Remanufacture of Medical Equipment: A viable sustainable strategy for medical waste reduction

Akinwale Coker[1] Chibueze Achi[1*], Olusola Idowu[1,2], Olabanji Olayinka[2], Kingsley Oturu[3] and Winifred Ijomah[3]

1. University of Ibadan, Ibadan, Nigeria
2. University College Hospital, Ibadan, Nigeria
3. University of Strathclyde, Glasgow, UK

Corresponding author: achicgjr@gmail.com

Abstract

The lack of and need for modern quality medical equipment in developing African countries has steadily increased with increasing population, leaving these countries to depend heavily on donated medical equipment from developed countries. Most of these second-hand and old medical devices which are most often not suitable for or suited to use in developing countries have a short life span and this has resulted in the large stockpiles of abandoned medical equipment waiting to be discarded as waste. The need to adopt a more sustainable approach for the management of this ever-increasing waste stream in many hospitals in most developing countries cannot be over emphasized. The recovery and utilization of discarded medical equipment for the remanufacture of medical products stands to significantly minimize environmental pollution and the amount of waste materials to be sent to the landfills. This study focused on assessing the current management practices of medical waste and the potential for the implementation of medical equipment remanufacture in Nigeria. We will be using Nigeria's premier teaching Hospital – University College Hospital as a case study and highlighting barriers such as poor infrastructure, and safety approval standards and processes, and other key factors that could influence the implementation of remanufacture within the Nigerian context, where local knowledge and understanding of needs, context and available resources could be more effectively incorporated into designs and implementation plans for a sustainable and robust remanufacture scheme.

Keywords: Remanufacture, sustainable development, medical waste management, recycling, product recovery

1.0 Introduction

Medical equipment also referred to as medical devices are essential in every healthcare facility, for the prevention, diagnosis, management and treatment of illnesses and diseases. As a response to the growing need to improve healthcare outcomes, notable advances and innovations in the accuracy, precision, efficacy and effectiveness of medical devices have been recorded over time, leading to a significant reduction in rates of mortalities.

Most of these advances have been recorded in developed countries, while, healthcare systems in low-income countries (LICs) often have limited access to even seemingly commonplace medical devices. The lack of modern quality medical equipment has been the bane of most developing nations. With steadily increasing populations in the developing world, the need for quality medical equipment is increasingly becoming critical, requiring urgent attention.

Currently, many developing countries in Sub-Saharan African region depend heavily on donated medical equipment from developed countries to meet their needs for medical equipment. Most of the donated medical equipment are most often not suited to, or suitable for developing countries. For instance, the discrepancies in the need for anesthetic machines and the conditions of use in developed countries have been reported to be quite different when compared with developing countries. (Adams and Dobson, 2019). Anaesthetic equipment in LICs needs to be able to withstand extreme humidity and temperatures, be easy to use, physically robust, and serviced locally, with readily available, affordable spare parts. Lack of reliable Electricity and Compressed gas supplies which are often in short supply are typical conditions faced by most LICs including in Nigeria; and so intensive care equipment needs to be able to function without either.

According to a report from eastern Uganda by Compton et al, 2018, most of these donated medical equipment are often old, obsolete, do not align with the frequency or voltage of the receiving facility or have out-lived their expected life span and have been known to suddenly fail during a procedure. Due to lack of a trained technician to troubleshoot the machine, lack of machine manuals, and the time and exorbitant cost of importing a replacement for the damaged parts, they end up in stockpiles unusable

and waiting to be disposed as waste or scrap. Such is the case in many developing nations that depend on donated medical equipment.

The current COVID-19 pandemic has left many developing countries even more vulnerable to risk of higher mortality rates, resulting from the lack of medical equipment, (Elhadi et al, 2020). In response to the global health priority needs, and the need to make the most of the discarded medical equipment, there is a critical need to integrate the concept of medical equipment remanufacture in Nigerian hospitals as a potential sustainable strategy to minimize the volume of stockpiles of abandoned medical equipment and also increase the availability and affordability of appropriate technologies.

Plate 1: Damaged and abandoned baby Incubators waiting for disposal

Plate 2: Stockpile of abandoned medical equipment

In addition to the sustainable development goal focusing on global health priority needs, there is also the goal of 'responsible production and consumption' (Goal 12 of Sustainable Development Goals) to be achieved through the remanufacture of discarded medical equipment which would have been stored in the stockpiles ready to be disposed of as waste. This is a strategy that will reduce the requirements for virgin materials, energy consumption, and landfill space.

Remanufacture is the process of rebuilding of a product to specifications of the original manufactured product using a combination of reused, repaired and new parts bringing the product to a condition where its performance is comparable to the original product with a matching warranty with a reduced price and potential environmental impacts. (Matsumoto and Ijomah, 2013). When the concept of remanufacture is localized in a developing country, it provides the opportunity for local jobs and skills creation, (Lund, 1984) through the process of recycling and recovery of damaged medical equipment.

