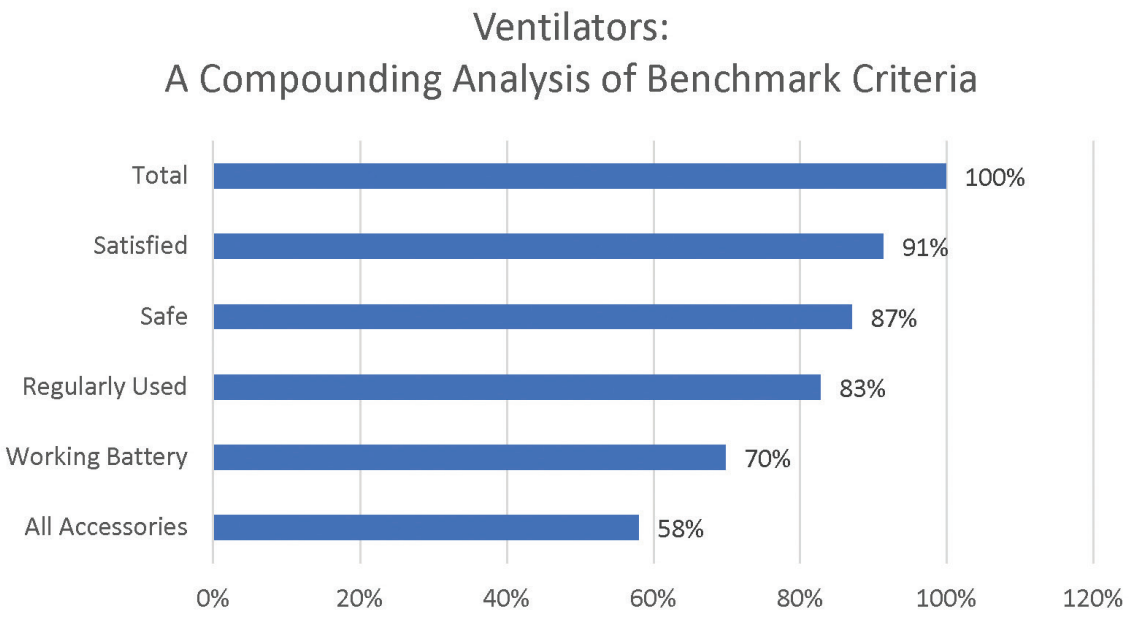
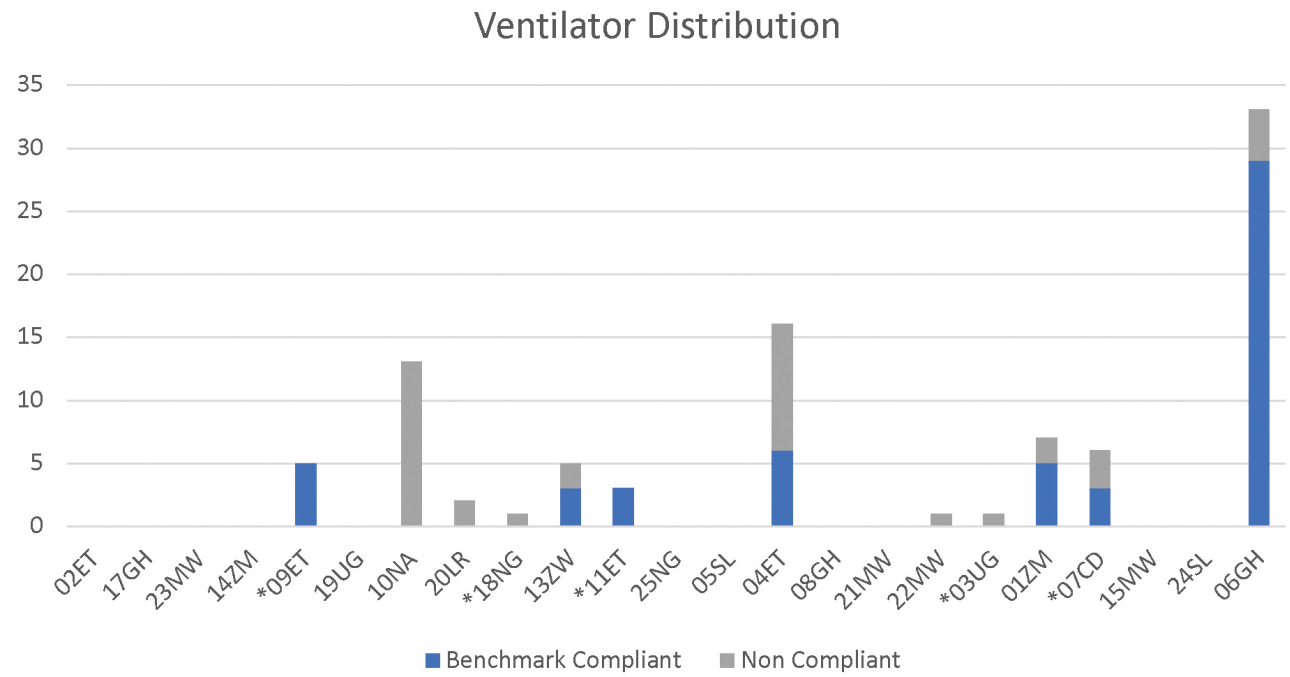


Figure 79 demonstrates ventilator distribution. Eleven (11) hospitals report no ventilators.

Figure 79.



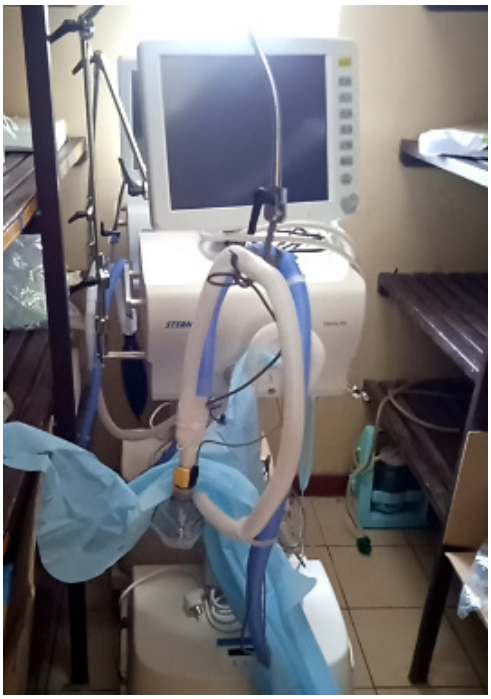
** Mission/charity hospital*

Summary of Optional Comments/Notes Section

Overall, while several ventilators are reported to be in good working condition, a significant proportion face issues due to missing spare parts and accessories. This highlights the importance of ensuring that not only are the ventilators themselves functional, but also that necessary components and maintenance support are available to keep them operational.

