Availability of Linear Accelerators for Radiation Therapy treatments in Africa

Review of the literature and ideas for reflection

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Abstract
Radiotherapy is an essential modality in the curative or palliative management of patients with cancer. Its importance is further accentuated by the ever-increasing number of new cases. Unfortunately, linear particle accelerators (linacs), which are the reference equipment for carrying out radiotherapy care, are dramatically absent from a major part of Africa continent. Half of the countries on this continent simply don't have any. The aim of this work is to review the literature on the availability of this type of equipment in Africa. Some initiatives are highlighted in this document, in order to provide suggestions for reflection on this major issue of the quality of care in radiotherapy.

Keywords
Radiotherapy, Linear Accelerators, Health Crisis, Africa.

1. Brief overview of radiation therapy

Radiotherapy is one of the leading treatments in the fight against cancer, used alone or in combination with other therapeutic approaches (surgery, chemotherapy, hormone therapy, etc...). The principle consists of delivering a localized dose of ionizing radiation, quantified in Gray (Gy), to the malignant cells, sparing healthy cells as far as possible, since the latter have a greater capacity to repair the damage inflicted. Consequently, by multiplying the number of treatment fractions (fractionation) at an optimum dose, will make it possible to destroy diseased cells by blocking their capacity to multiply, and giving healthy cells time to repair themselves.

Radiotherapy is estimated to be involved in the treatment process of 45-55% of new cancer patients. It can be curative or palliative, to relieve the patient of the suffering caused by the tumor.

Irradiation is mainly delivered by MV (MegaVoltage) linear particle accelerators, the type and energy of which will depend on the location of

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the tumour. Other modalities, which are not discussed in this document, exist but MV accelerators are the most common.

2. General Data on cancer worldwide and in Africa in particular

The data presented here mainly come from GLOBOCAN 2020, published by the International Agency for Research on Cancer (IARC), the organization responsible for collecting and analyzing global cancer data [1].

The number of new cases in 2020 for all cancers combined, including both sexes and all age groups, is expected to be around 19 million. Men are slightly more affected than women, with 10 million and 9 million new cases respectively.

All populations combined, breast and lung cancers are the most frequent, accounting for 11.7% and 11.4% of new cases respectively. Colorectal cancer comes next with 10% of new cases, followed by prostate and stomach cancers with 7.3% and 5.6% respectively. For women, cervical cancer will account for 6.5% of the 9 million new cases in 2020.

To retain simple orders of scale, cancer is the first or second cause of premature death (i.e. deaths at ages 30-69 years) in 134 out of 183 countries, and the third or fourth in 45 others. According to the World Health Organization (WHO) [2], one in five men and one in six women worldwide will develop cancer during their lifetime, and one in six deaths worldwide is due to this disease, representing almost 10 million deaths by 2020. The total number of people living with cancer within five years after diagnosis, called as five-year prevalence, is estimated at 50 million.

Unfortunately, the projections announced for the next 10 to 15 years by international organizations are pessimistic [3]. The number of new cancers in 2040 is estimated at 28.4 million, representing an increase of over 40% compared to 2020. The aging and growth of the world's population, as well as changes in lifestyle habits explain this increase. The latter is itself unequal and will be strongly correlated with the economic development of each country.

Several indicators, such as the Gross National Income (GNI) per capita or the 4-tier Human Development Index (HDI) based on the United Nation's 2019 Human Development Report, enable to classify different geographic regions according to their socio-economic development. These two indexes are the ones most often used in the various studies consulted for this document.

Based on the World Health Organization's definition, GNI per capita is the dollar value of a country's final income in a given year, divided by its population according to the Atlas methodology. Countries are then divided according to their GNI per capita: low-income < 1046 US$, lower-middle income from 1,046 US$ to 4,095 US$, upper-middle income from 4,095 US$ to 12,695 US$ and high-income > 12,695 US$.

Figure 1 is a map showing the world's distribution into 4 categories: low, medium, high and very high income countries this time based on the calculation of the HDI index, more complex than the GNI, which takes into account life expectancy at birth, access to schooling and the GNI.

