CONVERTING COBALT TO LINAC: SENEGAL INSTITUT JOLIOT CURIE ARISTIDE LE DANTEC HOSPITAL

Abstract

Senegal currently has three radiotherapy centres (four LINAC machines) that together serve a population of 17 million people. This paper describes the experience of the Institut Joliot Curie (IJC) as a key stakeholder in the conversion project and recipient of one of the purchased LINACs.

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INSTITUT JOLIOT CURIE ARISTIDE LE DANTEC HOSPITAL

INTRODUCTION

Senegal currently has three radiotherapy centres (four LINACs) located in two radiotherapy public centres and one private hospital that together serve a population of 17 million people. Senegal had relied on a single Cobalt-60 (Co-60) teletherapy unit until 2016, when it broke down, leaving an entire population with no treatment options. Following this breakdown, public debate on the lack of access to radiotherapy services and expensive treatment abroad became a national issue. This eventually triggered government action and the decision to purchase three LINAC machines. The LINAC machine in the private sector was also purchased after 2016, however there was no exchange between the two sectors during the preparation and implementation process. End users were involved and consulted to ensure the machine specifications met operational needs. Other major stakeholders in the transition process management, including the Ministry of Health (MoH), the regulatory authority, the Ministry of Finance, the hospital, and international organizations contributed to a smooth LINAC transition planning and coordination. This paper describes the experience of the Institut Joliot Curie (IJC) as the key stakeholder in the project and recipient of one of the purchased LINACs. Patient treatment with LINACs commenced in March 2018 and has been performing to the expected standard and receiving positive feedback.

BACKGROUND

Cancer is one of the most common causes of morbidity and mortality worldwide today. Currently, the World Health Organization estimates 12.7 million people are diagnosed with cancer annually worldwide [1, 2]. An estimated 7.6 million people die from cancer globally every year, of which 4 million people die prematurely (aged 30-69) [3]. This number is increasing significantly, and by 2030, the number of deaths will increase by 45% and reach 11.5 million deaths annually [4]. More than 70% of all cancer deaths occur in developing nations where the lack of access to cancer care is a significant problem. In Senegal, cancer is one of the major public health problems because diagnosis is often late, and treatment is difficult and expensive.

The incidence of cancer in Senegal is estimated to be 6,646 new cases per year with a mortality rate of about 72%, with breast cancer and cervical cancer being the most predominant (Figure 1 and Table 1). This high mortality rate is mainly the result of late consultation, as well as a lack of adequate equipment and human resources.

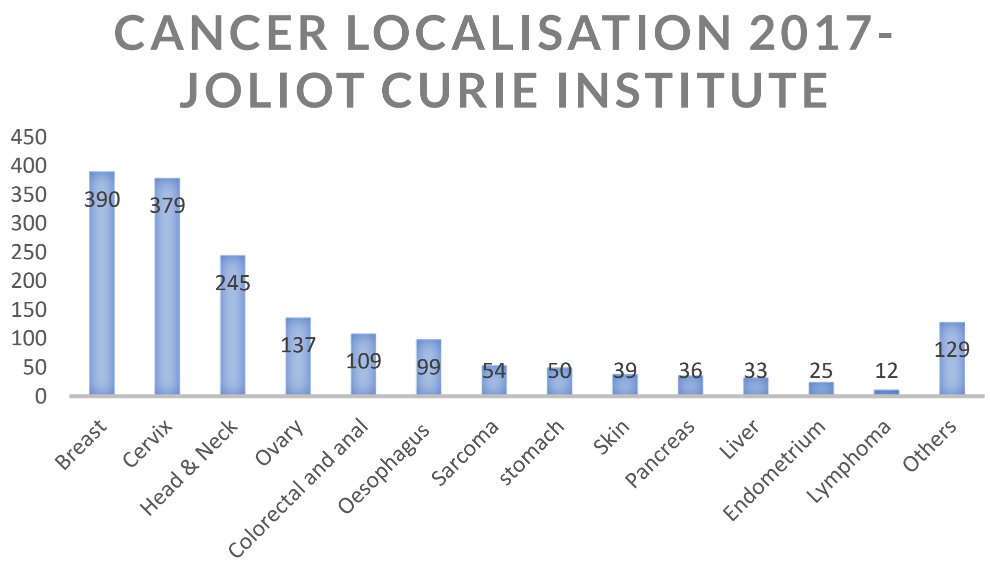


Figure 1: Cancer localisation, Cancer Institute Tumor Registry, 2017

Stage	Number of patients	%
I	0	0,0%
II	25	8,9%
III	110	39,0%
IV	147	52,1%

Table 1. Patients registered by disease stage, Cancer Institute Tumor Registry, 2017

Senegal installed its first Co-60 teletherapy machine at the Institut Joliot Curie (IJC) in 1989 as a gift from the Dead Arc de France, an Association for Cancer Research. The source had to be changed several times due to the normal decay as its activity decreases with time. In 1994, the source was replaced and used to treat patients until 2000 when the activity became very low, while the wait time for radiation therapy (RT) treatment in Senegal was typically between 7 to 9 months, partially due to a shortage of RT equipment and an insufficient number of specialists.