The concept of Remanufacture, as a cost-effective and resource-efficient alternative for advancing innovation and industrialization, is well established in developed countries, whereas in developing

countries, it has only been applied to automobiles, auto parts and electrical appliances. Remanufacture of medical equipment is yet to be established in Nigeria, although the production of some less complex medical equipment such as hospital beds, wheel chairs and stretchers have been achieved. The implementation of medical equipment remanufacture in Nigeria has faced some barriers such as poor infrastructure, and lack of safety approval standards and processes. Hence the need to investigate other key factors that could influence the implementation of remanufacture within the Nigerian context where local knowledge and understanding of needs, context and available resources may be incorporated into designs and implementation plans for a sustainable and robust remanufacture scheme.

1.1 Medical Equipment Supply and regulation in Nigeria

Medical Equipment manufacturers, regulators and end users are the major players in every medical equipment life cycle (Shah et al, 2009). The role of medical equipment regulators is critical, since they are to ensure that medical equipment to be deployed to the market are compliant with design standards and specifications for safety and appropriate quality standards. The regulations are meant to guide the activities of medical equipment importation and donations from foreign countries and also local manufacture and remanufacture. Medical equipment regulations have been reported to be weak and sometimes non-existent in many developing countries, (Eze et al, 2019), including in Nigeria.

In the light of the many challenges facing the health sector in the areas of procurement, supply chain and monitoring of medical equipment appropriateness in Nigeria, the Bureau for Public Procurement in collaboration with the Federal Ministry of Health, Standards Organization of Nigeria (SON) and the Nigerian Nuclear Regulatory Authority (NNRA) worked together following the direction of the Nigerian President to revise and develop a policy for the procurement of health and medical equipment including a list of manufacturers and equipment for tertiary hospitals which was recently approved. In spite of these regulations and importation policies, there are still many items of obsolete medical equipment in many hospitals in Nigeria which may have resulted from lack of strict adherence to the policies and regulations.

Medical device regulation is a vital tool for ensuring a uniform standard for medical devices that are available in the market, especially in developing countries where various devices are donated from different countries with varying specifications and designs. Since 70% of medical devices designed for use in developed countries don’t work when they reach developing countries, due to some peculiar

environmental factors (WHO 1979) there is a need to remanufacture the medical equipment with consideration and attention paid to those peculiar environmental factors and challenges.

To investigate the prospects, challenges and opportunities in adopting remanufacture of medical equipment in Nigeria as a sustainable and viable strategy to reduce the volume of discarded medical equipment needed to be disposed, this study focuses on conducting an assessment of medical equipment lifecycle at University College Hospital, (UCH) Ibadan. The investigation focused on how medical Equipment is supplied/purchased, maintained, tracked and the mechanism for periodic maintenance of medical equipment, including medical equipment repairs, storage of stockpiles and disposal of damaged medical equipment

3.0 Methodology

Qualitative and quantitative approaches were used in this research. The empirical data for this study were obtained from the head of each respective department/unit at a tertiary teaching hospital in southwestern Nigeria. Other key information pertaining to how medical equipment are purchased or acquired, including the chain of command for equipment purchase, the maintenance schedule, periodic calibration, storage and disposal of damaged equipment were collected using key informant interview (KII) from stakeholders such as clinicians, department heads, biomedical engineering unit, procurement and maintenance department. The data collected were presented using charts and tables.

4.0 Results and Discussion

4.1 Medical equipment purchase, tracking, maintenance and the general management practices at a tertiary teaching hospital in South western Nigeria

4.1.0 Purchase of medical equipment

As reported by the key stakeholders at University College Hospital Ibadan, over the years, the purchase or procurement of medical devices has always been done by the hospital management with little or no input from the User Department. In rare cases of Donations, all the donated equipment is transferred to the department that needs them while involving the contractors for its maintenance.

However, most of these practices have changed in the last four years. Realizing the importance of taking into consideration the inputs from key stakeholders prior to making the decision about the equipment to be purchased, the UCH management would invite the following stakeholders; Biomedical Engineering Department, User Department, Procurement, and Finance personnel.

Generally, medical equipment purchases are usually made after keen selections conducted by the Management Tenders Board where the Head of Department of Procurement opens the bids of any equipment in the presence of Federal Government Representatives, Hospital Management, and relevant Professional Associations/Bodies in attendance.

4.1.1 Tracking, Periodic Maintenance and Calibration of Medical Equipment

To begin with, hospital equipment was tracked through internal audit conducted by the Audit's Department. In more recent times the biomedical engineering department joined in the management and tracking of medical equipment. The department of Biomedical Engineering was created in 1996. The emergence of digital technology at that time made its creation necessary. Before now, it was known as Electro-Medical Unit under the Instruments Department. Medical devices available then operated mostly on mechanical principles and less of electronics and so did not require high technology, until later when these mechanically controlled devices and parts were gradually replaced with computer-based systems requiring microprocessors. In 2016, the department formerly known as **Biomedical Electronics Instruments Department** was renamed **Biomedical Engineering Department.**

Currently, through the Information Technology Department, the hospital Management has initiated steps to capture and store Patient's data electronically. However, there is no database for tracking and storing information about medical equipment. There is an obvious need to capture and develop a robust database for medical equipment to facilitate periodic maintenance, calibration and tracking of medical devices.

