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Overview

Is Africa a 'Graveyard' for Linear Accelerators?

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Abstract

Linear accelerator downtimes are common and problematic in many African countries and may jeopardise the outcome of affected radiation treatments. The predicted increase in cancer incidence and prevalence on the African continent will require, *inter alia*, improved response with regard to a reduction in linear accelerator downtimes. Here we discuss the problems associated with the maintenance and repair of linear accelerators and propose alternative solutions relevant for local conditions in African countries. The paper is based on about four decades of experience in capacity building, installing, commissioning, calibrating, servicing and repairing linear accelerators in Africa, where about 40% of the low and middle income countries in the world are geographically located. Linear accelerators can successfully be operated, maintained and repaired in African countries provided proper maintenance and repair plans are put in place and executed.

Key words: Africa; equipment maintenance and repair; linear accelerator; radiation therapy

Statement of Search Strategies Used and Sources of Information

This paper is based on about four decades of experience of Helmut Reichenvater in capacity building, installing, commissioning, calibrating, servicing and repairing linear accelerators in Africa. In addition, both authors have consulted the International Atomic Energy Agency (IAEA) Directory of Radiotherapy Centres (DIRAC) web page and conducted a literature study.

Introduction

Clinical linear accelerators (LINACs) are the battle horses of many radiation therapy facilities around the globe [1]. When no back-up is available, failure in using the treating LINAC for a couple of days can seriously compromise the treatment outcome of the patients under radiation treatment; therefore, long machine downtimes should be avoided. Due to its heavy mechanical and complex electronic components, highly qualified personnel are required for maintenance, comprehensive quality assurance, repair and successful operation of a LINAC [2–6]. In very complex cases, technical support from the vendor may be necessary [7,8]. Stable power and reliable cooling water supply systems are another requirement for sustainable operation of this type of equipment [7,9,10]. Maintenance and repair of LINACs in many African countries is a big challenge due to a variety of reasons, including limited government support, lack of qualified personnel with regard to repairs and maintenance, questionable assistance approach by manufacturers and their regional agents, inadequate storing of spare parts and poor management. Unfortunately these problems have not yet been properly addressed by competent local, national, regional and international bodies, and are part of the reasons that have led to the perception that LINACs cannot be successfully operated in

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Africa, where the income level of all countries varies between low and middle income (income level classification according to World Bank definitions for 2015). The relationship between the number of megavoltage teletherapy (LINAC and Co-60) machines per million population with the wealth of African nations has been presented elsewhere [11]. The obvious exceptions in maintaining LINACs are Egypt (lower middle income) and South Africa (upper middle income), who together hold about 60% of all LINACs available on the continent [1]. Most cancers in Africa can be managed with radiation therapy [12–14], which is used to manage about 50% of all cancer cases in high income countries (HIC) (income level classification according to World Bank definitions for 2015) [15,16]. Most causes of LINAC breakdown are common among African countries. Strategies to minimise these breakdowns could be shared among radiation therapy facilities in order to improve the dire situation of radiation therapy care in these countries. The problem in maintaining LINACs in Africa will probably become more evident in the near future when LINACs using advanced technologies are installed. Modern LINACs require information technology support and dedicated treatment planning systems; therefore, problems associated with information technology and treatment planning systems must be addressed in order to fully benefit from the advances in modern LINAC technology. The predicted cancer incidence increase on the continent over the next years [17] will require adequate maintenance, robust quality assurance and repair of LINACs in order to efficiently fight cancer using radiation.

Here we discuss some frequent and specific problems related to the operation of LINACs and propose possible alternative solutions relevant for local situations in African countries.