Figure 80.
Ventilator Images from Audit

01ZM, #020
Benchmark compliant ventilator.



13ZW, #023
Benchmark compliant ventilator.

01ZM, #011
Benchmark compliant ventilator.

04ET, #033
Benchmark compliant ventilator.

	
13ZW, #026 Ventilator is safe, satisfactory, and has been used in the past 7 days but does not have battery back-up.	18NG, #072 Ventilator has been used in the past 7 days, has satisfactory performance but is deemed unsafe.

Less Frequently Logged Equipment Summaries

Oxygen Cylinders

- Total: 156
- Acceptable: 75%
- Benchmark standards:
    - Acceptable
    - All consumables available
- Benchmark compliant: 42%
- Donated: 42%
- Without equipment manuals: 83%
- Percent of all equipment with all consumables: 52%
- Percent with all equipment accessories: Not asked

156 oxygen cylinders were reported. However, multiple sites mentioned that as they did not have their own oxygen pipeline, these cylinders were simply rented and would be returned (to be replaced with different cylinders) when refilled. In such instances some sites chose not to tag and report cylinders. While the cylinder count is thus unlikely to be accurate, what this data does reflect is that 63% (99) of cylinders are unchained and unsecure, posing significant safety hazards.

Backup Electricity Generators

- Total: 32
- Acceptable: 56%
- Benchmark standards:
    - Acceptable
    - Provide stable power
    - Fuel for to run for at least 8 hours
- Benchmark compliant: 38%
- Donated: 50%
- Without equipment manuals: 31%
- Percent of all equipment with all consumables: Not asked
- Percent with all equipment accessories: Not asked

Blood Gas Analysers

- Total: 14
- Acceptable: 79%
- Benchmark standards:
    - Acceptable
    - All consumables available
- Benchmark compliant: 71%
- Donated: 21%
- Without equipment manuals: 21%
- Percent of all equipment with all consumables: 79%
- Percent with all equipment accessories: Not asked

CPAP (Concentrator-Connected)

- Total: 27
- Acceptable: 70%
- Benchmark standards:
    - Acceptable
    - Airway pressure control is functional
    - All accessories available
- Benchmark compliant: 44%
- Donated: 74%
- Without equipment manuals: 44%
- Percent of all equipment with all consumables: 48%
- Percent with all equipment accessories: 52%

CPAP (Pipeline/Cylinder Oxygen-Connected)

- Total: 10
- Acceptable: 30%
- Benchmark standards:
    - Acceptable
    - All accessories available
- Benchmark compliant: 20%
- Donated: 50%
- Without equipment manuals: 50%
- Percent of all equipment with all consumables: 50%
- Percent with all equipment accessories: 60%

Dialysis Equipment

- Total: 13
- Acceptable: 62%
- Benchmark standards:
    - Acceptable
    - All available accessories and consumables
- Benchmark compliant: 54%
- Donated: 38%
- Without equipment manuals: 62%
- Percent of all equipment with all consumables: 69%
- Percent with all equipment accessories: 77%

Electric or Air-Powered Drill/Saws

- Total: 16
- Acceptable: 94%
- Benchmark standards:
    - Acceptable
    - All available consumables
- Benchmark compliant: 81%
- Donated: 31%
- Without equipment manuals: 25%
- Percent of all equipment with all consumables: 88%
- Percent with all equipment accessories: Not asked

Endoscopy Equipment Systems

- Total: 25
- Acceptable: 48%
- Benchmark standards:
    - Acceptable
    - Produced images when used with a display system
    - All available accessories
- Benchmark compliant: 28%
- Donated: 64%
- Without equipment manuals: 28%
- Percent of all equipment with all consumables: Not asked
- Percent with all equipment accessories: 36%

Head Lamps

- Total: 29
- Acceptable: 72%
- Benchmark standards:
    - Acceptable
    - Switches on
- Benchmark compliant: 72%
- Donated: 55%
- Without equipment manuals: 38%
- Percent of all equipment with all consumables: Not asked
- Percent with all equipment accessories: Not asked

There appears to be significant confusion regarding this item. Only one image is of a traditional wearable head lamp. All other devices are smaller OR lights.

Laparoscopy Equipment Systems

- Total: 6
- Acceptable: 67%
- Benchmark standards:
    - Acceptable
    - Produced images when used with a display system
    - All available accessories and consumables
- Benchmark compliant: 50%
- Donated: 33%
- Without equipment manuals: 0%
- Percent of all equipment with all consumables: 83%
- Percent with all equipment accessories: 83%

Laryngoscopes

- Total: 7
- Acceptable: 86%
- Benchmark standards:
    - Acceptable
    - All available accessories and consumables
- Benchmark compliant: 57%
- Donated: 57&
- Without equipment manuals: 71%
- Percent of all equipment with all consumables: 71%
- Percent with all equipment accessories: 86%

Operating Microscopes

- Total: 32
- Acceptable: 75%
- Benchmark standards:
    - Acceptable
    - Light works
    - Provides clear and focused image
- Benchmark compliant: 69%
- Donated: 53%
- Without equipment manuals: 34%
- Percent of all equipment with all consumables: Not asked
- Percent with all equipment accessories: Not asked

There appears to be significant confusion regarding this item. Only six of the microscopes were for use by surgeons in the operating room. Four of the microscopes were slit lamp microscopes for ophthalmology purposes. The remaining were standard lab microscopes.

Operation Room Table Traction Devices

- Total: 4
- Acceptable: 0%
- Benchmark standards:
    - Acceptable
    - All accessories available
- Benchmark compliant: 0%
- Donated: 50%
- Without equipment manuals: 25%
- Percent of all equipment with all consumables: Not asked
- Percent with all equipment accessories: 75%

Oxygen Pipelines

- Total: 19
- Acceptable: 74%
- Benchmark standards:
    - Acceptable
    - Supply oxygen
    - All available accessories and consumables
- Benchmark compliant: 37%
- Donated: 21%
- Without equipment manuals: 84%
- Percent of all equipment with all consumables: 68%
- Percent with all equipment accessories: 53%

Of the 23 sites, only seven sites report having onsite oxygen pipelines.

Discussion

It is important to remember the limitations of this study when reflecting on the outcomes. This study was designed in the UK and implemented across 12 countries with no on-the-ground oversight. Accordingly, there is no means of ensuring study compliance. Although the intent was for the engineers to audit every item on the list, it is our belief, based on field experience, that the majority of decommissioned or junk equipment was not audited (as only 4% of equipment was labelled as never used). Furthermore, the comments note that 54% of the never used equipment is brand new in biomed storage, or new and awaiting installation.