Table 1: Stock count of Medical Equipment at various Units and Department of the Hospital

Department/Unit	Total Number of Equipment	Total Number of Functional Equipment	Non-Functional	% Functional Equipment	% Non-Functional Equipment
Emergency Theatre	31	15	16	48.3	51.7
Microbiology	33	24	9	72.7	27.3
Pathology	18	8	10	44.4	55.6
OWENA DIALYSIS	29	17	12	58.6	41.4
OPHTAMOLOGY SUITE	22	12	10	54.5	45.5
FAMILY MEDICINE	54	46	8	85.1	14.9
SENATOR ABIOLA AJIMOBI BUILDING	9	4	5	44.4	55.6
Children Out-Patients (CHOP)	4	3	1	75	25
MOP	11	6	5	54.5	45.5
SOP	8	7	1	87.5	12.5
Blood Bank	1	1	0	100	0
Burn Unit	11	10	1	90.9	9.1
Haematology	14	11	3	78.5	21.5
ROW	5	4	1	80	20
South East	22	5	17	22.7	77.3
West	26	18	8	69.2	30.8
C1	17	13	4	76.4	23.6
ICU	47	47	0	100	0
ICB	4	4	0	100	0
GTH	9	9	0	100	0
GERIATRIC	30	30	0	100	0
Theatre Suites	28	28	0	100	0
EAST	8	7	1	87.5	12.5
ECG	9	8	1	88.8	11.2
Emergency Dept	21	14	7	66.6	33.4
Endoscopy Suite	31	14	17	45.1	54.9
Labour Ward	47	43	4	91.4	8.6
North West	3	1	2	33.3	66.7
Special Care Baby Unit	28	19	9	67.8	32.2
West West	6	4	2	66.6	33.4
South West	15	4	11	26.6	73.4
Antenatal Clinic THEATRE	8	6	2	75	25

Child Oral	9	5	4	55.5	44.5
Conservative	17	15	2	88.2	11.8
Dental Theatre	5	4	1	80	20
Oral Diagnosis	9	7	2	77.7	22.3
Oral Surgery	19	18	1	94.7	5.3
Orthodontics	8	6	2	75	25
Periodontology	13	12	1	92.3	7.7
Private Suite	12	10	2	83.3	16.7
Prosthetic	8	8	0	100	0
OTCHEW	4	4	0	100	0
Adeoye Lambo Ward	2	2	0	100	0
FMD	5	2	3	40	60
GOPD NHIS	4	4	0	100	0
CHEMPATH	13	12	1	92.3	7.7
GOP EYE	3	3	0	100	0
Pharmacy	9	9	0	100	0
SEG	3	3	0	100	0
Staff Clinic	27	27	0	100	0

4.1.2 Medical Equipment repairs, Storage of stockpiles and disposal of damaged/Obsolete Equipment

Medical equipment repair is carried out by the Biomedical Engineering Department. They are also in charge of assessing the conditions of medical devices and deciding when to send the obsolete equipment to decommission, although often the damaged equipment is not brought to the Department for proper assessment resulting in damaged equipment remaining in stockpiles at the user departments.

Furthermore, due to lack of replacement parts, and difficulties in importing replacement parts most of the medical equipment which could have been salvaged, ends up in stockpiles as damaged or obsolete equipment. Some of this equipment are sent to the board of survey of the hospital for disposal through the process of boarding by bidding and the final clearance is given to the highest bidders. However, the bulk of the damaged equipment is stored indefinitely at the various departments.

4.2 The need and Barriers to medical equipment remanufacture in a tertiary hospital in south western Nigeria and possible solutions

There has always been a need to establish a remanufacture program in Nigeria, this was brought to the front burner since the outbreak of COVID 19 pandemic. The evident lack of appropriate functional devices and presence of huge stockpile of medical equipment considered as 'waste' and occupying the functional space for equipment, necessitated the drive to remanufacture the existing equipment.

In order to gainfully institutionalize remanufacture as a strategy to reduce these stockpiles, there is a need to understand some of the potential barriers that could militate against the implementation of remanufacture. Some of these key factors to consider are;

- Lack of Spare Parts
- Lack of tools and expertise to achieve repair
- Lack of database to track all the Medical Equipment available at the Hospital
- Need to harmonize and adopt International standards before medical equipment are manufactured and remanufactured
- Lack of Government Policies and Funding support are the major threats in acquiring Medical Equipment purchase.
- Issues with Equipment Warranty and expiration of soft wares

5.1 Strategies to ensure the adoption and Use of Remanufactured Medical Equipment in Nigeria

The principle of remanufacturing allows for the management of resources, thereby contributing to the life cycle of its functionality and in maintaining the value of resources, materials, and final products for as long as possible, and also to minimize the generation of waste. The beneficial economic and environmental importance of remanufacturing has been reported by some authors. (Kim et al., 2008; Kim et al., 2009; Gutowski et al., 2011).

