Medical Equipment at Kilimanjaro Christian Medical Centre and Mawenzi Regional Hospital

EWH Summer Institute, June 17 - August 17 2014

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Assessment of Donations and Report of Repairs

Report, August 17 2014

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Abstract

The purpose of this report is to present the work of the Engineering World Health Summer Institute 2014 at Kilimanjaro Christian Medical Center and Mawenzi Regional Hospital, both in Moshi, Tanzania. The report highlights the troubleshooting, methods, and solutions for various medical equipment repairs encountered over the four-week period. An inventory of broken equipment in each department was first taken to assess the quantity and quality of donated medical equipment. Next, a wide range of equipment was repaired using local resources and innovative solutions. Training sessions with the hospital staff were also held to clarify the use of particularly relevant pieces of equipment. By providing a detailed report of repair and maintenance, we hope our work will surpass mere fixes and become truly sustainable – both by educating hospital staff and by harnessing the innovation of local technicians in a resource-poor setting.

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CHAPTER 1

Introduction

1.1 Engineering World Health

Engineering World Health (EWH) is an international non-governmental organization that exists to meet the challenges of global health in developing countries. The organization was founded in 2001 by Robert Malkin and Mohammad Kiani to involve students in the development of technological infrastructure in resource-poor countries. Engineering World Health's programs promote the development of innovative health technologies and the exchange of biomedical engineering knowledge through a Summer Institute program and Biomedical Engineering Technician program. These programs allow engineering students and professionals to introduce innovative medical equipment designed specifically for the developing world, install and repair donated equipment, and build a local capacity to maintain the equipment.

1.1.1 EWH Summer Institute

The EWH Summer Institute, founded in 2004, sends engineering students to Nicaragua, Rwanda, or Tanzania for a month of language and engineering training, followed by one month of work in a local hospital. The participants are trained specifically to repair medical equipment in resource-poor settings using local and sustainable solutions. The authors of this report were participants of the EWH 2014 Tanzania Summer Institute. The report describes our experiences working at the Kilimanjaro Christian Medical Centre and the nearby Mawenzi Regional Hospital in Moshi, Tanzania. Our results are presented, significant repairs are elaborated on, and suggestions for further maintenance are provided.

1.1.2 Biomedical Engineering Technician Program

One of Engineering World Health's most prominent programs is the Biomedical Engineering Technician Program. The program, founded in 2009 with the support of the GE Foundation, provides a three year training course for 45 technicians in Rwanda in order to create a local and sustainable workforce. Currently, the BMET program has educated 38 biomedical engineering technicians with an additional 22 graduating soon. Because of the continued support from the GE Foundation, the program has recently expanded to Cambodia, Honduras and Ghana.

1.2 Literature about Medical Equipment in Developing countries

A range of studies have been conducted on the subject of donated medical equipment and the resulting necessity of biomedical engineering technicians. For a more in-depth review of the subject, the following articles may be of special interest:

- Malkin[5] 2007 - *Design of health care technologies for the developing world.* This article reviews the barriers, both real and perceived, to the introduction of health care technology with a main focus on health care technology in hospitals.
- Malkin and Keane[3] 2010 - *Evidence-based approach to the maintenance of laboratory and medical equipment in resource-poor settings.* 2849 equipment-repair requests are analysed. 66% of the out-of-service equipment was placed back into service using only 107 skills covering basic knowledge in each domain; far less knowledge than that required of a biomedical engineer or biomedical engineering technician. It is concluded that a great majority of laboratory and medical equipment can be put back into service without importing spare parts and using only basic knowledge.
- Perry and Malkin[7] 2011 - *Effectiveness of medical equipment donations to improve health systems: how much medical equipment is broken in the developing world?* 112040 pieces of equipment are examined in this study. An average of 38.3% (42,925, range across countries: 0.83-47%) in developing countries was out of service. The three main causes were lack of training, health technology management, and infrastructure.
- Howitt et al.[2] 2012 - *Technologies for global health.* - A major report published in the Lancet, authored by several experts in the field of global health. Key points of the report are:
  - Technology can improve global health, and includes not only pharmaceuticals, vaccines, and devices, but also advances such as better sanitation and agriculture.
  - At present, technology for health focuses on the needs of the wealthy.
  - More frugal technology, specifically designed for the world's poorest people, is needed.
  - Such technology also has the potential to be a disruptive technology for health care in high-income countries.
  - Technology alone is not enough—it needs to be combined with innovations in processes to have the greatest effect.
  - Capacity to successfully create and use technology should be part of the post-2015 assessment of global development.
- Malkin and von Oldenburg Beer[4] 2013 - *Diffusion of novel healthcare technologies to resource poor settings.* This article describes and explores the manufacturing and distribution options in order to provide insights into when and how each can be applied to scale up a novel technology to make a difference in a resource poor setting.
- Malkin and Whittle[6] 2014 - *Biomedical Equipment Technician Capacity Building Using a Unique Evidence-Based Curriculum Improves Healthcare* This article assesses the impact of a unique evidence-based biomedical equipment technician training program on the healthcare infrastructure and the productivity of technicians in Rwanda. Technicians who completed 1 year of this unique biomedical equipment technician training program are dramatically improving healthcare by effectively using and sharing taught skills.

Finally, the following document prepared by Engineering World Health provides detailed troubleshooting flowcharts for different types of medical equipment: Cooper and Dahinten[1] 2013 - *Medical Equipment Troubleshooting Flowchart Handbook.*

CHAPTER 2

Methods

2.1 Navigating the Hospital

Upon arriving at KCMC, we first met the head of each department in order to integrate into the hospital. Our mission was two-fold: to create an inventory of all donated equipment and to fix the broken equipment in each ward. The purpose of creating an inventory for each ward was to quantify the amount of donated equipment and the proportion which was broken. This research will help Engineering World Health make medical equipment donations more efficient and effective. A study conducted by Professor Robert Malkin of Duke University concluded that of 112,040 pieces of equipment in developing world hospitals examined, about 40% was out of service due to lack of training, health technology management, and infrastructure.(Perry and Malkin [7]) In several departments, our first inquiries about donated or broken equipment were met with denial; many claimed they did not have any donated equipment or that everything was working properly. However, once we started asking more questions about specific equipment (i.e. does this machine work? Do you have any suction pumps? Are they broken?), we discovered that each ward had both donated and broken equipment. Because our time at KCMC was limited, we decided against creating a full inventory of the large hospital. We did, however, create a list of the most important pieces of equipment in each ward we worked at throughout the month. In the future, we believe it would be helpful for the KCMC engineering department to create an updated inventory of equipment in each ward in order to keep track of broken equipment and donations.

Two major approaches that helped us create a working relationship with the hospital staff were fixing equipment on site and updating staff about the progress of our projects. For example, we worked for two weeks on an incubator and suction pump in the hallway directly outside the Surgical Intensive Care Unit, allowing the head nurse and other staff in the department to observe our progress and dedication to fixing their machines. We also worked on several projects in the medical department alongside several of the KCMC engineers. The KCMC engineers were able to quickly procure parts and bring them directly to the ward to fix machines on-site. This also allowed us to show the nurses additional functionalities of machines in their department.

Maintaining continuous contact with the department heads has also improved our integration into the hospitals. While some staff were hesitant about giving us equipment at first, they were reassured when we promised to return the equipment regardless of whether we were able to fix it or not. Fixing a few small pieces of equipment first helped us gain the staff's trust, allowing us to then work on more expensive and difficult machines. Throughout the process of repair, especially for longer projects, we made sure to call or text message the heads of departments about any problems we found, parts we planned to buy in town, and our plans and time line for repair. On several occasions, we also brought the equipment back to the department heads to physically show them the problems or parts we were looking for.

2.2 Procurement of Parts

The following section provides details about the source of replacement parts used at KCMC and Mawenzi Hospitals throughout the month. While Engineering World Health provided basic supplies such as a toolbox, many of the more specific parts were purchased in Moshi Town, if they could be purchased at all.

The KCMC kiwanda had tools including:

- soldering iron
- hand saw
- nails and screws
- tools such as screwdrivers and wire strippers
- plastic, aluminium sheets, rivets (orthopaedic department)
- blood pressure cuffs (procurement office)

Engineering World Health supplied the following parts and tools:

- power supply (made in lab)
- transformer
- toolboxes
- masking tape
- sandpaper
- scissors, boxcutters, wirestrippers
- fuses
- spare batteries
- temperature sensor (made in lab)

Engineering World Health also supplied the following equipment, which was not used during the month:

- silicon
- rubber bands, balloons
- flashlight (made in lab)

The equipment and services that were lacking were purchased at various hardware stores in Moshi Town:

- fuses (those not provided by EWH)
- screws
- batteries
- solder
- electrical tape
- super glue
- epoxy
- shower curtain
- sewing of incubator sleeves
- spot glue (for repair of water container)

The following parts were unable to be purchased:

- Varta 80H 2.5V battery from Dar es Salaam (unavailable)
- Language software chip from HP
- Calibration tools for Ivac Tiva fluid pump

The following parts were needed from procurement, but unavailable:

- oxygen concentrator bottles
- oxygen concentrator filters
- suction pump filters
- tubing
- electrodes
- conductive gel

2.3 Operating and Service Manuals

Repairing the more complex equipment, in many cases, requires a service or operating manual. This manual was often misplaced and rarely found with the machine. One valuable on-line resource to find missing manuals is located at http://www.frankshospitalworkshop.com.