On average, hospitals report that 56% of medical equipment is satisfactory, safe, and regularly used. With slightly more stringent equipment-specific standards implemented, the percentage of equipment that meets these benchmark standards drops to 33%. Multiple studies[10,11,12] have been conducted over the past few decades attempting to characterise medical equipment in LMICs. While multiple variables hinder the ability to compare study outcomes, the greatest challenge is the inability to define a common definition of appropriate equipment. Terms such as "out of service," "broken," "non-operational," etc., have all been used to describe equipment. This study has gone to great lengths to describe the characteristics of acceptable and benchmark-compliant equipment to ensure clarity for the reader. Knowing that equipment is still used when broken, missing accessories, or unsafe, we developed criteria in an attempt to only capture equipment that actively aids in patient care without posing risks to patients and users.

The World Health Organization (WHO) suggests that "some [healthcare facilities] acquire nearly 80% of their healthcare equipment in the form of donations."[13] Additionally, in 2010, the Director General of the WHO stated that "about 70% of the more complex medical devices do not function when they reach their destination."[14] Although 14 years out of date, these statistics are still widely circulated and cited in current global health publications. This study suggests a shift in the procurement strategy moving away from the reliance on donations. We found only 46% (weighted average 56%) of equipment is donated. Of the donated equipment, 55% is satisfactory, safe, and regularly used (i.e., functional, albeit not on par with Western standards). This shift may be driven by the increased efforts to inform donors of appropriate medical equipment donations and more stringent local acceptance policies. However, it is likely also influenced by the increased market saturation of inexpensive medical equipment from countries such as China and India.

The two most reported anaesthetic machines in the study are the German-manufactured Dräger Fabius GS Premium and the Chinese-made Mindray WATO EX-35. Although prices vary, Dräger machines cost around $50,000 compared to the $35,000 for Mindray. The two most frequent oxygen concentrators are the American-made Airsep Newlife Elite and Chinese-made Longfian Jay-5; list prices for these are $2,000 and $800, respectively. As new medical equipment becomes more affordable for LMICs, it is critical to address appropriate procurement strategies to ensure high-quality, context-appropriate items are purchased. Context-appropriate considerations include the environment, strength and stability of the power grid, local burden of disease, skill of healthcare providers and maintenance teams, and market availability of consumables, accessories, and spare parts.

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[10]Perry, L., Malkin, R. Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world? ***Med Biol Eng Comput*** 49, 719–722 (2011). https://doi.org/10.1007/s11517-011-0786-3

[11]Gatrad, A.R, et al. "Equipment Donation to Developing Countries." ***Association of Anaesthetists***, 22 Oct. 2007, associationofanaesthetists-publications.onlinelibrary.wiley.com/doi/10.1111/j.1365-2044.2007.05309.x.

[12]Oosting, R.M., Wauben, L.S.G.L., Groen, R.S. ***et al.*** Equipment for essential surgical care in 9 countries across Africa: availability, barriers and need for novel design. ***Health Technol.*** 9, 269–275 (2019). https://doi.org/10.1007/s12553-018-0275-x

[13]WHO (2010). ***Medical devices: managing the mismatch: an outcome of the priority medical devices project.*** https://www.who.int/publications/i/item/9789241564045

[14]Chan. 2010. Medical devices: an area of great promise. 9 September 2010. Global Forum of Medical Devices, Thailand.

According to the statistical analysis of independent variables influencing the percentage of benchmark-compliant equipment, the inclusion of accessories emerges as a significant predictor of compliance. The regression analysis reveals a very strong positive relationship between the provision of accessories and the percentage of benchmark-compliant equipment. Therefore, it can be inferred that enhancing the availability and/or quality of accessories is associated with a higher likelihood of equipment meeting benchmark standards.

Lack of accessories poses one of the greatest barriers to equipment transitioning from acceptable to benchmark-compliant status, with only 58% of all equipment having all accessories. The lack of accessories and spare parts (only 16% of reported equipment has available spare parts) is routinely referenced as a hindrance to optimal performance in the notes and comment section. That said, we did not provide clear definitions for accessories and spare parts, therefore there may be significant cross-over between the two categories.

If accessories get lost, broken, or require routine replacement, the excessive variability in manufacturers within a single facility can exacerbate the difficulty in procuring the correct accessories, as they are not designed to be interchangeable across manufacturers. Figure 81 highlights the worst-case scenario with the greatest variability in patient monitors at a single facility. However, even when examining the five smallest healthcare facilities, as shown in Figure 82, there is still significant variability in manufacturers. Accordingly, procurement strategies should emphasise the importance of acquiring equipment from single manufacturers.

Figure 81.

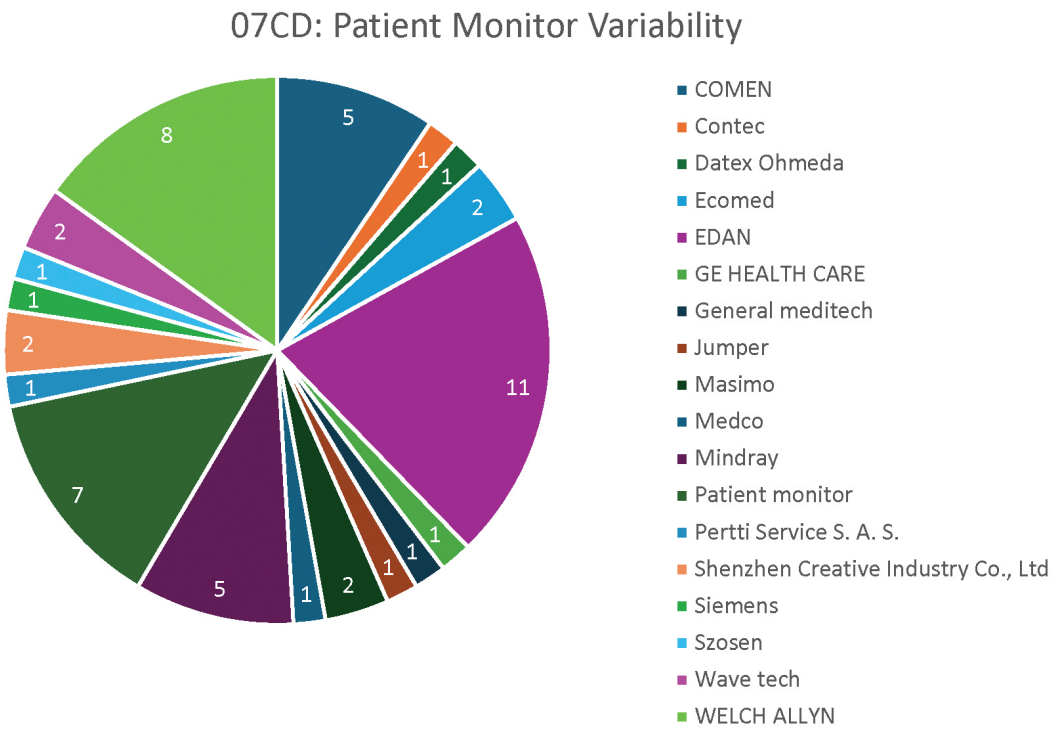
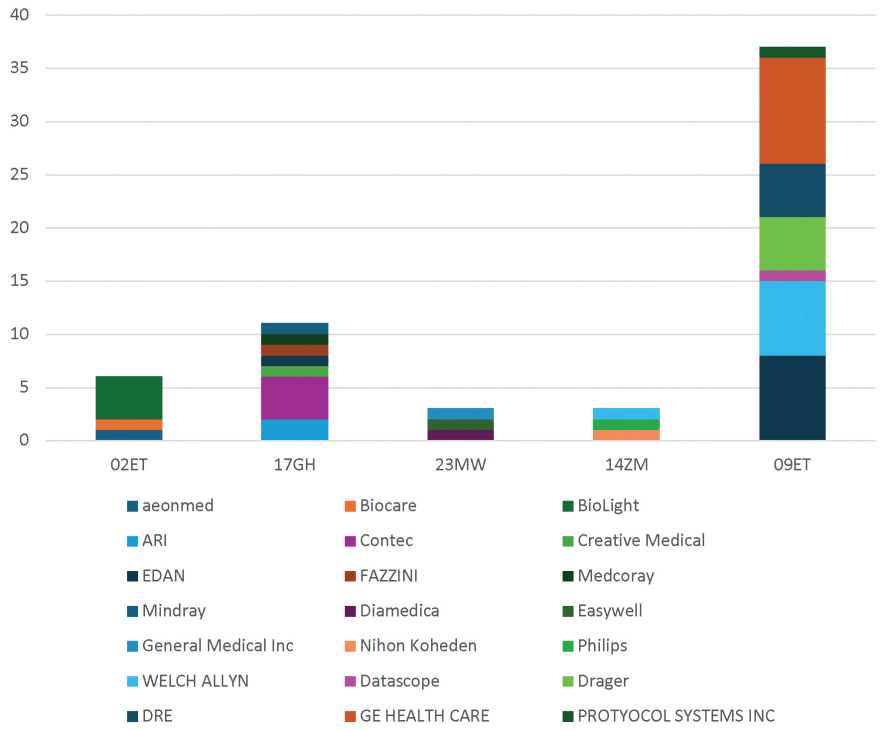