The adoption and use of remanufactured medical equipment in Nigeria will help to further redistribute this equipment across the country at a lower cost. Many of the healthcare facilities, especially in remote locations do not have the wherewithal to purchase some of the medical equipment that are needed for the delivery of the day-to-day healthcare needs of their population. Therefore, remanufactured medical equipment would cost less and would also help many of these health facilities to adopt this equipment. The implication of this would be that an improvement in the delivery of better health care services across the nation will be achieved, as the availability of functioning medical equipment will help to enhance productivity and to further save lives.

Some of the strategies that can be employed that would aid the adoption and use of this remanufactured medical equipment in Nigeria include:

- **Engagement among medical personnel across the various states:** Getting the medical personnel involved in remanufacturing processes will help to create rooms to see the potential benefits in adopting the remanufactured medical equipment that has been abandoned and damaged.
- **Sensitization on the level of fidelity with the use of remanufactured medical equipment:** Many end users are wary of second-hand equipment. This is also important in this context because the equipment will be used to serve the purpose of improving health care delivery among people. The sensitization on the level of reliability and safety with the use of the remanufactured medical equipment will help to develop a trust level and basis for its adoption and usage. The convincing report of its efficiency and ability to serve the same purpose as new equipment will further help to embrace the use of remanufactured medical equipment.
- **Training of medical personnel on how to remanufacture medical equipment;** The training of medical personnel on how to go about remanufacturing medical equipment will also help medical personnel to understand to intricacies of remanufacturing. This will further help to establish independent medical personnel that can engage in remanufacturing of medical equipment across different health centres within the various health facilities in the various states.
- **Aidfrom the government:** The support from the government on funding and with policies that will guide the favourable adoption and use of remanufactured medical equipment will further promote the overall goal of remanufacturing processes and its adoption
- **Applied learning theory:** This will involve the integration of remanufacturing into different learning curricula, which will help to reverse the situation of medical equipment wastage and to

highlight the need for proper orientation on the reasons to adopt and use remanufactured medical equipment.

5.2 Policies, standard testing, database for tracking

The introduction of policies, standard testing, and a database for tracking obsolete and remanufactured equipment would help in ensuring standard practices for the remanufacturing goal. In relation to medical devices, the assessment of their safety and risk management is needed for considerations. Many medical devices can give a level of degree of risk and this cannot be fully ascertained until feedback from their extensive use is obtained.

Policies and regulatory processes are needed to guide and reduce the level of risk associated with any product. These policies are ensured to checkmate any form of risk and to ensure the safety following the use of the products. The core elements of medical device regulations involve some forms of regulatory networks and tools of the Global Harmonization Task Force (GHTF). Firstly, the understanding of the different phases in the life span of a medical device and the common framework are crucial and regarded as the primary steps to successful harmonization and simplification.

The basic elements for regulatory attention on the safety and performance of medical devices depend on two major factors which are the product and its use. The engagement in pre-market review contributes to product control, and post-market surveillance ensures that medical devices in use continue to be safe and effective. The representation of the product to the user is also important.

The establishment of policies should be guided towards ensuring and establishing:

- Specialized training from the manufacturer for proper use and services
- Effectiveness/performance and product control
- Overseeing manufacturers and vendors
- Device listing and establishment control
- Advertising control
- Quality system requirements in terms of organizational structure, responsibilities, procedures, processes, resources, design, manufacture, packaging, labelling, storage, installation, servicing, etc.
- Ensure that medical devices sold or made available in the country are safe and effective
- Qualifications and training in the proper use of the device

- The user has the responsibility to employ the medical device only for the intended indications (or to assure that any non-indicated use of the medical device does not compromise the safety of the patient and other users)
- The role of the manufacturer which involves phases of the design, development/testing, manufacturing, and labelling with relevant information when packaged.
- Shared responsibility for medical device safety and performance
- Vendor establishment control
- Participation in post-market surveillance
- Periodic review of policies to respond to changes in technologies by incorporating appropriate amendments.

The standard systems involved in the development process and their use in relation to conformity assessment is now necessary for establishing medical device regulations. Standards are documented agreements that contain technical specifications or other precise criteria to be used consistently as rules, guidelines, or definitions of characteristics. This will help to ensure that materials, products, processes, and services are fit for their purpose.

The types of specifications in standards can help to establish a wide range of specifications for products, processes, and services. These include:

- Prescriptive specifications such as materials, dimensions, test or calibration procedures, and definitions of terms and terminologies.
- Design specifications such as operating room facilities or medical gas systems.
- Performance specifications such as strength requirements, measurement accuracy, battery capacity, or maximum defibrillator energy to ensure that a product meets a prescribed test
- Management specifications e.g. quality systems for manufacturing or environmental management systems.