In 2006, the Union of International Cancer Centres – which was at that time called Borderless Medical Physicists – supported the institute in replacing the cobalt machine with another unit and trained a local physicist to calculate treatment time (patient dose) and perform basic cobalt therapy quality control. In 2007, the source was replaced again, and the first medical physicist came back from academic training in France sponsored by the IAEA. Consisting of two radiation oncologists (RO), two medical radiation physicists (MP), an oncology nurse (ON), and two radiation therapists (RTT), the staff at the cancer centre in Dakar had the potential to treat approximately 30-40 patients per day with external beam RT using a Co-60 teletherapy unit. As the new source was highly active, there was a rise in the number of patients between 2007 and 2012. IJC was the only treatment facility within a 500-km radius and further served several neighbouring countries as shown in Figure 3.

In 2012, the source was replaced again by a safer radiation source, which was used in treating patients until 2016, when the machine broke down due to several successive failures (source stuck, electricity failure, shift in the physical and mechanical parameters of the machine).

Following this breakdown, public debate on the lack of access to radiotherapy services and expensive treatment abroad became a national issue. Between February 2017 and the end of January 2018, 150 patients were sent abroad for treatment, which cost 7,500 euros per patient (travel, subsistence, and radiation treatment). The government via the Ministry of Health and the Ministry of Finance invited stakeholders and end users to design a sustainable project within a limited budget. After several meetings and a discussion about which type of RT machine to use as well as the sustainability in the long run, participants decided on LINACs for the following reasons:

- ✓ LINACs will play a larger role for developing countries as they significantly improve the quality of treatment (optimization).
- ✓ Source-based devices require significant security considerations, such as a vault that houses the cobalt unit in operation as well as special security arrangements for source transfers and disposal.
- ✓ Safety considerations also played a significant role. Cobalt sources always produce radiation and have a high potential to cause harm. Therefore, an adequate radiation safety framework must be in place and compliant with the safety standards set by the IAEA.

PROJECT DESCRIPTION

This project included several stages: (1) assessment of needs, (2) choice of radiation delivery system, (3) acquiring funds for equipment purchase, (4) cobalt removal, (5) conversion of an existing cobalt treatment room to house the LINAC system, (6) obtaining regulatory approvals, (7) LINAC system installation and commissioning, and (8) personnel training.

1. Assessment of needs

When the Co-60 teletherapy unit broke down, patients went abroad for radiation treatment again. The government assessed the need based on the cancer registry, imaging, pathology, and tumor board and decided to purchase three LINACs: one to replace the cobalt unit at IJC and two others for the two bunkers at the Dalal Jamm Public Hospital, which were already built but waiting for budgetary resources to purchase the equipment.

2. Choice of the radiation delivery system

JCI wanted a state-of-the-art LINAC, however they needed one that would fit into a small bunker, which had previously housed the cobalt machine. Due to its built-in structural shielding, which reduced the amount of shielding needed inside the bunker walls, the

Unique™ Performance Edition Varian RT system was the only machine capable of fitting directly into the existing bunker. This device was also designed to be shipped in one container and installed in less than one month.

This particular system allows for medical staff to efficiently customise treatment based on the unique anatomic characteristics of the patient, which in turn maximises the benefit while minimises toxicity. This new device was designed to increase the number of patients who would receive therapy and substantially improve the quality of the treatment.

3. Acquiring funds for equipment purchase (initial financing)

The government funded the project, and according to the Ministry of Health, the total budget allocated to the Aristide Le Dantec Hospital was 2.5 billion Francs CFA (3.8 million Euro). It included the following:

- ✓ Cobalt source handling (removal, decommissioning, conventional simulator decommissioning, repatriation to Hungary)
- ✓ Purchase of the LINAC and its warranty (5 years)
- ✓ CT scanner (Hitachi, Supria 16 slices)
- ✓ Brachytherapy AfterLoader (GammedPlus and Source Iridium)
- ✓ Immobilization devices
- ✓ Quality control (QC) tools (Water tank, chambers, etc.)

The IJC supported the cost of smaller equipment (uninterruptable power supply system (UPS), air conditioning, network, generator) that was to be acquired.

4. Cobalt removal

In 2017, the Alcyon II (Alcyon Head: GK 60 T03) and serial number (001-09) needed to be decommissioned and removed. After a call for bids, Carrefour Medical – which is a national society for medical equipment – was charged with decommissioning the source, sending it back to Hungary (Institute of Isotopes, Budapest), and installing the new LINAC.