This website has been compiled by Frank, a German biomedical engineer working at Kibosho Hospital in Tanzania. Frank has compiled a large amount of user and service manuals on his website, which are organized by category of equipment, i.e. Autoclaves, ECG Machines, Pulse Oximeters, etc. Within each category, there are manuals from a variety of manufacturers. When a manual was not available on Frank's website, it could usually be obtained by directly contacting the manufacturer.

2.4 Education of Hospital Staff

One recurring problem we encountered was the hospital staff's lack of familiarity with new medical equipment. Many donated machines arrived at KCMC without user manuals, calibration tools, or consumable replacement parts. The lack of information transferred from the donors to the hospital staff caused problems in several areas, including usage of machines, report of broken equipment to the engineering department, and ability to repair machines with consumable or specific parts.

It was evident that while some of the basic features of the machines were understood, other functions were not being used simply because the staff did not know about the machine's capabilities. For example, the nurses were able to use the electronic suction pumps by powering on the machine. However, they did not know that the suction strength could be adjusted by turning a dial.

The hospital staff were also unaware of which parts were disposables and should be replaced after each patient. The suction pump and oxygen concentrator filters were usually replaced only after the machine stopped working due to blocked air flow. The nurses did not know what the problem was, so even though the solution was as simple as replacing a filter, the machine was usually deemed out-of-order. Other machines were functioning properly but could not be used because of a lack of disposables, such as the ECG machine which lacked disposable electrodes. We have provided directions in Appendix B on how to replace these disposables with commonly available items.

Some of the staff also had not undergone the appropriate training for their department. According to the head nurse in the Surgical Intensive Care Unit, the ICU staff had not received any training specific to the ICU. At government-supported regional hospitals in the area, ICU nurses may receive one year of training in South Africa. However, since KCMC is partially funded by the Good Samaritan Foundation, the nurses' training is not supported.

At Mawenzi Hospital, a new program had recently been introduced at the Friday morning report meetings. Each week, a different staff member would give a 30 minute presentation about a patient case that was mishandled or a short lecture on an interesting topic in their field. These presentations were treated as part of the staff's ongoing training and education. This program was especially critical in an understaffed hospital where night shifts were often run by staff from a different department who may need to address unfamiliar cases. These types of informal, quick training sessions would be an effective venue to introduce different types of medical equipment to each department. These sessions could regularly be hosted by the engineering department and could cover topics such as preventative maintenance, repair, and functionality of the machines.

CHAPTER 3

Results

Over the course of four weeks, we were able to repair 63 pieces of equipment at KCMC and Mawenzi hospitals, ranging from simple machines such as sphygmomanometers, suction pumps, and stethoscopes, to more difficult machines such as incubators and anaesthesia vaporizers. The following sections will highlight some of our most interesting, difficult, and innovative fixes. The complete list of fixed equipment for both hospitals can be found in Appendix A on page 29.

3.1 Simple Mechanical Fixes

Leaky Tubing Leaks were commonly encountered in malfunctioning equipment. These were often seen in the rubber bags and tubing of both automatic and manual blood pressure cuffs. Because of these leaks, the blood pressure machines failed to reach an adequate pressure to take a measurement. If the leak was not easily found by observing the tubing or feeling air escaping from the cuff, a simple test helped to determine the problem area. First, the cloth casing was removed. Next, the bag was inflated, and both bag and tube were submerged in a bucket of water. The leak was then easily identified by the escape of air bubbles from the hole. Once the leaks were identified, they were repaired at a local bicycle repair shop on Sokoine Road with a rubber tire patch. This process involved roughening the leakage spot with sandpaper, applying vulcanizing glue, and covering with a bicycle patch. An extra bicycle patch kit was purchased and given to the KCMC engineering department to repair future leaks. Leaks can also be found by covering the sus-

Figure 3.1: Aged tubing was one of the most common and simple fixes we encountered. Left: A Vital Signs Monitor, illustrating the amounts of tubing often found in medical equipment. Center: Aged rubber can simply be fixed using normal vulcanizing rubber bicycle patches. Right: A typical blood pressure cuff that can be repaired using bicycle patches as the bag is made of plastic. 5.6

Figure 3.2: Left: New Earbud for stethoscope using a small and a large diameter tube. Centre: Fixing a stethoscope. The screw for the stethoscope Right: Testing the newly fixed stethoscope with help from local Maasai.

pected area with a soapy solution. The passage of air through the solution will create bubbles, indicating the source of the leak. This technique was used on an oxygen concentrator to find a hidden leak at a bolt junction.

Stethoscopes Stethoscopes, found in many departments, commonly loose the rubber earpieces after prolonged use. These were made with various sized tubing placed inside of each other to make a contoured shape earpiece. The tubing should then be shaped using sandpaper. The rubber tube earpieces are attached to the stethoscope handles using epoxy.

3.2 Simple Electrical Fixes

Batteries Some of the simplest fixes involved thermometers and digital blood pressure cuffs, which simply required replacement batteries. LR41 button batteries were purchased from the "fundi wa saa," the watch technician, along Mawenzi Road. The rusty battery connections in the thermometers had to be thoroughly cleaned with alcohol swabs before the batteries were replaced.

Incompatible Power Plugs Another problem commonly encountered with otherwise functional machines was an incompatible power plug. It was possible to change 2-prong plugs to 3-prong, and vice versa, by simply splicing the correct wires together and securing with heat shrink or electrical tape.

Recharging batteries Several of the larger machines, including the pulse oximeter and infusion pump, used lead acid batteries that needed to be recharged. The batteries can be charged using a variable power supply, which can be built by the engineering department. The instructions for building the variable power supply and recharging the batteries can be found in Appendix C.

Replacing diodes When there is an unstable supply of current, the diodes in machine power supplies can break down over time. The function of a diode can be easily tested with the continuity function of a multimeter. Because a diode is a bipolar semiconductor, current should only pass in one direction. A diode can be damaged by passing too much current or voltage through the component. As a result, the failed diode will allow current to pass unimpeded through both directions. If the diode is functioning properly, the

Figure 3.3: Left: Four broken thermometers we were given by the medical ward, which all worked after changing the batteries. Center: Cast cutter that needed a different plug. Right: Tubing often stretches and cracks over time, increasing the likelihood of leaks. Here, Ashley is repairing an automatic blood pressure monitor by replacing the old tubes with newer tubing cannibalized from an old blood pressure cuff.

multimeter should measure full resistance in one direction and low to no resistance in the opposite direction. If the diode is not functioning properly, the multimeter should measure low resistance in both directions, indicating that the diode is actually allowing current to flow both ways. This technique was used to find a damaged diode in the circuitry of the infant warmer at Mawenzi Hospital.

Replacing fuses Blown fuses are a common problem, especially when there is an unstable current. It is very important that the replacement fuse has the same amperage and voltage-rating as the original. These ratings are always stated on the machine. It is not sufficient to match only one of the two ratings. Fuses can be tested using the continuity function on the multimeter; functional fuses will be continuous, blown fuses will not. It is a good idea to always check the continuity of the fuses as one of the first steps in troubleshooting a broken machine.

3.3 Repairs of Specific Interest

3.3.1 Incubator

The ICU department had a V-85 Atom Infant Incubator that was donated in 1994 by the Tanzania-Japan Cooperation. The incubator was not used for three years because every time it was powered on, it set off a series of alarms. It was evident that the overheating and ventilation alarms were ringing because the incubator was missing covers to the inlet holes. The heating coil inside of the machine warmed air that rose into the body of the incubator. Because the inlet covers were missing, the warm air escaped from the incubator, and the temperature sensor measured a lower temperature than what would be expected. As a result, the heater was then powered to a higher setting, which raised the incubator temperature to above the maximum allowable threshold. In addition, the lack of these inlet covers interfered with the expected ventilation of the machine, causing the ventilation alarm to sound.

After troubleshooting, the first step was to test if the problems could be solved with temporary solutions. The open inlet holes were covered with plastic gloves and grocery bags, the missing latch on one of the entry doors was replaced with tape, and the cracked container for the water humidifier was sealed with tape. After these these temporary fixes were made, the incubator was tested for one hour and no alarms sounded. This approach ensured that the machine was functioning correctly before we invested the time in more sustainable fixes.