The need for standards is to ensure that:

- Products or services are meeting the required needs
- Assurance on the continual reliability of the product
- Provide information that will enhance the safety of use

For a proper harmonization of all the recommendations to facilitate the distribution of products, the establishment of a comprehensive national policy or guideline on medical device management is

essential. The shouldered responsibilities of the policymakers should ensure legislations that will suit the conditions and needs of the country. This can be achieved by:

- Increasing the knowledge of the medical device sector, establishing basic regulatory programmes
- Helping in the drafting of a comprehensive policy/guideline that will include the recognition and use of standards
- Promoting compliance and cooperation and
- Setting priorities for regulatory programme development

The use of a database for tracking include different concepts in terms of information recording and retrieval from paper records or computerized collections. The key elements attributed to a database include the comprehensiveness and inclusiveness of stored and regularly updated information.

The use of traceability technologies would help to offer the technical possibility to track products along the supply chain from their point of manufacture to the point of usage. The establishment of tracking systems could be leveraged and used as a useful tool to ensure integrity and to improve the efficiency of supply chains. In the context of medical equipment, it can help to detect the medical equipment in supply and as well, assist regulators in responding quickly to any incidence that might arise. This is in the bid to ensure the quality, safety, and efficacy of the medical health equipment.

The various features for a tracking system include:

- Identification: The four key standard elements include the product identification without any form of ambiguity, the stakeholders, subsets of products based on manufacturing/production, and the locations. The locations and stakeholders must be identifiable to ensure that the supply chain between the manufacturers can be documented appropriately into the tracking system.
- Inclusion of batch-level and serial level identification
- The use of global standards: This should encompass a robust redesign that will ensure wide support and acceptance by health personnel.
- Data aggregation: Aggregation of data will help to provide valuable and accurate means for efficient tracing.
- Verification: This is a technique that allows checking for the authenticity and authorization of products within the supply chain or in the hands of end-users.
- Detection and response: This involves active surveillance and monitoring in order to ensure an appropriate response to any query.

The development of appropriate regulation for tracking will allow the compatibility and blending of information for essential monitoring. The opportunities involved in a database for tracking include:

- To create potential opportunities for monitoring, connecting, and improving with the various supply chains
- Linkage overtime i.e. the ability to analyze patterns, quality, and costs over some time
- To ensure quick access to information
- For control, ownership, and governance
- To ensure coordination and guidance in the use of resources
- To facilitate strengthened supply chain integrity and efficiency with the ability to trace where a product has been at any given time.
- To ensure real-time information, data access, and data ownership permitting
- To ensure proper delivery of services and evaluation means
- To ensure visibility of products so as to accelerate regulatory responses in ensuring that only approved medical equipment are in circulation, prevent the distribution of non-functional medical equipment, facilitate efficient and fast market recalls, ensure efficient supplies management at all levels, and also to minimize and monitor the reasons of shortages and stock-outs.

The potential risks of not engaging in database tracking will lead to a bridge in the gap between the manufacturers and the end-users.

5.3 Working together with clinicians during the design and testing of medical devices

Remanufacturing involves different manufacturing steps that are aimed at transforming an end of life (EoL) product or component to perform equivalent to or better than a new product and with equivalent warranty. The adoption of remanufacturing helps to meet the UN Sustainable Manufacturing goals because it extends the product life cycle, helps in closing the loop on material flows, and reduces medical equipment wastage (Nasr et al., 2011).

The initiation of remanufacturing sustainability performance from the first stage of remanufacturing process i.e. during material collections to the final stage of the remanufacturing process helps to improve on the final output in terms of potential economic, social, and environmental impact. However, the acceptance of these remanufactured medical devices lies in the hand of the clinicians.

Many studies have suggested that user involvement during the design and testing phase of medical devices offers many benefits that enable the development of safer and more usable medical devices that are better suited to users' needs. (Money et al. 2011). Ensuring the development of quality and well-designed medical devices require formal human factors engineering methods, which is also known as user-centred usability engineering methods. This is supposed to be employed at every stage of the medical device design and development (MDDD) process (Gosbee 2002).

This method helps to ensure and put in consideration every manufacturing step level i.e. the design phase, development phase, and also considers the environment in which the device is to be used, the work operations and patterns of users, and the detailed individual needs of the user i.e. encompassing the health personnel, patients, caregivers, etc. (Shah and Robinson, 2008; Shah et al. 2009).

Much significant importance with the need to focus on users' needs has been documented with reports of many health-related benefits with the overall goal of ensuring good health delivery and improvement in patient outcomes. (Wilson and Sheikh, 2002; Martin 2010) Additionally, it has been reported that the reduction in device development time is seen when human factors engineering methods throughout the MDDD process are employed before the launch. This will also help to identify any issue associated with the release of the product. (De Vito 2009; Bias and Mayhew, 2005).

In the case of remanufacturing of medical equipment, the interaction between the medical personnel and the technical workforce is also necessary to ensure that remanufacturing all input, process, impacts, and medical devices produced are well acceptable and able to use. Primarily, clinicians are trained on how to use and administered these devices, so, they are in the best position to vet the safety and reliability with the use of these remanufactured medical devices. In order to embrace the wide acceptability and use of this remanufactured medical equipment, there is a need for a cross-talk between the clinicians and technical designers. This cross-talk is necessary to be done at the preliminary design stage and during the testing phase.