Figure 82

Patient Monitor Variability across the 5 Smallest Facilities



The onboarding survey suggests that this study comprises highly educated, albeit poorly resourced, individuals. Although 81% of participants have received biomedical engineering education beyond secondary school, only 27% of participants report having the basic tools needed to maintain and repair medical equipment. This situation is reminiscent of the adage “give a man a fish and he eats for a day, teach him to fish and he eats for a lifetime.” But this allegory neglects the necessity of the fishing rod. Education without resources remains purely theoretical. Achieving tangible and measurable results requires both practical education and the appropriate tools to apply that knowledge. Although most participants are university graduates, the state of the equipment casts doubts on the practical skills component of the university degree. Technical and maintenance skills, more closely aligned with biomedical technician training rather than biomedical engineering education, must be emphasised. This is an area that requires further exploration.

It is difficult to ignore the inequitable distribution of items that do not correspond to bed capacity or number of ORs. Of particular note are the ESUs at 11ET, operating room lights at 07CD, pulse oximeters at 09ET and 11ET, syringe drivers at 06GH, and ultrasound machines at 19UG and 11ET. With the exception of 06GH and 19UG, most inappropriate quantities of equipment are seen at charity/mission funded hospitals. One might assume this is due to an influx of donations at charity/mission hospitals, but this is not necessarily the case. Government facilities receive a higher percentage of donations than charity/mission hospitals: 64% (simple average: 48%) and 38% (simple average: 42%), respectively. The surplus of certain equipment suggests facilities need to improve or instil data-driven procurement strategies. Comprehensive internal audits and needs assessments should be regularly conducted to inform administration on equipment needs. Engineers should be included in the decision-making process to ensure resources are allocated effectively and meet actual needs.

Conclusion

The preliminary findings from the initial audits and surveys highlight significant gaps and challenges faced by healthcare facilities in Sub-Saharan Africa. Despite a high level of education among participants, with 81% having received biomedical engineering training beyond secondary school, only 27% possess the basic tools required to maintain and repair medical equipment. This disconnect underscores a critical issue: education without the necessary resources translates to unfulfilled potential and theoretical knowledge that cannot be practically applied.

The data collected from 23 healthcare facilities by 73 participants reveal that, on average, only 56% of medical equipment is deemed satisfactory, safe, and regularly used. Only 33% meet benchmark standards.

The onboarding survey suggests that engineers often overestimate the operational status of their equipment. This discrepancy suggests a lack of standardised criteria for assessing equipment functionality. Key barriers to achieving higher standards include a lack of accessories and spare parts; this scarcity severely impacts the functionality and safety of essential medical devices.

The variability in equipment manufacturers further complicates maintenance efforts, as accessories and spare parts are not often interchangeable. Facilities with varying brands face heightened challenges in sourcing compatible components, emphasising the need for standardised procurement strategies that prioritise consistency.

Although donations remain a significant source of medical equipment, accounting for 46% of the audited items, this percentage is lower than previous estimates. This study indicates a shift towards purchasing new equipment, which tends to have a slightly higher (albeit not statistically significant) rate of acceptability.

Overall, this data serves as a crucial baseline for assessing the impact of the forthcoming online biomedical engineering course by Medical Aid International. It is anticipated that post-course audits will show significantly higher levels of unsatisfactory, unsafe, and unused equipment as participants are educated on fault-finding strategies, health and hygiene guidelines, electrical safety, and item-specific maintenance techniques. The ongoing maintenance logs and future reports will measure the success of implementing Medical Aid International's online training and resources.

Moving forward, it is essential to address the dual needs of education and resource provision to empower biomedical engineers and technicians to effectively support healthcare systems in LMICs. This task will be more achievable if hospitals procure the correct equipment from the start.

Appendices

Appendix 1. Onboarding Survey

Table 1A.1. Applicant Summary

Country	Hospital facilities submitting applications	Total number of applicants
Ethiopia	42	182
Malawi	37	93
Ghana	27	101
Nigeria	25	219
Kenya	20	71
Zambia	19	66
Uganda	17	53
Sierra Leone	16	40
Zimbabwe	16	69
Rwanda	16	52
Tanzania	12	45
Burundi	9	14
DRC	8	15
Madagascar	6	12
Cameroon	5	18
Liberia	5	13
Namibia	3	5
Burkina	3	9
St Lucia	1	1
Niger	1	1
Somalia	1	3
Djibouti	1	9
Congo	1	3
Pakistan	1	2
Yemen	1	5
Lesotho	1	3
Albania	1	1
Gabon	1	4
Gambia	1	10
Grand Total	297	1119

Hospital Type	Total
Charity/Mission Hospital	40
Government/State Hospital	228
Private Hospital	29
Grand Total	297