In this way, the source removal was designed around three phases: decommissioning, interim storage at the IJC, and transportation to Hungary.

Carrefour Medical carried out the decommissioning in conjunction with NCT, which is a nuclear transportation service company. This took one week from 28 July to 5 August 2017 (see Figure 4). The head was securely stored on site for one month (refer to Figure 5). The source was then transported to Hungary (see Figure 6), and the government funded the cost for repatriation.

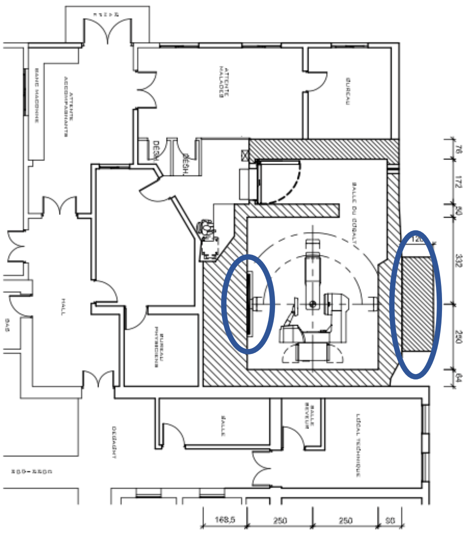
Figure 4: Cobalt decommissioning and removal

Figure 5: Interim storage of the head at the hospital

Figure 6: Repatriation of the source

5. Conversion of the existing cobalt treatment room to house the LINAC system

The bunker required some modifications to accommodate the LINAC machine, therefore the shielding was reinforced to meet radiation safety and regulatory requirements. Steel and



concrete were added to the left side wall of the bunker and to the back, front right side as shown in Figure 7. A pit was also added on the floor to house the base of the LINAC. The maze required modifications to accommodate a new door and to provide access for the cooling system required by the LINAC. Finally, the treatment console area was also improved and modernised. Altogether, it took approximately three months from when the bunker was modified to when the LINAC machine was installed. There were no particular challenges that emerged during the conversion of the treatment room.

Figure 7: Additional shielding for the bunker.

6. Obtaining regulatory approval from the National Regulatory Authority (ARSN)

Before the LINAC was put into use, the modification of the clinical use license for the linear accelerator was submitted to the National Regulatory Authority (ARSN). There was a delay on the regulator's part, because the ARSN was not ready to commission a LINAC at the time. ARSN inspectors went to France for training under the auspices of the IAEA project. After this, an onsite inspection took place. After several measurements of the vaults, rooms, and the building for the LINAC, the inspection concluded that everything was appropriately prepared, and ARSN issued the permit at the end of February 2018.

7. LINAC installation and commissioning

One month after completing the bunker shielding, the installation of the LINAC began, a process which proved to be challenging. The main logistical constraints were (1) the weight and size to bring the machine, (2) the air conditioner, (3) the power supply, and (4) permanent cooling water.

In general, linear accelerators have significant infrastructure demands. A stable and reliable power supply is required to ensure efficient functioning. Indeed, electrical power supply instability that causes alternating current voltage fluctuations can result in damage to electronic equipment and significantly affect magnetron lifetime, therefore impacting the treatment planning and control systems. Power cuts can cause components to operate outside normal rated values, leading to overheating and operational issues, such as data error or loss, equipment malfunction and component failure. Therefore, the hospital decided to purchase an uninterruptible power supply system to provide protection for the LINAC, desktop computers, workstations and other electronic devices in the radiotherapy facility by maintaining a steady voltage during brownouts and blackouts. The hospital was responsible for handling the placement of the machine, air conditioner, and permanent cooling water. Despite the substantial weight and size of the equipment, they were able to successfully complete the task.

After the installation was completed, the acceptance process began, followed by commissioning. The new LINAC had not been preconfigured, meaning that there was a need to perform measurements on beam data (beam profiles, percent-depth dose, output factors and absolute dose in the reference condition). Collecting this data is a prerequisite; it is later used in the treatment planning system to model the LINAC treatment beam. All the tests were executed successfully, and the results were within tolerance.

The LINAC is now operating as expected, and its downtime periods are less than three days. JCI has a five-year maintenance contract for the LINAC with Carrefour, the Varian local distributor, which has a well-established protocol with 4 reviews per year and as needed upon request.

Two biomedical engineers went to Las Vegas, NV, USA for maintenance training level I and level II to learn how to handle small breakdowns of the machine. This training was included into the purchase contract.