6.0 Sustainability measures for remanufacture

Sustainability measures according to Hacking and Guthrie, (2008) was defined as a process that guides decision making towards sustainability. It is also described as the means of creating manufactured products that use processes that minimize negative environmental impacts, conserve energy, and natural resources, that are safe for employees, communities, and consumers and are economically sound". (US Department of commerce in (2011). Sustainability measures for remanufacturing can be used as a tool to

improve the decision and policy that would be useful for management. The decision to measure and to improve the sustainability performance during the remanufacturing process will have a great impact on the general outcome.

Remanufacturing offers many sustainable values like economic potential values in many developed and developing countries.
Generally, the sustainability following remanufacturing has emphasis on the reparability, durability, and upgrade of products. The process involved in remanufacturing allows bringing used products into new conditions, which will help to prevent wastage. This will also enhance the recovery of a substantial portion of the parts or materials that are used in the primary production at a low additional cost and consequently will lead to a reduction in the price of the product. The general concept of sustainability also has an effect on the environment, economy, and society at large (Ijomah et al., 2004).

The review of the lack of maintenance culture for medical equipment raises the issue that most of the medical equipment is usually abandoned following a few months to years of use with no plan for repair, and the occurrence of this is stems from a lack of routine maintenance and servicing. With the issue of the increasing demand for medical equipment, the adoption of remanufacturing for damaged or abandoned equipment would help to prevent or reduce medical equipment wastage.

Oftentimes, it is usually assumed that remanufacturing process is sustainable without carrying out any further investigation. However, it is essential to ensure the sustainability of remanufacturing processes. Some of the key elements involved in sustainable manufacturing processes include:

- Remanufacturing cost-effectiveness
- Health implication
- Operational safety
- Materials recovery and waste management
- Environmental impact

Overall, these sustainable measures for remanufacturing are aimed at ensuring:

- Sustainability accountability: This is carried out to monitor, document resources, utilization, and to avoid waste in medical processes.
- Impact analyses: This is aimed at measuring the impact relative to the level of availability of the equipment.
- Use of fewer resources

- Generating less waste and pollution
- Contributing to social progress and wellbeing

Similarly, indicators are important key required for defining, evaluating, monitoring, and improving sustainability performance. It helps to ensure tracking of performances and productivity, and as well to ensure interactions. The indicator selection principles in remanufacturing are based on understanding the need, application, and its relevance. The establishment of this will help in the adoption and use of remanufactured medical equipment in Nigeria.

The presence of indicators helps to mark the progress of sustainable measures in remanufacturing. For a remanufacturing process to be sustained, it requires an integration process and approach. Usually, remanufacturing process begin with core collection, dismantling, cleaning, reconditioning, reassembling, and testing. Primarily, the understanding of the application and relevance of the need for sustainability is essential in ensuring sustainability. These indicators are also considered to meet the remanufacturing purposes, raise economic values, improve social equity, and increase environmental consciousness.

The key success factor in achieving remanufacturing sustainability involve the holistic implementation of all remanufacturing processes. These include material availability, technical workforce, management, equipment, and technology, etc. Sustainable measures and indicators in terms of the economic impact of remanufacturing are centered on:

- Continuous remanufacturing in form of job creation
- Processes to enhance material, energy, and productivity
- Technology impact on the return of investment
- Market suitability for further development
- Waste management

Social sustainability advantages and indicators include job and labour productivity. Some of the elements and indicators include:

- Employee: skill level, labour productivity, and educational level
- Derived satisfaction
- Public acceptability

Environmental sustainability: This involves remanufacturing activities which include availability of materials and the accessibility of spare parts.

6.1 Curriculum integration at Universities, the establishment of a Centre for the design and remanufacture of medical equipment

Curriculum integration denotes the materials, pedagogical strategies, and different multidisciplinary teams that are put in place to ensure a meaningful connection across subject areas. The early intimation with the knowledge and reasons for the need for medical equipment remanufacturing is quintessential to achieving the goal of sustaining medical equipment to avoid wastage.

In a survey, the willingness to study more and to work harder is hinged on the relevance of the knowledge of medical equipment remanufacturing. The motivation to learn will be spurred when the need to acquire knowledge in accomplishing the need for the establishment of a centre for the design and remanufacture of medical equipment is established. (Peter 2006).

The applied learning theory via curriculum integration at universities has been referred to be a veritable tool that helps to get people motivated when they are enlightened on the need to accomplish something they care about, that relates to them, when they are curious about an interesting and challenging problem, and when the material relates to their own lives. The adoption of this can be used for the strategy of ensuring a reduction in medical equipment waste and for further sustainability measures. (Svinicki 2002).