Figure 3.4: Plastic Sleeves of the Incubator

Figure 3.5: Testing the Incubator

Figure 3.6: Cleaning the Incubator

Figure 3.7: Cleaning the Opened

Figure 3.8: Incubator Latch Mechanism


[1]

Figure 3.9: Incubator Door

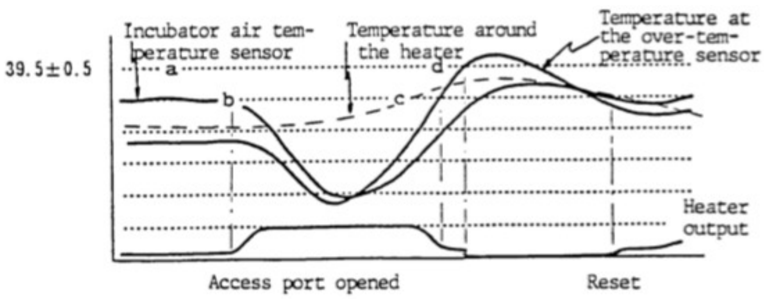

Figure 3.10: This diagram describes the behaviour of the internal incubator temperature. When the access port is opened at stage b, the hot air escapes and the internal temperature of the incubator is lowered. As a result, the heater output is increased at stage c to compensate for the lost heat. There is a time delay in the heater's response to internal temperature change, which explains why the internal temperature overshoots at stage d. This causes the over-temperature sensor to set off an alarm.

Figure 3.11: Incubator humidifier holder.

Arm Sleeves Replacements were not available for the missing plastic arm sleeves that cover the inlet holes, so we had to invent our own solution. The fabric for this part had to be waterproof and airtight, so we bought a 100% polyester shower curtain from Nakumatt Supermarket in Moshi Town. A seamstress on Uru Road created five arm sleeves, modelled after a worn-out plastic sleeve found with the machine. These sleeves had elastic bands on each end that could be fastened to the incubator and tightened to seal the air when not in use. They were also removable and washable. Extra fabric was stored below the incubator in case a replacement sleeve is needed in the future.

Door Latch One of the plastic latches which secures the incubator doors had detached from the machine and been replaced with medical tape. The latch consisted of two parts: a push button mechanism and spacer. The latch was found below the incubator, but the spacer was missing. The orthopaedics department fashioned a new spacer based off of the identical one for the other door. The original piece was 7 mm thick, so we used two 4 mm pieces of plastic which we sanded down to a thickness of 7 mm. The orthopaedic department electrically sanded the plastic into the correct shape and drilled holes to finish the spacer.

Water Humidifier The final broken piece of the incubator was the water humidifier system, which consisted of an inlet container leading to a water bath inside the machine. As the incubator heated, the water would slowly evaporate and humidify the air inside. The water container and the plastic holder were both broken and unable to be used. The water container was designed specifically to fit onto a tube leading inside the machine, so we decided the best solution was to use a very thick super glue to seal the crack rather than remodel the entire container. The orthopaedics department repaired the holder for the water container by building a small box that screwed onto the incubator. The box was made of a 4 mm thick plastic, cut and held together with a thick super glue. However, the super glue quickly gave way and failed to hold the box together. Thin aluminium sheets and rivets were then added to reinforce the box.

When the final components were attached to the incubator, it was evident that the box would not be sufficient to hold the water container because it was slightly too deep, and therefore failed to provide an adequate platform. The aluminium reinforcements also added extra weight to the component and put stress on the small screws holding it to the incubator. As a result, the holder solution was abandoned and replaced with Velcro strips that were salvaged from an old blood pressure cuff. The Velcro was roughened up with sandpaper to make a tighter connection, then fastened to both the water container and incubator with super glue.

Figure 3.12: Left: Infant Warmer at KCMC Maternity Ward. Right: The skin temperature sensor had been placed below the machine, causing the system to overheat.

3.3.2 KCMC Infant Warmer

The infant warmer we worked on at KCMC functioned perfectly, both mechanically and electrically, but user errors prevented the machine from being utilized. The department possessed the operating manual for the extremely new machine, and they specifically asked us to read the manual and explain its functions.
The first thing we noticed was that the room itself was so hot that the babies could not even be placed directly under the heater. This was caused by the incorrect use of the skin temperature probe. The probe was placed underneath the machine instead of on the infant's body. Therefore, it never measured a temperature of 35.5 degrees Celsius, which the machine was set to. As a result, the heater worked at full power, continually heating the machine and the entire room. Once the temperature sensor was placed up on the mattress pad where the baby would be, the heating power was drastically reduced.
Another user error with this machine involved the APGAR score button. The APGAR score is a manually determined score given to a baby to quantify health according to five criteria at specific time intervals after birth. The infant warmer was equipped with a stopwatch labelled "APGAR" that was programmed to set off at 1 minute and 5 minutes. The button had no other function than to notify the nurses that it was time to take the APGAR Score, but they wanted us to fix the machine so it could determine the APGAR Score for them. After learning about the true function of this button, the nurses realized that lacking this capacity did not mean that the machine was broken.
Lastly, the X-ray tray below the baby led the nurses to mistakenly believe the infant warmer could give X-ray scans. However, the tray is actually provided so that the infant warmer can be wheeled under the X-ray machine and the scan can be taken without removing the baby from the machine. After working through the user manual, the nurses understood the purpose of the X-ray tray. The nurses quickly applied this knowledge and the machine was instantly put to use with a newborn baby.

3.3.3 Mawenzi Infant Warmer

Mawenzi Hospital's maternity ward had an infant warmer that had not been out of order for several years. This machine had several problems that were discovered over a long troubleshooting period. First, an initial inspection identified a faulty connection in one of the two fuses. While the fuse itself was functioning properly, the fuse holder was clogged with dirt. After cleaning the holder, connectivity was restored across the component. The next problem to be tackled involved the malfunctioning circuit board. By testing each component for connectivity or resistance, it was evident that one of the diodes was not working. Diodes should show high resistance in one direction and low resistance in the other, as they only conduct current optimally in one direction. However, the diode in this situation conducted current in both directions, so

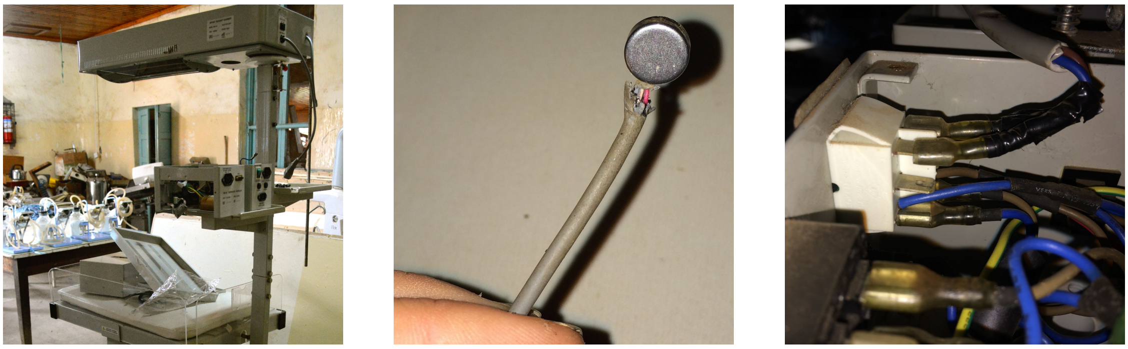

Figure 3.13: Left: Infant Warmer at Mawenzi Hospital Centre: Broken temperature sensor of the Infant Warmer. Right: Malfunctioning wiring of the Infant Warmer

it was replaced. The infant warmer has a skin temperature-probe which is used to automatically regulate the heating intensity to maintain the baby skin temperature at approximately 35.5 degrees Celsius. The temperature sensor on this specific machine was not working and needed to be replaced. While awaiting a new temperature probe, the machine could still be used in "manual" mode. This requires the hospital personal to closely watch the baby's temperature and regulate the machine accordingly. Using the Infant Warmer in manual mode requires resetting when the machine is turned on. We have developed a quick-start guide explaining how to reset the machine and set it to manual mode. The infant warmer has been given back to the maternity department at Mawenzi Hospital and is now in use.