Table 1A.2 Higher Level Learning Institutions

University/College/Polytechnic	Country	Attendees
University of Ghana	Ghana	6
Jimma University	Ethiopia	6
Evelyn Hone College	Zambia	3
Mbarara University of Science and Technology	Uganda	3
Malawi University of Science and Technology	Malawi	3
Federal University of Technology, Owerri	Nigeria	2
University of Antananarivo	Madagascar	2
Mekelle University	Ethiopia	2
Sierra Leone Opportunity Industrialization Center (SL. O. I. C)	Sierra Leone	1
Federal university of Agriculture Makurdi	Nigeria	1
Université de technologie de Compiègne	France	1
California Institute of Technology*	USA	1
Private university	Unknown	1
Hawassa University	Ethiopia	1
The Copper belt University	Zambia	1
Addis Ababa Institute of Technology	Ethiopia	1
All Nations University, Coventry University	Unknown	1
Keyan Medical Training College	Kenya	1
Northern Technical College	Zambia	1
Kwame Nkrumah University of Science and Technology	Ghana	1
Regent University of Science and Technology	Ghana	1
Kwekwe Polytechnical College	Zimbabwe	1
Tegbare-Id Polytechnic College	Ethiopia	1
Abia State Polytechnic	Nigeria	1
The Mombasa Polytechnic College	Kenya	1
Akanu Ibiam Federal Polytechnic	Nigeria	1
All Nations University College	Ghana	1
University of Malawi at Polytechnic	Malawi	1
Accra Technical University	Ghana	1
Biomedical apprentice training M O H Liberia,/ Electricity National Vocational Training Institute(NVTI) Liberia.	Liberia	1
Michael Okpara University of Agriculture Umudike	Nigeria	1
M'Hamed Bouguerra University of Boumerdes in Algeria	Algeria	1

Table 1A.3 ANOVA. Education's Impact on Ability to Maintain Equipment

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
No Education	14	111	7.928571	4.840659
College/Polytechnic	15	129	8.6	2.828571
University	45	368	8.177778	2.876768

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.434191	2	1.717096	0.532128	0.589678	3.125764
Within Groups	229.1063	71	3.22685			
Total	232.5405	73				

The p-value of 0.590 is greater than the significance level of 0.05, indicating no statistically significant difference in the self-assessed ability to maintain equipment across the different education levels. This suggests that education level (whether no education, college/polytechnic, or university) does not significantly impact the ability to maintain medical equipment.

Table 1A.4 ANOVA. Education's Impact on Ability to Fix Equipment

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
No Education	14	109	7.785714	6.027473
College/Polytechnic	15	126	8.4	3.114286
University	45	347	7.711111	2.346465

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	5.447061	2	2.723531	0.858656	0.428084	3.125764
Within Groups	225.2016	71	3.171853			
Total	230.6486	73				

The p-value of 0.428 is greater than the significance level of 0.05, indicating no statistically significant difference in the self-assessed ability to fix equipment across the different education levels. This suggests that education level (whether no education, college/polytechnic, or university) does not significantly impact the ability to fix medical equipment.

Table 1A.5 ANOVA. Education's Impact on Ability to Communicate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
No Education	14	124	8.857143	1.824176
College/Polytechnic	15	133	8.866667	2.980952
University	45	378	8.4	2.518182

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.765894	2	1.882947	0.758531	0.472111	3.125764
Within Groups	176.2476	71	2.482361			
Total	180.0135	73				

The p-value of 0.472 is greater than the significance level of 0.05, indicating no statistically significant difference in the self-assessed ability to communicate professionally amongst colleagues across the different education levels. This suggests that education level (whether no education, college/polytechnic, or university) does not significantly impact the ability to communicate professionally.

Table 1A.6. ANOVA. Education's Impact on Ability to Train

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
No Education	14	99	7.071429	4.225275
College/Polytechnic	15	132	8.8	2.742857
University	45	361	8.022222	2.658586

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	21.69365	2	10.84683	3.661918	0.03065	3.125764
Within Groups	210.3063	71	2.962061			
Total	232	73				

Based on the ANOVA results, it can be concluded that the level of education (no education, college/polytechnic, or university) has a statistically significant impact on the self-assessed ability to train medical personnel. This implies that education plays a critical role in enhancing the ability to train others, with those having college or polytechnic education showing the highest average score in training ability.

Table 1A.7. ANOVA. Education's Impact on Perceived Respect

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
No Education	14	109	7.785714	4.796703
College/Polytechnic	15	121	8.066667	2.780952
University	45	349	7.755556	3.961616

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.114629	2	0.557314	0.143574	0.866507	3.125764
Within Groups	275.6016	71	3.881712			
Total	276.7162	73				

The p-value of 0.867 is greater than the significance level of 0.05, indicating no statistically significant difference in the perceived respect levels across the different education levels. This suggests that education level (whether no education, college/polytechnic, or university) does not significantly impact one's perceived respect.

Table 1A.8 Experience's Impact on Ability to Maintain Equipment

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0-1 years	9	70	7.777778	4.194444
2-5 years	33	264	8	4
6-10 years	20	173	8.65	2.028947
11-15 years	5	40	8	4.5
16-20 years	4	33	8.25	0.25
21+	3	28	9.333333	1.333333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.01832	5	2.203664	0.676452	0.642725	2.349573
Within Groups	221.5222	68	3.25768			
Total	232.5405	73				

The P-value (0.6423) indicates that there is no statistically significant difference in the ability to maintain equipment among participants with different years of experience.

Table 1A.9. Experience's Impact on Ability to Fix Equipment

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0-1 years	9	70	7.777778	4.194444
2-5 years	33	259	7.848485	3.382576
6-10 years	20	158	7.9	3.252632
11-15 years	5	39	7.8	4.7
16-20 years	4	30	7.5	0.333333
21+	3	26	8.666667	2.333333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.584002	5	0.5168	0.15409	0.978114	2.349573
Within Groups	228.0646	68	3.353892			
Total	230.6486	73				

The P-value (0.978) indicates that there is no statistically significant difference in the ability to fix equipment among participants with different years of experience.

Table 1A.10. Experience's Impact on Ability to Communicate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0-1 years	9	71	7.888889	3.111111
2-5 years	33	286	8.666667	2.979167
6-10 years	20	177	8.85	2.239474
11-15 years	5	43	8.6	1.8
16-20 years	4	32	8	0.666667
21+	3	26	8.666667	0.333333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.374625	5	1.474925	0.580952	0.714409	2.349573
Within Groups	172.6389	68	2.538807			
Total	180.0135	73				

The P-value indicates that there is no statistically significant difference in the ability to professionally communicate amongst participants with different years of experience.

Table 1A.11. Experience's Impact on Ability to Train Peers

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0-1 years	9	65	7.222222	2.694444
2-5 years	33	264	8	4.375
6-10 years	20	169	8.45	1.944737
11-15 years	5	41	8.2	4.2
16-20 years	4	30	7.5	1
21+	3	23	7.666667	1.333333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	11.02778	5	2.205556	0.678718	0.641044	2.349573
Within Groups	220.9722	68	3.249592			
Total	232	73				

The P-value indicates that there is no statistically significant difference in the ability to train peers amongst participants with different years of experience.