Background

The choice whether to operate a Co-60 machine or a LINAC requires careful consideration of the aim of the treatment [10,18], the cost of the megavoltage machine [6] and the available or planned radiation therapy infrastructure including physical, technical and clinical support [6,9,10]. There is an ongoing discussion about the costs and benefits of Co-60 machines and LINACs [6,9,10,18–22]. For simple treatments, similar treatment plans can be produced with either a Co-60 machine or a LINAC [18,19,21,22]; however, for complex treatments, LINACs are better suited [6,9,18]. The risk of the Co-60 machine radioactive source getting stolen for its potential use in dirty bombs may impose additional security costs. Maintenance costs, except source replacement, are cheaper for Co-60 machines in contrast to LINACs [6], which are technically more sophisticated and may require replacements of klystrons or magnetrons [10,22], which are major LINAC components. LINACs require robust and frequent quality assurance to ensure that the expected beam quality and dose rate are produced [3–5]. Although quality assurance and maintenance are simpler for Co-60 machines relative to LINACs [6,10], many African nations have chosen to operate LINACs instead of Co-60 machines upon upgrading or introduction of new radiation therapy facilities [1,23]; consequently, the number of LINACs on the continent in 1998 tripled to 189 units in 2010, whereas the number of Co-60 machines decreased from 93 to 88 units [23]. Notwithstanding the increase, the number of LINACs per million population in Africa remains low (0.2) in comparison to Asia (0.7), Europe (5.5), North America (7.5) and South America (1.5) [1,24]. This paper is based on about four decades of extensive experience in training local staff, installing, commissioning, calibrating, servicing and repairing LINACs in many African countries and presents an overview on typical LINAC problems and strategies on how to reduce their breakdowns in a resource-constrained setting.

Inadequate Repair Approaches and Qualifications of the Maintenance and Repair Personnel

The responsibility to operate, maintain and repair a LINAC pertains to the operator of the radiation therapy equipment. Specialised human and technical capacity is critical when a repairable breakdown is verified. Although maintenance and repairs in HIC are executed by the manufacturers or engineers employed by the hospitals, this is mostly not so in Africa, were government support to radiation therapy may be limited. Table 1 compares the most probable qualifications of personnel involved in maintenance and repair of LINACs between HIC and African countries.

The repair and maintenance plans recommended and prescribed by the suppliers and international bodies may not address the requirements of the operators in Africa. Table 2 shows a contrast of typical approaches to repair between HIC and African countries.

Due to poor remuneration, highly trained and specialised staff are not attracted; instead high staff turnover leads to inadequate operation, maintenance and repair work. Regulatory authorities should ensure that qualified personnel carry out the maintenance and repair of LINACs and that international assistance is sought if appropriate. In addition, governments in Africa should find ways to adequately reimburse personnel employed for the operation and upkeep of radiation therapy equipment for the services they render. Fortunately, some African governments are slowly introducing measures to alleviate these adverse conditions for specialist employees.

Prohibitive Training Course Prices Offered by Manufacturers

Most of the time, as part of the after sales services offered by the manufacturers, training courses are offered to counterpart institutions only when they have purchased new equipment. Even so, the prices for in-depth training amount to around $12 000 per trainee per week. It should

Table 1
Contrast of typical personnel who may execute maintenance and repair of linear accelerators in high income countries and Africa

High income countries	Africa
Maintenance work carried out by an engineer	Maintenance work carried out by a physicist
First level repairs carried out by a hospital engineer	First level repairs carried out by a physicist
Higher level repairs carried out by the manufacturer	Exceptionally, higher level repairs may be assisted by the International Atomic Energy Agency

be noted that in order to gain an adequate knowledge of an accelerator and its ancillary equipment (e.g. electronic portal imaging devices, multileaf collimator, image-guided radiation therapy, cone beam computed tomography, online patient supervision, etc. …), a minimum of 8 weeks of training would be necessary. Together with the air ticket, accommodation and subsistence allowance, the costs for training a single person could reach about $100 000, which is out of the reach of many low income nations.

Most training programmes have been devised for operators in HIC and their successful implementation in African countries would require embedded training [25–28] together with expert service personnel who know the local conditions rather than costly short training exercises offered by the manufacturers. The advantages would be hands-on work together with experienced staff, confrontation of real problems experienced by end-users in HIC and Africa, low expenditures (only travelling and subsistence allowances necessary) and longer periods of training (4–6 weeks) are possible due to lower costs.

Reluctance by Manufacturers and their Agents to Train Counterpart Institutions

It may be very prudent to assume that after sales services such as training, preventive maintenance and repair work are a lucrative business for both manufacturers and their agents. Therefore, by providing in-depth training courses covering maintenance and repairs of LINACs for their customers in developing countries, profitable income could be eroded, since end-users would no longer enter into expensive service and repair contracts. For instance, it transpired that in an institution in one of the Maghreb nations, the regional representative of the accelerator manufacturer refuses to allow the engineering staff or physicists from the local institution to witness any of the required service exercises or repairs. For example, thousands of dollars are wasted for each replacement of a multileaf collimator drive motor, which could easily be done by the maintenance staff or the medical physicists working at the hospital. Given the considerable failure rate of the multileaf collimator motors, a lot of money could be saved by this in-house service alone.