3.3.4 Vaporizers

The surgical department routinely uses anaesthesia vaporizers with an interlock system. The interlock system allows for the use of two calibrated vaporizers. The accompanying selector valve has three positions: to the left one vaporizer is used, in the center neither is used, and to the right the other vaporizer is used. The interlock system contains two rings which rotate with the selector valve. There are two latches set about a pivotable point, which allows each latch to flip between two positions. These latches are asymmetrical, resulting in a selective fit in the recesses. When one latch is in the "on" position, the second latch is physically prevented from moving into it's own "on" position. The vaporizer we worked with in the surgical department was missing a small screw ring that held one of the latches into place. As a result, the interlock system was stuck in the "off" position because the latch was not properly placed in the mechanism. Once we repaired the vaporizer and returned it to the doctor in charge, we were shown a cabinet full of broken vaporizers, many with the same problem. While we did not have time to work on these machines, this would be a valuable project for the KCMC engineering department to pursue. If necessary, the vaporizers could be cannibalized for parts in order to put at least a fraction of the broken vaporizers back into use.

3.3.5 Suction Pumps

The surgical ICU possessed a relatively new Atmos C 451 automatic suction pump that was not in use. The nurses claimed it sometimes produced suction, but often stopped working. Connecting the power supply proved that the motor was audibly functioning. Next, we checked for leaks in the tubing by removing tubes one-by-one and monitoring the suction; this can help to narrow down the problem area. We also looked for clogs in the tubing, which are commonly seen in suction pumps as a result of their function. The problem was determined to be faulty connections between tubing elements, which can be solved by tightening connections. After testing, we also discovered that the filters – which prevent the suctioned

Figure 3.14: The isofluorane vaporizer was put back into the anaesthesia machine and is now in use in the surgical department.

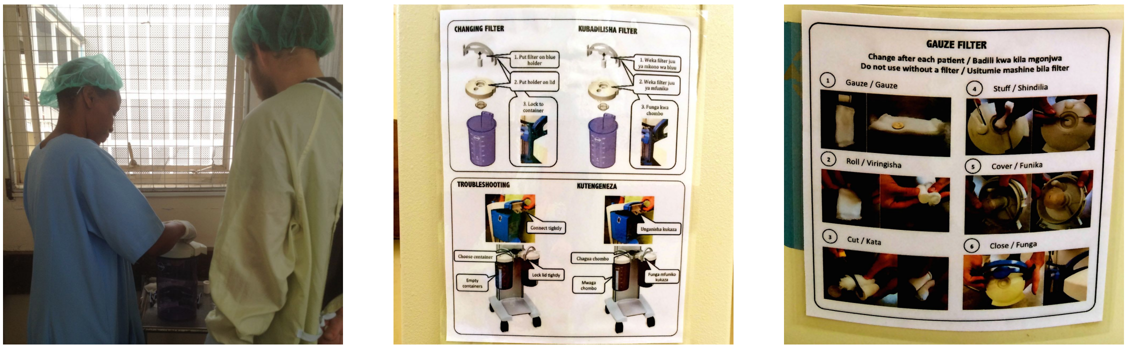

Figure 3.15: Left: David explains how to change the filters in the Atmos suction pump and how to create gauze filters. Centre: We created a laminated quickstart guide for the suction pump. The guide highlights the importance of tight connections in the tubing and includes instructions on how to replace filters. Right: When filters are clogged or missing, a substitute can be made with guaze, as illustrated in this quick-start guide. While this alternative does not function as a bacterial filter, it does protect the motor from getting clogged.

materials from contaminating the motor – were not regularly replaced and had become clogged. We created a troubleshooting guide to explain which connections must be secured and a quick-start guide instructing how to make gauze replacement filters. An identical machine was found in the maternity ward, which was currently being used for C-section surgeries. However, this machine was missing a lid to one of the two collection jars and a filter to the other. Therefore, when the jar had overfilled during a previous surgery, blood had been sucked into the motor. This machine required replacement parts and thorough cleaning of the biohazardous material, which still needs to be accomplished. Additionally, four identical manual suction pumps were collected at Mawenzi Hospital. One of these machines required a replacement collection jar, which was cannibalized from a spare machine. The others had leaky connections at the ends of the tubing because the tubes had stretched over time. This was quickly fixed by cutting off and discarding a small portion of each tube from both ends, and then reconnecting the remaining pieces.

3.3.6 Gauze Filters

A main issue we have encountered with many suction pumps is the lack of filters. When the existing filters get clogged with dirt, the suction level is significantly reduced. It is not advisable to simply remove the filter, as it puts the motor at risk of damage from aspirating fluids. A simple and effective alternative to

Figure 3.16: Gauze

Figure 3.17: Creating a Gauze Filter

Figure 3.18: Creating a Gauze Filter, cutting to the right size

Figure 3.19: Creating a Gauze Filter, Rolling up the gauze filter tightly

Figure 3.20: Placing the rolled gauze filter in place of the original filter.

Figure 3.21: Placing the Gauze tightly

expensive commercial filters is to create a home-made filter from gauze. Figure 3.16 through 3.21 illustrate how to create a gauze filter for an Atmos suction pump.

3.4 Quick Start Guides

Many pieces of equipment in the developing world are donating without user manuals. Therefore, many machines are not being used because the hospital staff are unsure how to properly operate the equipment. To remedy this problem, we created quick-start guides for several pieces of equipment at KCMC and Mawenzi Hospital. When creating quick-start guides, it is important to explain with pictures and to keep the wording brief. Because English and Swahili are both official languages of Tanzania, the instructions are written in both languages after being corrected by several native speakers. The guides were printed and laminated at local stationary shops, then permanently attached to their respective machines.

3.5 Training at Mawenzi Hospital

Almost every department at Mawenzi had a manual suction pump that was out of use because of weak suction. After working on four of these pumps, we determined that the major problem was user error. Therefore, we created a quick-start guide and associated training to explain how to properly use the pumps.

Figure 3.22: Left: Manual suctions pumps at Mawenzi hospital that had been repaired. KJ discusses the details of the quick start manual with a nurse from the medical ward. Centre: Correct use of the manual suction pump requires some special techniques as described in the quick start guide. Right: The quick start guides were supplemented by hands-on training with nurses from each department at Mawenzi hospital.

We had initially planned to train the nurses by demonstrating during one of the Friday morning reports, which all doctors and nurses at Mawenzi Hospital attended. However, the head doctor suggested we train one nurse from each department, who could then teach the others. This would ensure that the nurses present at the training were actively engaged, and had the responsibility to pass along the knowledge to the others in their department. The training consisted of showing the quick-start guide, demonstrating the operation techniques, and then letting the nurses operate the pumps independently. Our quick-start guide, attached to each machine, was pre-checked by a native speaker and practised on several students and nurses before the training session. Five nurses showed up in our workshop after being selected by the head doctor, who also came to our teaching session. This added credibility and weight to our training. We went step-by-step through the quick-start guide while demonstrating each stage. This was done in English, but a couple of the nurses translated for the others in Swahili. The nurses asked questions about the functionality of the machines which we hadn't even considered, such as, "Can we still add water to the bottom of the collection container so that the blood is easier to clean out?" We then had the nurses try for themselves on one of the four suction pumps. Several had trouble holding the tube tightly to maintain the suction, so we went through some troubleshooting steps with them to find the leak. Shortly after this, a few more nurses came to the shop and the nurses whom we had just taught were able to teach the others. The whole process lasted under thirty minutes. Afterwards, the nurses took the pumps back to their respective departments.

CHAPTER 4

Discussion

4.1 Donated Medical Equipment: Lessons Learned

Our fixes over the course of the month have led to several conclusions about equipment donations in the developing world. The large amount of broken equipment we found in the hospital closets and hallways supports the existing literature that about 40% of all donated medical equipment is broken and out of use. Our experiences fixing these devices and interviewing hospital staff has convinced us that donations to the developing world should be accompanied with continued support and maintenance. While this may be at an additional cost, we believe the hospitals we visited would benefit the most from fewer donations that are guaranteed to work for an extended period of time.

While physical repairs were important, many of our fixes involved merely training the hospital staff on how to use the equipment correctly. The success of our quick start guides suggests that medical equipment companies should include a short guide physically placed on the machine, since separate operation manuals are often misplaced. These guides should also be made for many existing machines to accompany training, ensuring that knowledge is not lost over time.

Our report also highlights the importance of obtaining disposables, either donated separately or with the respective machine. This need is exemplified in the case of the oxygen concentrators, which had stopped functioning because of a lack of disposable humidifier bottles. Parts that must be commonly replaced should be kept in stock at the hospitals because deliveries in Tanzania can take weeks to months.

4.2 Staffing Future Repairs and Maintenance

The results of this case study suggest several changes for next year's Engineering World Health Team. As recommended to us earlier by Mary Mushi, the amount of broken equipment at KCMC and Mawenzi mandate a larger team, perhaps as large as six engineers. We suggest organizing this by sending a team of two to Mawenzi, and a team of three or four to KCMC.