Curriculum integration is the first step to creating knowledge and to the extent of developing technical know-how outside the scope of the four walls of the class to ensure that the aim towards establishing a centre for the designing and remanufacturing of medical equipment might not be jeopardized. To also achieve the desired goal, it is expected that the curriculum integration is tailored to project the relevant themes on medical equipment remanufacturing, while also addressing the technical content that will require a suitable model for instruction. (Lipson et al. 1993)

The research on integrated curricula and the establishment of Centre for the design and remanufacture of medical equipment will be very beneficial. This incorporation into the university curriculum would help to:

- Gain and apply skills
- Lead to faster retrieval of information

- Create multiple perspectives that will lead to a more integrated knowledge base
- Ensure that Integrated curricula would encourage depth and breadth in learning
- Engage students in solving problems
- Aid in active exploration which can help to get an extension beyond the classroom by connecting to internships and field-based investigations
- Connect with the wider community.

6.2 Training a technical workforce of Biomedical Engineers to repair and maintain Medical Equipment

The lack or shortage of skilled technicians able to to repair and maintain medical equipment in many health care facilities contributes to the burden associated with medical equipment remanufacturing. To eliminate this occurrence, the offer of training programs using expert trainers could help to offer an appropriate transfer of skills that will be useful for the goal to know about medical equipment repair, medical equipment wastage management, and to ensure the adoption of remanufacturing.

The presence of well trained biomedical equipment technicians will greatly improve the management of medical equipment. The lack of biomedical equipment technician within health care facilities especially in many low-resource settings affects the judicious use and maintenance of the limited available medical equipment. Likewise, the limited number of available technicians has its significant effect on both the medical personnel, patients, and on the general delivery of health services.

It is observed that many patients could overcome the challenges of being vulnerable to unnecessary pain and discomfort, poor health outcomes, and even death when the right technological equipment that supports the appropriate diagnosis and treatment of health conditions are available. The prompt access to emergency care and the use of diagnostic and therapeutic tools helps in ensuring a better health delivery service and also to reduce patient mortality. However, the situation observed within many low-resource health centre settings is the fact that about 40 percent to 70 percent of the medical equipment available is either idle or not functional (Perry & Malkin, 2011; WHO, 2000).

The recommendations to develop a model to train biomedical engineers to repair and maintain medical equipment would help to provide a scalable, replicable, and a redistribution method which will be a supportable measure in ensuring the sustainability of remanufacturing of medical equipment that would help to solve the problem of low or lack of medical equipment. Also, a form of an academically oriented programs will be structured to address both theoretical and practical know-how. This will as well create a room to grow and produce more technicians. A blend of all of these would help to ensure adequate

knowledge that will translate to a more relatable connection as to the reasons and significant importance of the training.

7.0 Conclusion

The training of a technical workforce of biomedical engineering to repair and maintain medical equipment would encompass ways to imbibe knowledge on remanufacturing to avoid medical equipment wastage, ways to access equipment, the parts, tools, accessories, information, and all other resources that would be useful to bring about a positive outcome. Additionally, this will help to foster a good connection between them and the clinicians who need the medical equipment. It will also create room to interact and share knowledge on ways to devise improvement in the repair and maintenance of medical equipment. At the same time, it will help to create an environment for interconnected support from the medical personnel that will be making use of the repaired medical equipment.

Additionally, the provision of training to the technical workforce of biomedical engineering will help to create an ecosystem that can birth forth education infrastructure, professional associations, and gaining policies and procedures that will help to build stability in the remanufacturing and redistribution of medical equipment where they are needed. This will also help to eliminate any form of medical equipment wastage.

The supply of qualified instructors to teach both the theoretical and practical hands-on experience on the maintenance and repair of these medical equipment would be a key factor that would help to ensure the acceptability of remanufactured equipment among healthcare personnel as well as the prevalence, acceptability, affordability, and performance (durability) of remanufactured medical equipment in many healthcare facilities.

References

A.O. Coker, F.O. Akintayo, C.G. Achi, M.A. Odeniyi , A.O. Olorunnisola, D. Akano (2019) Recent Developments in Biomedical Engineering Education in Africa: A Focus on Nigeria and the University of Ibadan. In *Biomedical Engineering for Africa*. Douglas, T.S. Ed. 2019. Biomedical engineering for Africa. Cape Town: University of Cape Town Libraries. 11–17. DOI: http://dx.doi.org/10.15641/0-7992-2544-0

Bias RG, Mayhew DJ: Cost-Justifying Usability: An Update for the Internet Age. 2005, San Francisco, CA, USA: Morgan Kaufmann Publishers

Compton, B., D. M. Barash, J. Farrington, C. Hall, D. Herzog, V. Meka, E. Rafferty, K. Taylor, and A. Varghese. 2018. Access to medical devices in low-income countries: Addressing sustainability challenges in medical device donations. NAM Perspectives. Discussion Paper, National Academy of Medicine, Washington, DC. doi: 10.31478/201807a

Claire E Adams and Michael Dobson, 2019. Anaesthetic equipment in low and low-middle income countries. *Anaesthesia In Developing Nations. Anaesthesia and Intensinve care medicine 2019 pp 518-521*

De Vito Dabbs A, Myers B, McCurry K, Dunbar-Jacob J, Hawkins R, Begey A, Dew M: User-Centered Design and Interactive Health Technologies for Patients. Computers Informatics Nursing. 2009, 27: 1-16. 10.1097/NCN.0b013e3181920769.