Table 2
Comparison of typical linear accelerator repair situations between high income countries and African countries

High income countries	Africa
Maintenance contracts with suppliers	In-house maintenance
Repair contracts with suppliers	In-house repairs
High labour costs	Low labour costs
Low material costs	Exorbitant material costs
Availability of hard currency	Hard currency restrictions
Replacement of defective parts	Repair of defective parts
Repair work by manufacturers	No financial resources for external support
Preventive maintenance	Crisis management

Exorbitant Prices Charged by Manufacturers and their Agents for Services

In most oncology institutions in Africa, end-users are not allowed to deal directly with the manufacturers. Instead, they have to deal with local or regional representatives who may usually have inadequate knowledge of the equipment that they represent. The acquisition of spare and replacement parts is routed through these agents, causing undue delays and uneconomical prices. However, it should be acknowledged that local government systems might not support the timely replacement of parts of the equipment; consequently, manufacturers may not release equipment parts unless payment has been received. Factory prices received by the agents are usually marked up by unreasonable amounts and depending on the value of the enquiry, prices may be increased by large amounts.

A perfect example is a recent purchase by one institution in Southern Africa, where the regional representative of the manufacturer demanded three times the factory sales price of a new klystron.

As a number of developing nations lack sufficient reserves of hard convertible currency, long downtimes may partially be the result of this business approach. The manufacturers of the radiation therapy equipment could show more sympathy for the plight of the African countries and should not act purely on economic considerations.

Inadequate Spare Part Holding and Poor Management

Users in HIC need different spare parts when compared with the requirements in African countries because the technical support and environmental parameters are vastly different. Many African countries do not have a stable and high-quality power supply [29], which is critical for the normal functioning of a LINAC [7,9,10]. Factors needing consideration include high voltage fluctuations, voltage spikes and surges resulting in electronic faults of the equipment, prolonged power failures causing undue strain on the thermocycling of the machinery, poor cooling water quality causing blockages of the intricate cooling system, vermin and rodents damaging the equipment and electric cables, and inexperienced operating personnel being responsible for crashes and maloperations.

These factors imply that the type of spare components holding in African countries will be markedly different and larger in number in relation to equipment operated in HIC, where access to manufacturers is relatively easy and new components can be readily fabricated. Unfortunately, the set of spare parts recommended by suppliers do not match the requirements of African countries.

With a good collaboration and communication system, spare parts could be shared among radiation therapy facilities in different countries in the same region and acting as a group they could potentially improve purchasing and negotiation leverage with the vendors. In fact, there has been interest, at least on an informal basis, among some radiation therapy facilities to share spare parts. Such contacts should be expanded in order to reach out to more facilities. The African Regional Cooperative Agreement for Research, Development and Training related to Nuclear Science and Technology (AFRA) could be ideally placed to network different radiation therapy facilities [28].

Conclusion

Challenges and alternative ways for the sustainable management of LINACs for resource-constrained settings in Africa have been presented. There could be more alternatives. The aim of this work was not to give a recipe on how to repair LINACs but rather to promote and encourage research on novel ways of maintaining them in a resource constrained setting prioritising local solutions.

Very distinct changes in paradigms in the management of radiation therapy, training, quality assurance, cost of maintenance and repairs, and spare parts holding should be accepted in order to guarantee the safe and sound clinical operation of LINACs and ancillary equipment in Africa. These changes could be supported by the manufacturers of the radiation therapy machines, the International Atomic Energy Agency and the governments of the countries in Africa operating or planning to install radiation therapy systems, international organisations associated with radiation therapy, the hospital administrations using LINACs and the actual staff working on the machines.

LINACs can successfully be operated in African countries if most of the challenges faced by radiation therapy facilities, some of which are outlined in this work, are addressed.

After the introduction of at least some of these changes, the availability of LINACs and simulators in Zimbabwe and Mauritania has for some time improved considerably and is now similar to machines in HIC; therefore, it would seem that by implementing the recommendations in this presentation, a great amelioration in availability and sustainability of radiation therapy services in African countries could be achieved.

Conflicts of Interest

H. Reichenvater has been working as a freelance consultant for the International Atomic Energy Agency (IAEA) for the past 12 years, has regularly been appointed by the IAEA to train staff from different countries at the research laboratories of the IAEA in Seibersdorf, Austria, has conducted on-site training in the repair of LINACs and Co-60 machines, the assessment of radiation therapy facilities and held IAEA missions to African countries.

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