We also suggest increasing the local capacity to repair these machines. At KCMC, the shortage of technicians trained specifically to repair biomedical equipment limits the ability to maintain the numerous machines in the hospital. In the long-term, this can be remedied by developing a biomedical technician training program in Tanzania, led by EWH or another organization. In the short-term, we believe most of the repairs we made were simple fixes that involve electrical circuits, plumbing, and mechanics. While the machine may be used in the biomedical context, the problem is usually comparable to any machines. Therefore, electrical engineers, plumbers, welders, and other members of the engineering department can make the majority of the fixes covered in this report. We do suggest that before troubleshooting a piece of medical equipment, the technician ask the nurse or doctor how to use the machine and what the problem is. These questions were invaluable to us when tackling unfamiliar pieces of equipment.

CHAPTER 5

Further Work

5.1 Project Awaiting Parts

Ivac Tiva Fluid Pump P6000

This fluid pump in the pediatric department (neonatal ward) was repaired by clearing the RAM and recharging the green Varta 80H 2.4V battery soldered to the circuit board inside. However, the machine must now be fully calibrated, according to the IVAC-P6000-P7000 Service Manual, located at Frank's Hospital Workshop website. The required calibration tools include 1000TG00010 (50 mL Spacer A), 1000TG00011 (100 ml Spacer B), 0000TG00059 (105 mm Spacer), 0000TG0020, a pressure gauge (Range 0-140 mmHg), P7000 (dedicated pressure disc infusion set), and a 50 mL Luer-lock syringe.

ECG

The ECG machine in the paediatric department is now functioning, but cannot be used because it lacks electrodes. See Appendix B for instructions on how to make consumable ECG electrode pads and conductive gel in the case that the procurement office is unable to obtain the needed parts.

Hewlett Packard OmniCare 240 Neonatal vital signs monitors

The Medical 2 department has four Hewlett Packard OmniCare 240 Neonatal vital signs monitors that measure blood pressure, heart rate, SpO2, and ECG. Out of these four machines, there are zero ECG electrodes, one functional SpO2 sensor, and three functional blood pressure cuffs. The engineering department

Figure 5.1: Cardiac monitor from the SICU and MICU. Several of these machines have been donated to KCMC. Usually the machines work, the most common problem being either the power supply, SPO_2-meter, blood-pressure cuff or lack of ECG electrodes and ECG gel.

should build ECG electrodes, as detailed in the Appendix B, for each machine. The SpO2 sensors are Philips M1191B sensors that can be purchased directly from Philips through the procurement office. However, the Engineering World Health students will attempt to get these parts donated from Philips due to the high cost ($423 per piece).

5.2 Unfinished projects at KCMC

Blood Pressure Machine This machine is an automatic blood pressure machine from the medical department. The monitor had two blown fuses, which were replaced with 2 Ampere, 250 Volt fuses. The battery was also fully dead, and is currently being recharged with the variable power supply we built. After observing the inner mechanisms of the machine, it was evident that the power supply was being used solely to recharge the battery, which in turn powered the machine. Since the hospital staff had only been running the machine solely off the battery, it was understandable why the battery was completely discharged and the machine was no longer in use. The KCMC engineering department should procure a new transformer and ensure that the battery is fully charged before returning the machine.

ECG Machine (Paediatrics) This machine was not in use before, but is now functioning properly. The machine can be used as soon as the department can acquire new electrodes. The engineering department should try to procure the new electrodes or make their own as detailed in Appendix B, section B.1 on page 33.

Ultrasound: Sonos 5500 Agelent (Radiology)
This machine currently has problems with two of its transducers. The button that powers on the machine requires a simple mechanical fix. The power connection should also be converted from a 2-pronged round pin plug to a 3-pin plug to match the available sockets in the department.

Ultrasound: HDI ATL Node ID 08890 (Radiology)
This ultrasound was not connected to the power supply during our inventory rounds, and we noticed that the machine has no power supply connection, no transducers, and takes an input of 110 V rather than 220 V. These may be points of interests for the engineers who later pursue this project.

Ultrasounds (2): Philips (Radiology)
One of the two ultrasounds in the main room of the radiology department is functioning, but has a few keys on the keyboard (B,N, and the space bar) which are stuck. This problem could most likely be quickly remedied with cleaning. The transducer cords for both of these machines have broken cord coverings which have been repaired with duct tape. A more sustainable solution would be help maintain the longevity of these machines.

Ultrasound: Philips (Radiology)
A third ultrasound in the department was found in the administrative hallway of the radiology department. This machine was currently being used, but is not functioning at its maximum capability becasue the lower corners of the viewing screen are blurry.

X-Ray: Siemans, Division Elektromed Service (Radiology)
Registration Number 0000015, Telephone 22 63 93 00 This Norwegian machine has not worked since installation.

Figure 5.2: A problem commonly seen in ultrasound machines is damage from stress and strain at the junction of the cable and transducer cord.

Figure 5.3: Close-up of typical transducer found at KCMC.

X-Ray: Ziehm GMBH W. Germany (Radiology)
Exposcop CB7-D, Register Number 100815
Vastra Frolunda Telephone: 031-69 09 73
This machine is located in room 4 of the surgical theater. The monitor is now working, but should be tested with x-ray images by a doctor in the department.

5.3 Unfinished Projects at Mawenzi

Oxygen Concentrators (Storage) Mawenzi Hospital has a store room maintained by Mwanga Sala, which not only has many spare parts and replacement consumables such as filters and oxygen concentrator bottles, but also many pieces of non-working equipment. We observed two oxygen concentrators that could be easily repaired and many other pieces of equipment that is either broken, or new and has not yet been assembled. Much of this equipment could be put back into use by the KCMC engineering department as an initial project at Mawenzi Hospital.

5.4 Recommended Projects

Oxygen Concentrator
Many department at KCMC are in possession of oxygen concentrators, which are well utilized and vital pieces of equipment when oxygen cylinders are unavailable. The most common problems we encountered with this machine were humidifiers that needed to be changed. Keeping the humidifiers clean is important to prevent the cross-contamination between patients, especially in wards that deal with infection diseases.

We recommend that the total number of oxygen concentrators at the hospital be assessed by the engineering department. The humidifier bottles should be changed every month, or at the very least when the humidifier filter becomes blocked. The procurement department should buy enough oxygen concentrator bottles so that the each and every bottle can be changed every month.

An example of a calculation to determine the number of humidifiers needed is as follows: if there are 50 oxygen concentrators, 50 machines x 2 humidifiers per machine x 12 months = 1200 bottles. This calcuation should be made as soon as the oxygen concentrator inventory has been completed, and the number should be reported to procurement.

The humidifier bottle should also be cleaned between each patient. Cleaning the humidifier between every use will make the humidifier last longer.

Pulse-oximeter SPO_2 sensors

The hospital SICU and MICU are in possession of several cardiac monitors that are out of order due to issues with the SPO_2 sensors. A complete inventory should be done of each cardiac monitor and a spare SPO_2 sensor should be procured for each machine.

ECG Electrodes and conductive gel

The use of ECG machines is currently a major issue at KCMC because commercial disposable electrodes are unavailable and conductive gel is expensive.

We recommend that the engineering department produces its own electrodes and conductive gel for the hospital using the procedure described in the Appendix B, section B.1 on page 33. While this method may seem crude at first, it produces reliable, cheap electrodes that ensure patient conditions can be monitored.

Sanitation Dispensers

The use of hand sanitation dispensers at the entry of patient rooms would help minimize the risk of transmitting infections between patients and staff. While hand washing with soap and water is the primary method of sanitation, it would be beneficial to provide an additional method of disinfection that could be used more frequently. An alcohol-based sanitizer should be supplied in places of high traffic, but away from risk factors such as medical equipment and electrical outlets. Dispenser bottles should be installed and routinely refilled when emptied. Maintaining hand sanitation bottles in public places rather than supplying doctors with individual bottles ensures that the staff do not lose the bottles and are constantly encouraged to use those that are supplied at the entrance of every ward.

Paediatric Blood Pressure Cuffs The paediatric, medical, and neurology departments have no paediatric blood pressure cuffs, and therefore do not have the capability to measure the vitals of these patients. The departments use adult cuffs on some older children, but the readings are consistently low and inaccurate. We recommend that KCMC invest in the procurement of paediatric blood pressure cuffs for each of these departments so that children can be monitored correctly. The risks faced by failing to monitor infant and child patients are too high to ignore the lack of paediatric blood pressure cuffs.

Figure 5.4: Paediatric blood-pressure cuff

Figure 5.5: Circumference

Figure 5.6: The paediatric-size bag that needs to be designed and attached to a tube.

CHAPTER 6

Conclusion

In conclusion, this case study of the work done by the 2014 Engineering World Health team at Kilimanjaro Christian Medical Center and Mawenzi Hospital demonstrates the obstacles faced by developing world hospitals in regards to donated medical equipment. Many repairs involved simple mechanical or electrical fixes, which can be replicated by following the included procedures. Some larger projects involved a combination of repair techniques. The use of quick start guides and training highlight the importance of educating hospital staff, since equipment problems often involved user errors. During our time in Tanzania, we were able to repair a mere fraction of the broken medical equipment in these hospitals. Further work is needed by local and visiting technicians to continue to improve the quality of healthcare provided at Kilimanjaro Christian Medical Center and Mawenzi Hospital.