Table 1A.12. Experience's Impact on Perceived Respect

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
0-1 years	9	57	6.333333	3.75
2-5 years	33	254	7.69697	4.467803
6-10 years	20	172	8.6	2.357895
11-15 years	5	40	8	2.5
16-20 years	4	27	6.75	0.25
21+	3	29	9.666667	0.333333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	47.52985	5	9.505971	2.820438	0.022541	2.349573
Within Groups	229.1864	68	3.370388			
Total	276.7162	73				

While education plays no statistically significant difference in individual's perceived respect from colleagues, years of experience does. The P-value (0.022541) is less than the significance level (usually 0.05), indicating that there is a statistically significant difference in perceived respect among participants with different years of experience. Therefore, years of experience significantly impact the perceived respect among participants, with those having more years of experience generally perceiving higher respect.

Appendix 2 Audit Data

Table 2A.1 Dissatisfaction by Equipment Type

	Satisfied	Unsatisfied	Unknown	Total	Percentage Dissatisfaction
Dialysis Equipment	8	5	0	13	38%
Steriliser/Autoclave	57	40	9	106	38%
Operating Lights	64	32	2	98	33%
Infant Radiant Warmer	52	25	2	79	32%
Endoscopy Equipment System	18	7	0	25	28%
Anaesthetic Machine	59	22	3	84	26%
Ultrasound Scanner (Imaging Machine)	50	19	6	75	25%
CPAP (Concentrator-Connected)	20	6	1	27	22%
Backup Electricity Generator	23	7	2	32	22%
X-ray/C-arm	43	12	2	57	21%
CPAP (Pipeline/Cylinder Connected)	5	2	3	10	20%
Suction Machine	188	51	24	263	19%
Oxygen Concentrator	266	68	37	371	18%
Infant Incubator	61	14	5	80	18%
Pulse Oximeter	124	20	0	144	14%
Operating Table	73	12	4	89	13%
Surgical Diathermy/ESU	64	11	14	89	12%
Patient Monitor	433	51	12	496	10%
Defibrillator	54	6	4	64	9%
Operating Microscope	29	3	0	32	9%
Oxygen Cylinder	141	13	2	156	8%
Ventilator	85	7	1	93	8%
Head Lamp	27	1	1	29	3%
Infusion Pump/Syringe Driver	334	12	6	352	3%
Oxygen Pipeline	18	0	1	19	0%
Electric or Air-Powered Bone Drill/Saw	16	0	0	16	0%
Blood Gas Analyser	14	0	0	14	0%
Laryngoscope Handle (with Light)	6	0	1	7	0%
Laparoscopy Equipment System	5	0	1	6	0%
Operating Table Traction Device	3	0	1	4	0%

Table 2A.2 Safety Concerns by Equipment Type

	No Safety Concerns	Safety Concerns	Unsure	Total	Unsafe
Operating Table with Traction	0	4	0	4	100%
CPAP (Pipeline/Cylinder Connected)	3	4	3	10	40%
X-ray/C-arm	37	18	2	57	32%
Backup Electricity Generator	19	10	3	32	31%
Oxygen Concentrator	245	112	14	371	30%
Infant Radiant Warmer	54	23	2	79	29%
Anaesthetic Machine	58	23	3	84	27%
Head Lamp	22	7	0	29	24%
Steriliser/Autoclave	69	25	12	106	24%
Pulse Oximeter	102	33	9	144	23%
CPAP (Concentrator-Connected)	21	6	0	27	22%
Operating Lights	75	20	3	98	20%
Infant Incubator	62	16	2	80	20%
Operating Table	69	17	3	89	19%
Ultrasound Scanner (Imaging Machine)	57	13	5	75	17%
Oxygen Cylinder	128	26	2	156	17%
Laparoscopy Equipment System	4	1	1	6	17%
Operating Microscope	27	5	0	32	16%
Dialysis Equipment	11	2	0	13	15%
Suction Machine	203	39	21	263	15%
Laryngoscope Handle (with Light)	6	1	0	7	14%
Defibrillator	53	9	2	64	14%
Oxygen Pipeline	17	2	0	19	11%
Patient Monitor	442	45	9	496	9%
Surgical Diathermy/ESU	80	7	2	89	8%
Infusion Pump/Syringe Driver	328	24	0	352	7%
Ventilator	86	6	1	93	6%
Electric or Air-Powered Bone Drill/Saw	15	1	0	16	6%
Endoscopy Equipment System	23	1	1	25	4%

Table 2A.3 Onboarding Survey Responses as Predictors of Acceptable Equipment

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.319257
R Square	0.101925
Adjusted R Square	-0.03988
Standard Error	0.28107
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.170354	0.056785	0.718787	0.552995
Residual	19	1.501011	0.079001		
Total	22	1.671365			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.313402	0.459	0.682793	0.502979	-0.6473	1.274101	-0.6473	1.274101
total years of experience	0.000215	0.003085	0.069704	0.945158	-0.00624	0.006673	-0.00624	0.006673
Average Maintain	0.140316	0.097716	1.435963	0.167273	-0.06421	0.344837	-0.06421	0.344837
Average Fix	-0.11416	0.102954	-1.10889	0.281319	-0.32965	0.101321	-0.32965	0.101321

Interpretation of Regression Analysis

Regression Statistics:

- **Multiple R (0.319):** This value represents the correlation coefficient between the observed and predicted values of the dependent variable. A value of 0.319 indicates a weak positive correlation.
- **R Square (0.102):** This indicates that approximately 10.2% of the variance in the dependent variable is explained by the independent variables in the model.
- **Adjusted R Square (-0.040):** This value adjusts the R Square for the number of predictors in the model. With an adjusted R Square of -0.040, the model's explanatory power is very low, suggesting that the independent variables do not explain much of the variance in the dependent variable when adjusting for the number of predictors.
- **Standard Error (0.281):** This value indicates the typical distance that the observed values fall from the regression line. A lower value would indicate a better fit.
- **Observations (23):** This is the number of observations included in the analysis.

ANOVA Table:

- **F-statistic (0.719):** The F-statistic tests whether at least one of the regression coefficients is different from zero.
- **Significance F (0.553):** The p-value for the F-statistic. Since this value is greater than 0.05, it suggests that the overall regression model is not statistically significant at the 5% level, meaning there isn't strong evidence that the model explains a significant portion of the variance in the dependent variable.