Analysis of the increase in cancer incidence can then be more closely linked to human development in a given country. The Word Health Organization (WHO) predicts that this increase is inversely proportional to GNI. More

precisely, between 2008 and 2030, the increase in cancer incidence is estimated at 82%, 70%, 58% and 40% in low, lower-middle, upper-middle and high-income countries respectively. As a reminder, radiotherapy will be required in the therapeutic care of 45-55% of new cancer patients.

Linear particle accelerators are the main delivery systems for ionizing radiation used in radiotherapy. The aim of this document is to review the literature on the availability of these devices on the African continent, which at the same time brings together the highest number of low and lower-middle income countries.

3. Availability of MV accelerators in Africa

The statistics presented in this section are mainly taken from the Directory of RAdiotherapy Centers (DIRAC) digital database [4], which lists radiotherapy centers and equipment around the world. This database, initiated by the International Atomic Energy Agency (IAEA), is constantly updated and provides access to an inventory of the material resources required for the practice of radiotherapy worldwide.

According to Elmore *et al.* [5] in their study on current MV machines resources in Africa and their estimate of needs for the coming decades taking into account GLOBOCAN 2020 projections: « no country had a capacity that matched the estimated treatment need. The message is clear.

DIRAC has registered 15,130 accelerators spread across 214 countries. The distribution is as follows: 9449 (62%) for High income (Hi), 4023 (27%) for Upper-middle income (UMi), 1615 (11%) for lower-middle income (LMi) and 40 (0.3%) for Low income (Li) countries. In 2020, only 430 units were available in Africa, half of which were installed in Egypt (119) or Southern Africa (97) [5]. Approximately half of African countries have no external beam radiation units for radiotherapy.

Today, the world's population is estimated at almost 8 billion, more than half of whom live in low or lower-middle income countries. Over 70% of these countries are located in Africa. These data should be set against the data from DIRAC [4] and Elmore *et al.* [5] on the availability of MV machines in these regions.

The IAEA has defined recommendations for the minimum equipment to be made available, in order to ensure proper patient care in radiotherapy. The objective to be achieved is 4 accelerators per million inhabitants. High-income countries reach 7.71 machines per million inhabitants. DIRAC also provides the results for the African continent: 1.12 for North Africa, 1.27 for South Africa and 0.08 for the rest of Africa. The statistics speak for themselves: 18 of these countries, with a population of over one million, are still without any radiotherapy facilities [6].

Christ and Willmann [6] in their recent study (2023) on global inequalities in radiotherapy more modestly estimate that: "the availability of a MVM per every 1 million inhabitants already helps to significantly reduce the cancer burden in LMICs" (Low and low-middle income countries).

These authors, taking up previous studies such as those by Levin *et al.* in 1999 [7], Wahab *et al.* in 2013 [8], Datta *et al.* in 2014 [9] and Elmore *et al.* in 2021 [5], outline the evolution of the situation in the countries with the most limited resources. Their findings are alarming: in 1999, 61% of African countries had no MV

accelerators at all; in 2013, this rate was 54%, rising to 52% in 2021. They rightly «point out that addressing these extreme health inequities remains a highly complex work in progress». To overcome this gap, Elmore *et al.* [5] estimate that between 1,500 and 2,000 treatment units would be needed in these low and low-middle income countries by 2030 to resolve these inequalities in care. According to the fairly consistent estimates in the various publications, this corresponds to 150 to 200 MV machines installed per year.

Moreover, it should be noted that the type of equipment needed to operate a radiotherapy center also requires multidisciplinary teams with strong medical and technical skills. This point is addressed by Christ and Willmann in their work. They estimate that African countries with low and low-middle incomes lack more than 500 radiation oncologists, 450 medical physicists, 900 radiation therapists and almost 400 nurses.

4. Few suggestions to get foward

No matter how modern an accelerator is, it involves a non-negligible investment cost ranging from 1 to several million USD for the most efficient. Jacob Van Dyk *et al.* in 2017 [10] carried out an analysis of the cost of setting up a radiotherapy center for the 4 regions (Hi, UMi, LMi and Li) defined by the Word Bank (http://data.worldbank.org).