Elhadi, M., Msherghi, A., Alkeelani, M., Alsuyihili, A., Khaled, A., Buzreg, A., Boughididah, T., Abukhashem, M., Alhashimi, A., Khel, S., Gaffaz, R., Ben Saleim, N., Bahroun, S., Elharb, A., Eisay, M., Alnafati, N., Almiqlash, B., Biala, M., Alghanai, E., Concerns for low-resource countries, with under-prepared intensive care units, facing the COVID-19 pandemic, *Infection, Disease & Health*, https://doi.org/10.1016/j.idh.2020.05.008.

Eze, S., Ijomah, W., and Wong, T.C. 2019. Accessing medical equipment in developing countries through remanufacturing. Journal of Remanufacturing https://doi.org/10.1007/s13243-018-0065-7

Global Harmonization Task Force 2012. Definition of the Terms 'Medical Device' and 'In Vitro Diagnostic (IVD) Medical Device' Study Group 1 Final Document GHTF/SG1/N071:2012

Gosbee J: Human factors engineering and patient safety. Quality and safety in health care. 2002, 11: 352-354. 10.1136/qhc.11.4.352.

Gutowski, T. G., Sahni, S., Boustani, A., & Graves, S. C. (2011). Remanufacturing and energy savings. Environmental Science & Technology, 45(10), 4540-4547.

US Department of Commerce (2011), Sustainable Manufacturing Initiative website, http://trade.gov/competitiveness/sustainablemanufacturing/index.asp

Ijomah, W. L., Childe, S., & McMahon, C. (2004). Remanufacturing: a key strategy for sustain-able development. In: Proceedings of the 3rd International Conference on Design and Manu-facture for Sustainable Development, 1-2 Sep 2004, Loughborough, UK.

Kim, H.-J., Skerlos, S., Severengiz, S., & Seliger, G. (2009). Characteristics of the automotive remanufacturing enterprise with an economic and environmental evaluation of alternator products. International Journal of Sustainable Manufacturing, 1(4), 437-449. http://dx.doi.org/10.1504/IJSM.2009.031363,

Kim, H. J., S. Severengiz, S.J. Skerlos, and G. Seliger. (2008). Economic and environmental as-sessment of remanufacturing in the automotive industry. LCE 2008: 15th CIRP International Conference on Life Cycle Engineering: Conference Proceedings. Sydney, N.S.W, 195-200.

Lipson, M., Valencia, S., Wixson, K., and Peters, C. (1993). Integration and Thematic Teaching: Integration to Improve Teaching and Learning. Language Arts, 70(4): 252–264.

Lund R.T. (1984) "Remanufacturing: Experience of the U.S.A. and implications for Developing Countries" World Bank Technical Paper No. 3.

Martin JL: Design for patient safety: User testing in the development of medical devices. 2010, National Patient Safety Agency, London, UK

Money, A.G., Barnett, J., Kuljis, J. *et al.* The role of the user within the medical device design and development process: medical device manufacturers' perspectives. *BMC Med Inform Decis Mak* **11,** 15 (2011). https://doi.org/10.1186/1472-6947-11-15

Matsumoto. M., Ijomah. W. (2013) Remanufacturing. In: Kauffman J., Lee KM. (eds) Handbook of Sustainable Engineering. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-8939-8_93

Nasr, N., Hilton, B., & German, R. (2011). A framework for sustainable production and a strate-gic approach to a key enabler: remanufacturing. In Advances in Sustainable Manufacturing (pp. 191-196). Springer Berlin Heidelberg.

Peter D. Hart Research Associates, Inc. (2006). Report Findings: Based on a Survey Among California Ninth and Tenth Graders. Conducted for The James Irvine Foundation. Washington, DC: 2006, April 5.

Shah SGS, Robinson I, AlShawi S (2009) Developing medical device technologies from users' perspectives: a theoretical framework for involving users in the development process. Int J Technol Assess Health Care 25(4):514–521

Shah SGS, Robinson I: Medical device technologies: who is the user?. International Journal of Healthcare Technology and Management. 2008, 9: 181-197. 10.1504/IJHTM.2008.017372.

Shah SGS, Robinson I, Alshawi S: Developing medical device technologies from users' perspectives: A theoretical framework for involving users in the development process. International Journal of Technology Assessment in Health Care. 2009, 25: 514-521. 10.1017/S0266462309990328.

Svinicki, M.D. (2002). Some Applied Learning Theory. Austin, TX: Center for Teaching Effectiveness, The University of Texas at Austin. Retrieved August 3, 2007, from http://www.utexas.edu/academic/cte/sourcebook/learningtheory.html.

Wilson T, Sheikh A: Enhancing public safety in primary care. British Medical Journal. 2002 324: 584-587. 10.1136/bmj.324.7337.584