Appendices

APPENDIX **A**

Inventory of Broken Equipment

Equipment Type	Manufacturer	Model	Department	Description
		KCMC		
Suction Pump	Atmos	C451	SICU-A	Replaced clogged filters, ensured tight tubing connections, made quick start guide for operation
Incubator	Atom	V -85MC	SICU-A	Missing hole covers, broken latch, missing humidifer, alarms
Cast cutter	Fein	FMM250	Engineering	Change 3 prong plug to 2 prong plug
External Harddrive	WD	Passport	Engineering	Download software to recover files
Sphygomanometer	Geratherm desktop	GP 6621	Medical	Leakage in bag
Isoflourine container	Penlon	Sigma Delta	Surgical	Broken spring, missing screw for latch system
Oxygen Concentrator	Nidek Medical	M5C5/Mark5	Medical	Cut off filters at ends of bottle tubes
Blood Pressure Device	CE	dinamap xl	Medical	Patched hole, sewed cuff
ECG Machine	W Neoscope		Pediatric	Needs electrodes
Oxygen Concentrator	Nidek Medical	M5C5/Mark5	Medical 2	Untight connection in tubing
Suction Machine	Einar Egnell	EKP-5pF	Medical 2	Collection bottles connected in series
Blood Pressure Device	Geratherm desktop			Missing cuff, 4 AA batteries
Nebulizer	Mercury Med	EZ Flow	Medical	Blocked tube
Blood Pressure Device			Pediatrics	Loose Dial
Infant Warmer	GE Lullaby	2041599-001	Labor	Thermometer placed before machine, heating element always on
Oxygen Concentrator	Nidek Medical	M5C5/Mark5	Medical	Cut off filters at ends of bottle tubes, replaced filter in back, tightened screws
Oxygen Concentrator	Nidek Medical	M5C5/Mark5	Medical	cut off filters at ends of bottle tubes, replaced filter in back, tightened screws
Oxygen Concentrator	Nidek Medical	M5C5/Mark5	Medical	cut off filters at ends of bottle tubes, replaced filter in back, tightened screws
Pulse Oximeter			Medical Endoscopy	Extension cord broken, removed extension cord, cleaned probe
Nebulizer			Medical	Missing part
Nebulizer			Medical	Missing part
Nebulizer			Medical	Missing part

Continued on next page

Table A.1 – continued from previous page

Equipment Type	Manufacturer	Model	Department	Description
Pulse Oximeter	Novametrix Medical System Inc	2001 Mars Tech		Recharged battery, in progress
Blood Pressure Device	Boso			Loose Screw
Infusion pumps	Ivac Tiva	P6000	Pediatric	Cleared RAM, recharged RAM battery, missing calibration tools, repaired but unable to be used
Pressure Gauge	GCE Nedi-line	Oxylitre		Epoxied broken connection
Blood Pressure Device			Medical	Loose screw in diaphragm
Blood Pressure Device			Medical	Leak in tube, cut tube
Blood Pressure Device			Medical	User error
Blood Pressure Device			Medical	Bent needle
Blood Pressure Device	Geratherm desktop	GP 6621	Medical	Replaced leaky bag
Blood Pressure Device	Geratherm desktop	GP 6621	Medical	Replaced leaky bag
Thermometers	A.I.N.E.		Medical	Dead batteries
Thermometers	A.I.N.E.		Medical	Dead batteries
Thermometers	A.I.N.E.		Medical	Dead batteries
Thermometers	Microlite AG	MT3001 EZ	Medical	Missing batteries
Blood Pressure Device			Surgical	Replaced tubing inside machine housing
Vital Signs Monitor	Medical Data Electronics	MDE Escort Polymount		Changed 3 prong plug, blood pressure cuff, needs new SpO2 probe
Blood Pressure Device				Replaced tubing
Vital Signs Monitor	Dinamap	728-634A	Medical 2	Blown fuses, discharged battery, transformer not working, cap burned, tubes not connected
Vital signs monitor	HP Omnicare	M1204A		connection to power source
Oxygen concentrator				Epoxied humidifier bottle
Doppler system			Radiology	Reset gain function
Mawenzi				
Stethoscopes			Medical	Replaced missing screw
Infant Warmer		HKN90	Maternity	Replaced diode and fuse holder
Stethoscopes			Medical	Replaced earpieces with shaped tubing
Thermometer	Hartmann	Thermoval Basic		Changed batteries
Suction Machine			Maternity	staff training, leaky jar lid
Suction Machine			Medical	staff training, leaky jar lid
Suction Machine			Medical	staff training, leaky jar lid
Suction Machine			Surgical	staff training, leaky jar lid
Blood Pressure Device			Maternity	Leaky tubing
Blood Pressure Device			Maternity	Leaky tubing
Blood Pressure Device			Medical	Loose screw
Beds (75)			Medical	Loose screws
Water filter			Medical	Epoxied holes in container
Suction Machine				Air leak inside machine
Blood Pressure Device	Risestar	Precisan	Maternity	Replaced blood pressure cuff
Water Bath	ShakIt		Eye	Replaced power cord
Curtain	Titanox SRL	M600826/C	Psychology	Repaired with metal rod tape
Curtain	Titanox SRL	M600826	Medical	Repaired with string and tape
Infant Warmer	ARI Medical		Maternity	Clogged fuse, power supply, user error

Continued on next page

Table A.1 – continued from previous page

Equipment Type	Manufacturer	Model	Department	Description
Table			Medical Ward 2	Welded connections

Table A.1: Complete list of fixed equipment by Engineering World Health students at Kilimanjaro Christian Medical Center and Mawenzi Hospitals from July - August 2014

APPENDIX **B**

Creating Homemade Disposable Parts

B.1 ECG Electrodes

Disposable parts such as electrode pads and conductive gel are extremely difficult to find at KCMC, but can be easily made with local resources. ECG electrode pads can be fashioned out of soda bottle or beer bottle caps and size-3 nickel-plated brass sewing snaps. The following instructions explain how to make an ECG electrode with commonly available materials.

Electrode Materials

1. Beer or soda bottle caps
2. Size 3 nickel plated brass sewing snaps
3. Flathead screwdriver
4. Boxcutter
5. Pot, water, and stove

Boiling the bottle caps for thirty minutes allows the thin plastic lining on the inside of the cap to be peeled off. These plastic circles are perfect for the base of the electrode pad. Create a small hole in the middle of the pad to allow for the brass snap. These electrode pads can be attached to the skin of a patient using medical tape and conductive gel.

B.2 ECG Conductive Gel

Conductive Gel Materials

Conductive gel can be made with household kitchen items, or can be substituted by a variety of common household products. The conductive gel used for the ECG electrodes can be made with a simple recipe from water, flour, salt, and bleach. If these materials are not available, aloe vera gel may be used as a substitute.

1. Water, 1 cup
2. Salt, 2 Tbs
3. Flour, 1 cup
4. Bleach, just a drop

Instructions

1. Mix the water and salt in the glass bottle.
2. Slowly pour in the flour. It will become gelatinous. Mix it until it the consistency is even throughout.
3. Add a drop of bleach to sterilize the gel.

B.3 Suction Pump Gauze Filters

Each suction pump is equipped with a gauze filter that prevents the transmission of fluids from the collection jar into the motor and main body of the machine. These filters are meant to be disposable and changed after every patient. However, in the developing world where consumable materials are largely unavailable, these filters are used repeatedly until they become clogged and cause the machine to stop functioning. The guide below gives instructions on how to make home-made disposable filters out of gauze, which is available in almost every department. These filters should be replaced after every patient or after the filter becomes dirty when being used on the same patient for a prolonged period of time.