In this study, the authors compare different scenarios, taking into account various operating parameters such as the number of treatment machines, the impact of the number of fractions per treatment, the irradiation technique used, the number of hours worked or the salaries of the various healthcare professionals. The results can then provide useful guidelines for optimizing local conditions. For their baseline scenario, of a center operating 8 hours a day with 2 MV accelerators, the annual operating cost is USD 4,595,000 for Hi countries versus USD 1,736,000 for Li countries. The difference is essentially due to salaries. MV machines are sold by manufacturers at approximately the same price in all countries. The authors then modulate the different parameters to compare to this reference operation. For example, it makes more sense to increase the size of the department up to 3 linacs than to operate with a single machine. Another example, reducing the number of working hours below 8 per day has a considerable negative impact on the cost per treatment.

Teleradiotherapy, in which a referent center takes charge of all pre-treatment steps and 2 satellite sites perform only the irradiation step, is discussed by Van Dyk *et al.* [10]. The latter compares this scenario with the installation of 4 totally independent radiotherapy centers. Their calculations show a 17% reduction in treatment costs for low-income countries. This strategy could provide solutions in countries where access to healthcare is mainly concentrated in big cities, and where large geographical areas are neglected.

The number of treatment fractions, whatever the tumor site, has a direct impact on the cost of patient management and the number of patients that can be scheduled per day. Hypo-fractionation means delivering a larger dose in fewer fractions than with a standard protocol. Obviously, this particular therapeutic regimen must achieve at least the same results in terms of treatment

efficacy and side effects as conventional fractionation. This is particularly the case for breast and prostate treatment.

Irabor *et al.* in 2020 [11], compared the two dose/fractionation schemes for these two cancers in terms of cost and access to care. The authors studied the potential benefits for Africa, country by country, of reducing breast treatment from 25 to 15 fractions, and prostate treatment from 35 to 20 fractions. Adopting a protocol with fewer fractions but higher doses could reduce total treatment costs by up to 40% and increase access to care by 30%. Calculated over 7 years, the cost reduction for the continent as a whole would be $2.7 billion.

In this document, only the aspect relating to MV treatment machines has been addressed. Clearly, to find solutions to this health crisis in Africa, many other points need to be taken into account. These considerations must be part of a national cancer plan. For example, improving prevention and diagnosis would reduce the burden of cancer on African countries. According to the World Health Organization, over 70% of female breast cancer cases in Africa are detected at very advanced stages of the disease. In this situation, no treatment can provide satisfactory results.

Ndlovu *et al.* [12] point out that in addition to the obvious improvements in terms of prevention, diagnosis, training and cost, socio-cultural aspects must also be considered. Quoting him: «There is a general lack of knowledge and fear of radiotherapy treatment by the public in Africa. This is largely driven by limited awareness and education on cancer, its causes and various treatment modalities. Some cultural practices may promote mysticism about cancer and its management that leads to reduced acceptance and uptake of radiotherapy as a standard form of cancer treatment. There is a common belief of linking cancer to spiritual issues such that the preferred default health seeking behaviours for cancer patients are those of looking to alternative rather than mainstream forms of treatment. Also, since patients present with late-stage disease, which is a cause of poor survival even with the best of interventions, fear of radiotherapy may stem from the association of the intervention with demise that may usually follow shortly after palliative radiotherapy treatment».

Finally, for the purposes of this study the African continent was considered as a whole, but disparities in access to healthcare between different countries can be very considerable. It would therefore be appropriate to consider more closely each geographical region.

5. Conclusion

The whole international community (rich countries, non-governmental organizations, charitable associations, etc...) has a role to play in finding solutions to this health crisis. However, the key actors are the Africans themselves, who know their own socio-cultural environment better than anyone else.

As a final reference, Ige *et al.* in an article published in 2021 [13], present a collaborative platform bringing together 28 African countries, all of which have at least one radiotherapy center, and also inviting several high-income countries. Initiated in 2016, their purpose has been to brainstorm accelerators prototypes that are more robust to more challenging local conditions. In particular, taking into account the instability of the power supply in these regions.

There are indeed many obstacles before achieving

the target defined by the World Health Organization for noncommunicable diseases (NCDs), of which cancer is one: «The Agenda sets the target of reducing premature deaths from NCDs by one third by 2030». However, many actors in Africa and outside are responding to this Herculean task with optimism and dynamism.

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