Coefficients Table:

- **Intercept (0.313):** This is the predicted value of the dependent variable when all other variables are zero. It has a p-value of 0.503, indicating it is not statistically significant at the 5% level.
- **Total years of experience (0.000215):** This coefficient is positive but very small, suggesting a negligible and non-significant effect on the dependent variable (p-value = 0.945).
- **Average Maintain (0.140):** This coefficient suggests a positive relationship, indicating that higher self-assessed ability to maintain equipment might lead to higher values of the dependent variable, but it is not statistically significant (p-value = 0.167).
- **Average Fix (-0.114):** This coefficient suggests a negative relationship, indicating that higher self-assessed ability to fix equipment might lead to lower values of the dependent variable, but it is not statistically significant (p-value = 0.281).

Summary:

The regression model explains 10.2% of the variance in the dependent variable, but the overall model is not statistically significant (Significance F = 0.553). Among the predictors, none are statistically significant at the 5% level. The coefficients for "Average Maintain" and "Average Fix" show positive and negative effects respectively, but these effects are not statistically significant.

Appendix 2A.8. Chi-square tests

Null hypothesis (H0): there is no association between equipment acquisition (new or donated) and acceptable (simultaneous satisfactory, safe, and regularly used) equipment performance.

Alternate Hypothesis (H1): There is an association between equipment acquisition (new or donated) and acceptable (simultaneous satisfactory, safe, and regularly used) equipment performance. Acceptable performance is dependent on equipment acquisition type.

Table 2A.8 Chi-Square Tests

Observed Values				Expected Values			Summary	
Anaesthetic Machine								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	17	23	40	Donated	14.08451	25.915493	0.144117	Fail to reject H_0
New	8	23	31	New	10.91549	20.084507		
Sum	25	46	**71**					
Defibrillator								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	12	18	30	Donated	8.421053	21.5789474	0.034612	Reject H_0
New	4	23	27	New	7.578947	19.4210526		
Sum	16	41	**57**					
Infant Incubator								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	9	25	34	Donated	7.96875	26.03125	0.541992	Fail to reject H_0
New	6	24	30	New	7.03125	22.96875		
Sum	15	49	**64**					
Infant Radiant Warmer								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	24	20	44	Donated	19.55556	24.4444444	0.014075	Reject H_0
New	4	15	19	New	8.444444	10.5555556		
Sum	28	35	**63**					
Infusion Pump/Syringe Driver								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	23	24	47	Donated	5.628743	41.3712575	3.8E-17	Reject H_0
New	17	270	287	New	34.37126	252.628743		
Sum	40	294	**334**					

Operating Lights								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	22	31	53	Donated	20.71264	32.2873563	0.562099	Fail to reject H_0
New	12	22	34	New	13.28736	20.7126437		
Sum	34	53	**87**					
Operating Table								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	11	37	48	Donated	11.25926	36.7407407	0.889956	Fail to reject H_0
New	8	25	33	New	7.740741	25.2592593		
Sum	19	62	**81**					
Oxygen Concentrator								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	117	133	250	Donated	108.7302	141.269841	0.020203	Reject H_0
New	20	45	65	New	28.26984	36.7301587		
Sum	137	178	**315**					
Patient Monitor								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	34	115	149	Donated	21.05077	127.949227	0.000201	Reject H_0
New	30	274	304	New	42.94923	261.050773		
Sum	64	389	**453**					
Pulse Oximeter								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	44	30	74	Donated	27.38583	46.6141732	5.94E-10	Reject H_0
New	3	50	53	New	19.61417	33.3858268		
Sum	47	80	**127**					
Steriliser/Autoclave								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	31	19	50	Donated	23.45679	26.5432099	0.00055	Reject H_0
New	7	24	31	New	14.54321	16.4567901		
Sum	38	43	**81**					
Suction Machine								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	27	71	98	Donated	22.42786	75.5721393	0.124585	Fail to reject H_0
New	19	84	103	New	23.57214	79.4278607		
Sum	46	155	**201**					
ESU/Surgical Diathermy								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	11	23	34	Donated	7.555556	26.4444444	0.050484	Fail to reject H_0
New	5	33	38	New	8.444444	29.5555556		
Sum	16	56	**72**					

X-ray/C-arm								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	12	9	21	Donated	8.217391	12.7826087	0.021778	Reject H_0
New	6	19	25	New	9.782609	15.2173913		
Sum	18	28	**46**					
Cylinder								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	11	52	63	Donated	11.84211	51.1578947	0.708166	Fail to reject H_0
New	14	56	70	New	13.15789	56.8421053		
Sum	25	108	**133**					
Backup Electricity Generator								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	7	6	13	Donated	4.68	8.32	Insufficient sample size	
New	2	10	12	New	4.32	7.68		
Sum	9	16	**25**					
Blood Gas Analyser								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	1	2	3	Donated	0.642857	2.35714286	Insufficient sample size	
New	2	9	11	New	2.357143	8.64285714		
Sum	3	11	**14**					
CPAP (Concentrator-Connected)								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	6	13	19	Donated	5.115385	13.8846154	Insufficient sample size	
New	1	6	7	New	1.884615	5.11538462		
Sum	7	19	**26**					
CPAP (Pipeline/Cylinder Oxygen-Connected)								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	3	2	5	Donated	2.857143	2.14285714	Insufficient sample size	
New	1	1	2	New	1.142857	0.85714286		
Sum	4	3	**7**					
Dialysis Equipment								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	3	2	5	Donated	1.923077	3.07692308	Insufficient sample size	
New	2	6	8	New	3.076923	4.92307692		
Sum	5	8	**13**					
Endoscopy Equipment System								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	9	6	15	Donated	7.173913	7.82608696	Insufficient sample size	
New	2	6	8	New	3.826087	4.17391304		
Sum	11	12	**23**					

Head Lamp								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	5	9	14	Donated	3.111111	10.8888889	Insufficient sample size	
New	1	12	13	New	2.888889	10.1111111		
Sum	6	21	**27**					
Microscope								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	5	12	17	Donated	4.103448	12.8965517	Insufficient sample size	
New	2	10	12	New	2.896552	9.10344828		
Sum	7	22	**29**					
Oxygen Pipeline								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	1	2	3	Donated	0.666667	2.33333333	Insufficient sample size	
New	3	12	15	New	3.333333	11.6666667		
Sum	4	14	**18**					
Ultrasound								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	5	15	20	Donated	4.230769	15.7692308	Insufficient sample size	
New	6	26	32	New	6.769231	25.2307692		
Sum	11	41	**52**					
Ventilator								
	Not Acceptable	Acceptable	Sum		Not Acceptable	Acceptable	p-value	Result
Donated	6	24	30	Donated	4.615385	25.3846154	Insufficient sample size	
New	8	53	61	New	9.384615	51.6153846		
Sum	14	77	**91**					

The chi-square tests reveal that for several types of medical equipment, including defibrillators, infant radiant warmers, infusion pumps/syringe drivers, oxygen concentrators, patient monitors, pulse oximeters, sterilisers/autoclaves, and X-ray/C-arms, there is a significant association between the type of acquisition (new or donated) and the equipment's acceptable performance. Specifically, new equipment in these categories is more likely to be acceptable compared to donated equipment. Conversely, for other equipment types such as anaesthetic machines, infant incubators, operating lights, operating tables, suction machines, and ESUs/surgical diathermies, there is no significant association, indicating that the performance of these types of equipment does not significantly depend on whether they were newly purchased or donated. For several other categories, the sample size was insufficient to determine the association.