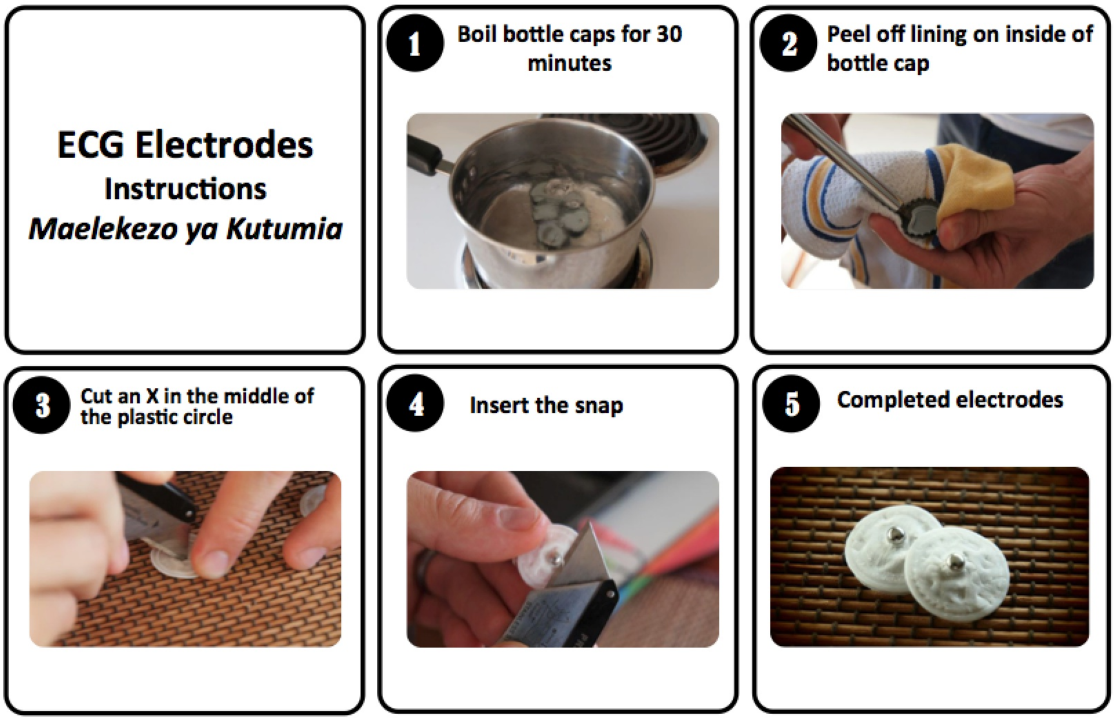

Figure B.1: Instructions on how to make ECG electrode pads

Figure B.2: Ingredients for conductive gel

Figure B.3: Final consistency of conductive gel

Figure B.4: Application of homemade ECG electrodes

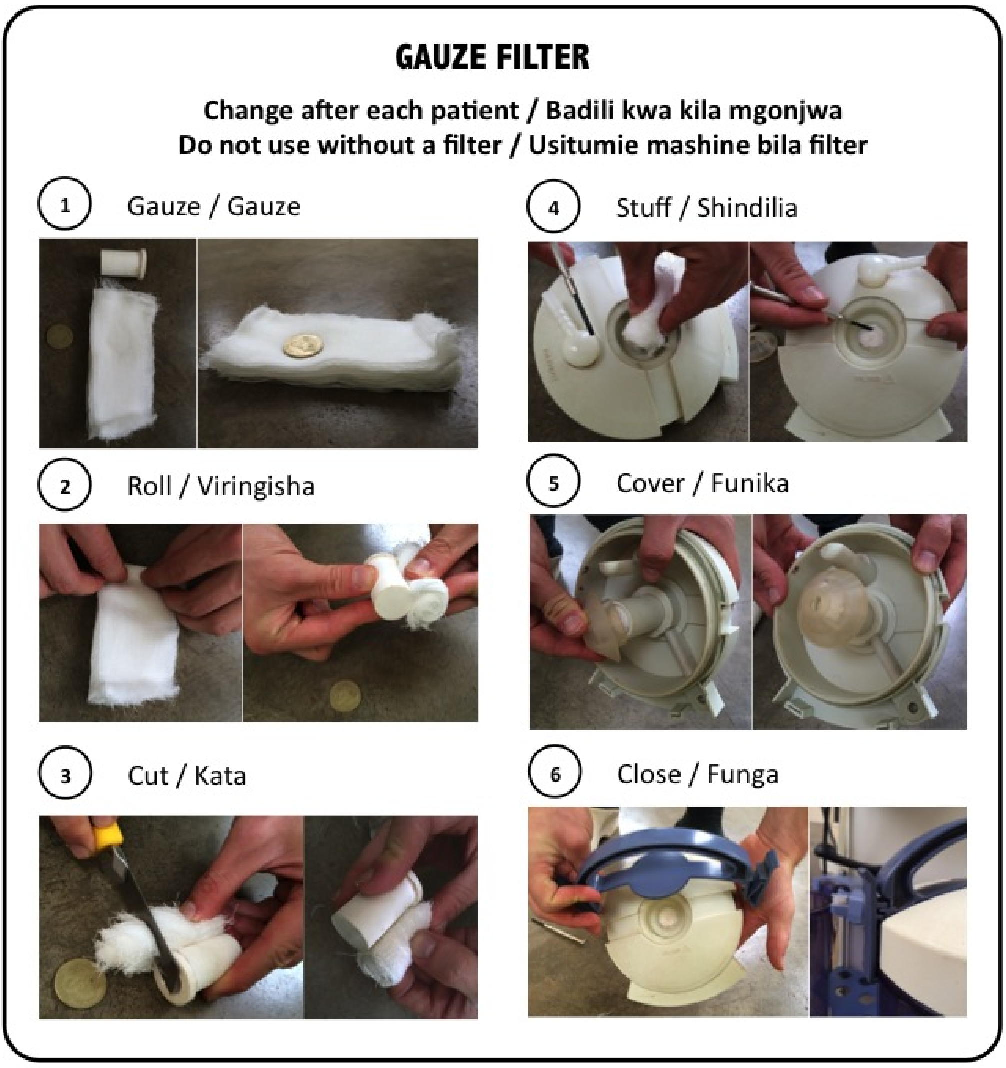

Figure B.5: Quickstart guide for making disposable gauze filters

B.4 Oxygen Concentrator Gauze Filters

Gauze can also be used to replace the oxygen concentrator filters. The filter shown below is encompassed in a black plastic box that must be cut along the seam with a box cutter to access the filter inside. The accordion folded filter will most likely be full of dust and should be removed and thrown away. The stuffing can remain inside as long as it is still clean. The accordion folded filter should be replaced with a stack of gauze cut to fit the size of the box. The entire component can then be repaired using electrical tape and placed back into the machine.

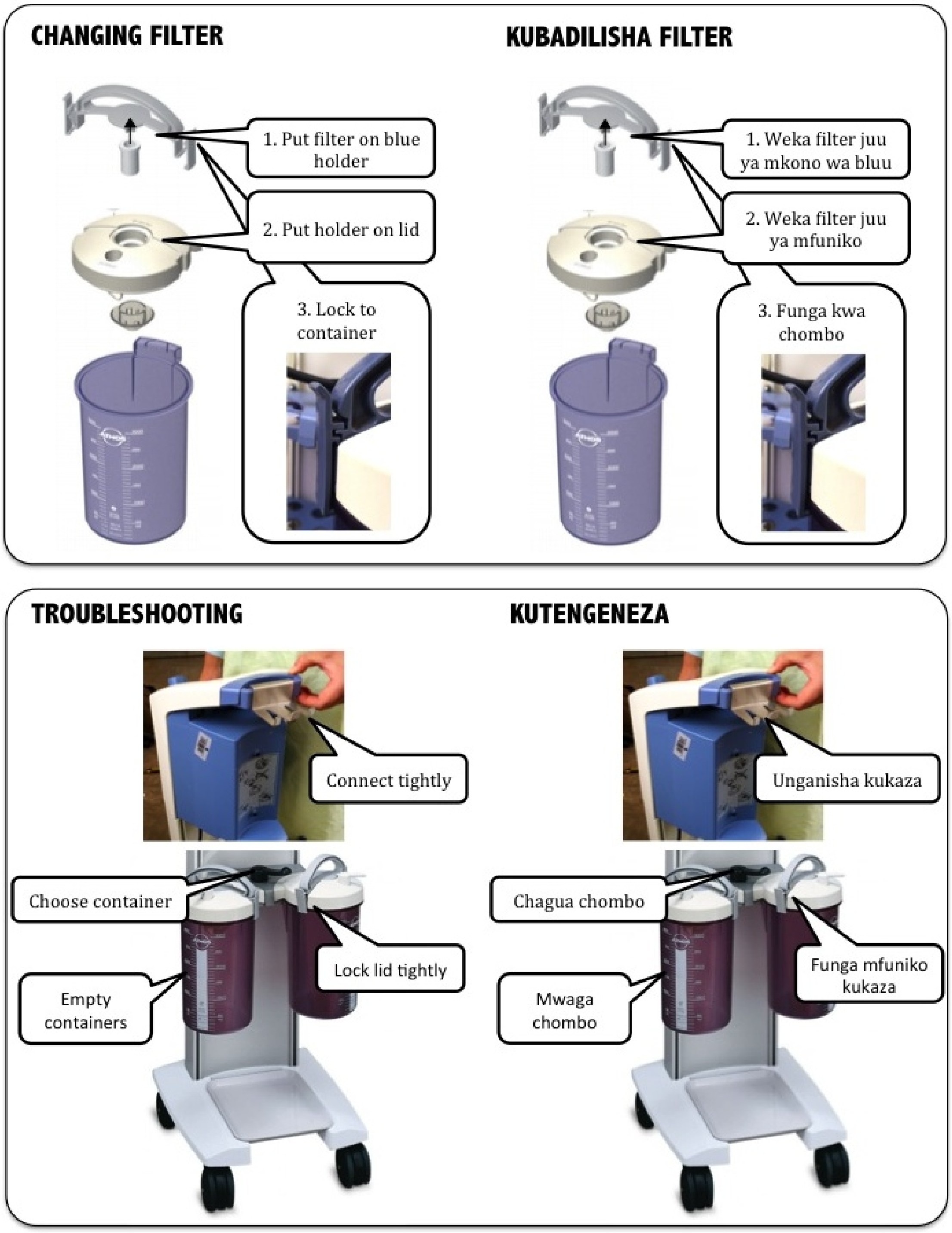

Figure B.6: Instructions on how to change filters and troubleshooting for the Atoms suction pump

Appendix **C**

Recharging Batteries

Several machines, including the MarsTech2001 Pulse Oximeter and IvacTivaP6000 Infusion Pump, needed recharged lead acid and nickel metal hydride batteries. Recharging batteries can be done with minimal calculations and a variable power supply, built from the instructions below which are provided by the Engineering World Health Student Lab Book.

C.1 Building a Variable Power Supply

Almost every piece of medical electronics today contains a power supply. This is because most hospitals receive their power in the form of alternating current (AC). AC is cheaper to transmit from a generator to a piece of equipment like in the operating room. However, almost all pieces of equipment require direct current (DC) power. The power supply converts AC power (that is transmitted) to DC power (so that it can be used). Most power is delivered as either 120 or 220V, however most medical equipment runs at 5, 9 or 12V. The power supply also corrects this voltage so that it matches the needs of the device it powers. An internal transformer is used to either step up or step down the power supply voltage, where an internal rectifier is an arrangement of diodes which converts sinusoidal AC power to a constant DC power.

The power supply converts AC power to DC power at the correct voltage. In Tanzania, voltage is supplied at 230V and 50 Hz. The power supply can be divided into two basic component: the rectifier and the regulator. The basic function of the rectifier is to convert the negative polarity of the AC current into a positive polarity (or vice versa) in order to obtain a constant, time-independent single polarity output i.e. DC signal. In order to rectify the transformer/wall output to what our load requires, we use diodes. Consider diodes to be similar to a one-way switch (or valve), instead of a non-linear element. In other words, if the voltage is positive, the current through the diode is large. If the voltage is negative, the current is very small. If you consider diodes to be ideal one-way switches, then any time the voltage is negative, the diode would allow no current to flow. However, in real life diodes are not ideal and require a threshold voltage to turn on.

It is important to build a diode bridge, or full wave rectifier, to convert all available AC power into DC power. A diode bridge converts any negative humps to positive humps to achieve full wave rectification.

Building the Rectifier

Materials To test the rectifier circuit, add a 1 kOhm resistor across the bridge, and measure the AC and DC voltages being delivered to the load resistor. To complete the power supply, connect a large capacitor (100µF electrolytic capacitor) across the output of the bridge circuit. The capacitor will pass all frequencies above a certain frequency and block all signals below that frequency. Capacitors can also absorb voltage signal spikes and reduce “noisy” circuits. Remember that the capacitor has polarity before adding it to the circuit – the indicator arrow always points toward the negative end on capacitors. If a 1 kOhm resistor is now added across the circuit terminals, measuring the AC and DC voltage across the load resistor will have converted almost all available AC power to DC power.

Adding the Regulator The power supply at this point in time has two major limitations. First, there is a considerable amount of AC remaining in the output voltage. Second, the output voltage is fixed and not, perhaps, appropriate to the specific medical equipment load. By using a voltage regulator, the voltage output of the power supply can be varied according to the output needed for a specific machine. A voltage regulator is a small piece of electronics that uses amplifiers and feedback to remove most of the remaining AC. The regulator also allows the user to select the voltage output. Because the output of the diode bridge and capacitor combination is a higher voltage than the output of the regulator, the regulator must absorb some of the power. For this reason, it gets quite hot and requires a heat sink to carry the heat away. The list of materials below can be seen in the figures of the circuit schematic.

Materials

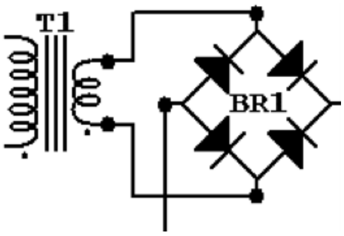

Figure C.1: Schematic diagram of rectifier circuit

- Transformer
- 1 kOhm Resistor
- PCB Board
- Heat shrink tubing
- 100 uF 50 VDC capacitor
- 4 Power diodes, 3A 50V
- Alligator clips

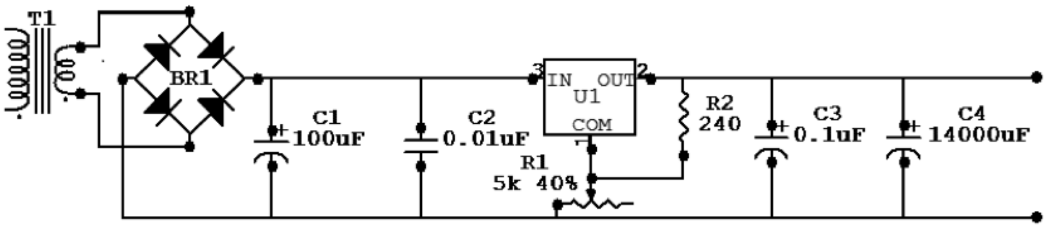

Figure C.2: Schematic diagram of variable power supply circuitry

- Capacitor, 14000uF 40V DC
- Capacitor, 0.1 uF
- Capacitor, 0.01uF disc
- Resistor, 5kOhm pot
- Resistor, 240 Ohm, 0.25W
- Regulator, 1.2 V - 32V 5A
- Regulator heat sink
- Transformer
- Fuse and holder
- 2 Alligator clips
- PCB board
- Wire

C.2 Recharging Batteries

The batteries should be charged at a maximum rate of 10% of the battery rating in amp-hours for 10 to 12 hours. For example, a battery with a rating of 400 mAh would be charged at 40 mA for 10 to 12 hours. To calculate the appropriate charging current and charging time, the following formulas can be used.

$$I_C = R \cdot C \tag{C.1}$$

$$T_C = \frac{1.1}{R} \tag{C.2}$$

where Ic is the charge current in mA, R is the charge rate (usually 10%), C is the battery capacity in mAh, and Tc is the charging time.

#	Name	Specs	Function
T1	Transformer	24V, 100mA	Steps-down the mains power
BR1	Diode bride	3A, 50V	Converts AC to DC voltage
C1	Electrolytic capacitor	100μF, 50V DC	Smoothing capacitor
C2	Ceramic disc capacitor	0.01μF	Smoothing capacitor
C3	Electrolytic capacitor	0.1μF	Noise filter
C4	Electrolytic capacitor	10000μF, 35V	Circuit stabilization and load regulation
R1	Variable resistor	5kΩ	Alters the resistance
R2	Carbon-film resistor	240Ω, $\frac{1}{4}$W	Resistor
U1	Voltage regulator	1.2V - 32V, 5A	Regulates voltage; introduces high frequency noise

Figure C.3: Chart of components for variable power supply

The power supply provides a constant voltage to the battery and therefore a resistor is needed to limit the current supplied to the battery. When the battery is connected to the power supply with a resistor, the charging current can be described by:

$$I_C = \frac{V_s - V_c}{R} \tag{C.3}$$

Where I is the charging current; V_s is the power supply voltage; V_c is the cell voltage and R is the resistance.

Select a maximum charging rate for your cell between 1% and 10% of the battery capacity C. From the rate R and cell capacity C, derive the maximum charging current the battery will tolerate using the formula C.1. Using the minimum expected voltage for the cell, it is possible to select the voltage for the power supply and resistor in order to satisfy the charging current equation C.1.

The most common cause of destruction in chargers is too much power being drawn from the charger or too much power being put through the resistor. Calculate the maximum amount of power dropped in the resistor by using following formula:

$$P_R = \frac{(V_s - V_c)^2}{R} \tag{C.4}$$

Calculate the max power in the charger using:

$$P_C = V_S \cdot I_C \tag{C.5}$$

Ensure that the resistor and regulator can handle the amount of power being supplied to the circuit so that it does not damage the resistor or power supply. In addition, measure the starting voltage of the battery to avoid charging a completely dead cell. It is a good idea to check the temperature and current of the circuit during charging to compare with the theoretical values calculated above and to avoid overheating.

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