Appendix 2A.9i

Assessing Difference between onboarding operational equipment estimates and Audit Acceptable (satisfactory, safe, regularly used) levels

t-Test: Paired Two Sample for Means

Null Hypothesis (H0): There is no significant difference between the engineers' guesses and the actual audit results.

Alternative Hypothesis (H1): There is a significant difference between the engineers' guesses and the actual audit results.

	est. % operational	*total*
Mean	0.750797101	0.564347826
Variance	0.038950283	0.075971146
Observations	23	23
Pearson Correlation	0.474762265	
Hypothesized Mean Difference	0	
df	22	
t Stat	3.554897859	
P(T<=t) one-tail	0.000887012	
t Critical one-tail	1.717144374	
P(T<=t) two-tail	0.001774025	
t Critical two-tail	2.073873068	

Summary

The mean estimated percentage of operational equipment (75%) is significantly higher than the actual percentage of acceptable equipment (565) determined by the audit. Since the p-values are very small and the t-Statistic is higher than the critical values, we reject the null hypothesis (H0). This indicates that there is a statistically significant difference between the engineers' estimated percentages of operational equipment and the actual audit results. Specifically, engineers tend to overestimate the operational status of the equipment compared to the actual audit findings.

Appendix 2A.9ii

Assessing Difference between onboarding operational equipment estimates and Audit Satisfaction scores

t-Test: Paired Two Sample for Means

Null Hypothesis (H0): There is no significant difference between the engineers' guesses and the actual audit results.

Alternative Hypothesis (H1): There is a significant difference between the engineers' guesses and the actual audit results.

	est. % operational	*Audit results Satisfactory*
Mean	0.750797101	0.717826087
Variance	0.038950283	0.034635968
Observations	23	23
Pearson Correlation	0.175872453	
Hypothesized Mean Difference	0	
df	22	
t Stat	0.641979226	
P(T<=t) one-tail	0.263760014	
t Critical one-tail	1.717144374	
P(T<=t) two-tail	0.527520027	
t Critical two-tail	2.073873068	

Summary

there is no statistically significant difference between the engineers' estimated percentages of operational equipment and the actual audit results for satisfactory equipment levels. Thus, engineers' estimates of operational equipment closely match the audit results in terms of equipment being satisfactory. Together with the conclusion from 2A.9i, this implies engineers estimates for "operational equipment" more closely align with their satisfaction with the equipment rather than whether the equipment is satisfactory, safe, and regularly used.

Attachments

Attachment 1:

Medical Aid International's Online Biomedical Engineering Course

Medical Aid International believes that training biomedical engineers is crucial for improving healthcare in LMICs. As such they have developed a fully remote online learning platform specifically designed for individuals working in LMIC healthcare facilities.

Course Overview

The course exemplifies critical thinking and advocates for biomedical engineer integration into the hospital decision-making processes. It equips biomedical engineers with fundamental theory and physiology, in order to deepen their understanding of medical equipment and its uses. Additionally, the students are fully equipped with the tools needed to maximise their impact. Students are provided with a comprehensive, professional toolkit, four engineering textbooks, and a digital library of service manuals. Biomedical engineers are not only responsible for procuring, installing, and maintaining medical equipment but also for training the end user. For user training to be well-received, biomedical engineers must be able to convey confidence in themselves and their skills. This course has instils a level of confidence among its graduates that did not previously exist. The course is Assured by City & Guilds; upon completion of the course, each graduate will receive a a certificate of course completion.

Course Units

- Unit 0: Health and Safety
- Unit 1: The Frequency Spectrum
- Unit 2: Electrical Safety
- Unit 3: Electrocardiogram (ECG)
- Unit 4: Defibrillation
- Unit 5: Patient Monitoring
- Unit 6: Infusion Devices
- Unit 7: Premature Baby Incubators (PBIs)
- Unit 8: Ultrasound
- Unit 9: Surgical Diathermy/ESU
- Unit 10: Hygiene Guidelines
- Unit 11a: Anaesthetics, Oxygen and Suction Devices
- Unit 11b: The Operating Department and Sterilisation
- Unit 12: First Aid
- Unit 13: Train the Trainer and Applying what you have learnt

Toolkit Inventory and Additional Resources

The following items are provided for every enrolled student:

- Plastic toolbox – 610x325x305mm
- Soft grip plier set – 4 pieces
- Circular plier set – 5 pieces
- Cross pein pin hammer – 110g/4oz
- Inspection mirror
- Soft grip screwdriver set – 8 pieces
- Hacksaw with soft grip – 300mm
- Hexagon key set & wallet – 25 pieces
- Telescopic magnetic pick-up tool
- Retractable blade trimming knife – 5 spare blades
- VDE approved fully insulated screwdriver set – 7 pieces
- Precision screwdriver set – 6 pieces
- Junior hacksaw blades – 10 pieces
- Fiberglass shafted claw hammer – 450g/16oz
- Adjustable wrench – 150mm
- Combination spanner set – 14 pieces
- Combination spanner – 6mm
- Combination spanner – 7mm
- Bi-metal hacksaw blades – 300mm, 32tpi, 10 pieces.
- Measuring tape – 5m/16ft x 19mm
- Square socket set – ¼", 20 pieces
- Safety glasses
- Professional safety goggles
- Pocket multi-tool
- Head lamp – 3W
- Heavy duty AAA alkaline batteries – 4 pieces
- Digital multimeter
- Heavy duty 9V alkaline battery
- Junior hacksaw and blade
- Soldering Iron – 230V, 30W
- Lead-free solder – 1.2mm x 20g
- Ear plugs
- High visibility vests
- Medical Aid International portfolio & desk pad
- Biomedical Engineer polo shirt
- USB- preloaded equipment manuals
- Textbooks:
    - Beginner's Guide to Reading Schematics – ISBN: 978-1260031102
    - Complete Electronics, Self-Teaching Guide – ISBN: 978-1118217320
    - Encyclopaedia of Electronic Components – ISBN: 978-1449333898
    - Oxford Concise Medical Dictionary – ISBN: 978-0198836612

Additional Resources

One of each of the following is provided to the enrolled facility for shared use by enrolled students

- Oxygen analyser
- Desktop magnifier
- Laptop with:
    - Monitor
    - Mouse
    - Keyboard
    - Carrying case

Hospital Resources

One of each of the following was provided to the healthcare facilities enrolled in this initiative as a token of appreciation for their role in the project:

- Handheld pulse oximeter
- Neonatal resuscitation kit

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