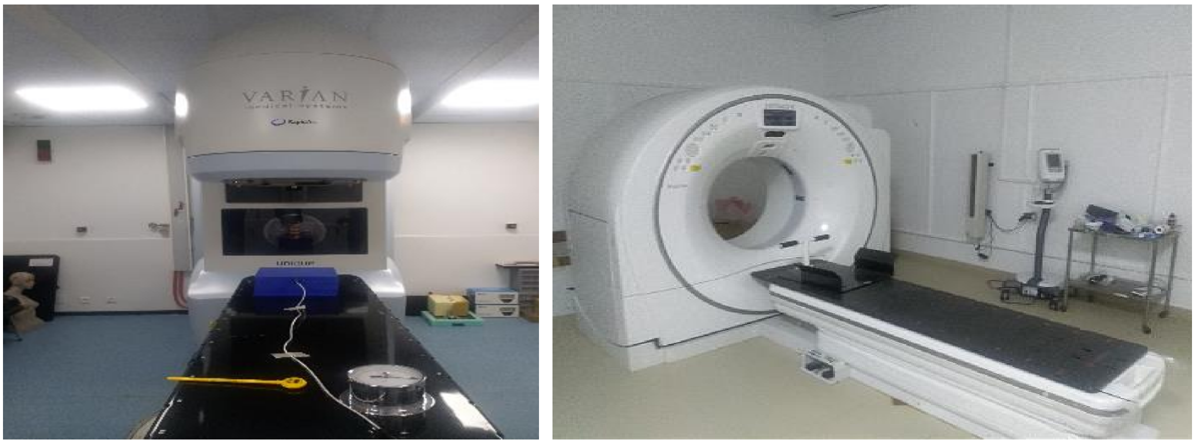


Figure 8: Installation of the LINAC and CT scanner.

8. Training

Linear accelerators require more staff to run than Co-60 machines, and IJC had to consider specific training programmes to operate this highly technical piece of equipment. After identifying the knowledge, practices, or skills needed to successfully reach the desired radiotherapy service goals, ten radiographers and three resident radiation oncologists were sent to Morocco for a six-month training programme with the support of Belgium in June 2017.

The purchase contract for the LINAC included not only operations, service, and maintenance of the machine but also educational and training opportunities. One radiation oncologist, one medical physicist, and two radiation therapists went to a three-week long training to a site where the same machine was already installed.

Further plans

	Actual, 2021	2028
Number of RT Centers	2 (+1) Private	6
Radiation Oncologists	8	14 (Minimum)

Resident Oncologists	10	
Medical Physicists	4 (+1) Imaging	
Radiation Oncology Nurses	2	12
Radiation Therapists	10	32
Dosimetrists	0	7
Mechanical Engineers (LINAC)	4	6
Electronics Engineers	0	6

Senegal is planning on expanding its staff for treatment capacity in the following years (see Table 2 below).

Table 2: Targeted increase in the number of staff up to 2028

THE ROLE OF INTERNATIONAL SUPPORT PROGRAMMES

1. The IAEA

The IAEA TC Program has a delivery mechanism in which IAEA recipient Member States can propose national projects in different fields of activity. For instance, SEN6023 is a Senegal national project, the overall objective of which is to strengthen capacities of nuclear medicine and RT in a sustainable manner to improve the management of non-communicable diseases in the country.

From 2017 to 2019, Senegal made related efforts to enhance cancer treatment and build new radiotherapy facilities. The following initiatives were implemented to achieve the project's goals:

- ✓ Two expert missions to audit radiotherapy units
- ✓ Training courses for ROs, MPs and radiation therapists (RTTs) on "Moving from 2D to 3D radiotherapy" with the delivery of contouring tools (Educase)
- ✓ Procurement of immobilization devices, QC tools (ionizing chamber), in radiotherapy delivery (November 2019)
- ✓ Training (fellowship) of one medical physicist in Trieste
- ✓ Training (fellowship) of two RTTs

To assure the proper calibration of radiotherapy beams with the aim of avoiding mistreatment of cancer patients and preventing radiation accidents, the IAEA dosimetry service carried out an audit. The Agency sent thermoluminescent dosimeters (TLDs), and a local physicist performed the measurements to later send the TLDs back to the IAEA. The process took place as part of the national project, which included irradiation for validation of radiation beams calibration. IJC conducted the measurement on 23 April 2018 and received the results in mid-June 2018. The audit was executed successfully, and the results were within tolerance.

2. Radiating Hope

Radiating Hope (http://www.radiatinghope.org/) is a non-profit organization focused on improving radiation oncology care around the globe and has been collaborating with the IJC and the clinic since 2012. The organization further donated a brachytherapy machine that was installed in 2013.

Radiating Hope also supported a scientific visit (train-the-trainer) of one radiation oncologist, one medical physicist and one dosimetrist to the Karmanos Cancer Center Detroit, IL, USA.

Radiating Hope also sent a team that consisted of an RO, MP, and dosimetrist in May 2019 to help with the transition from 2D to 3D and donation of equipment (two breast boards and a head base plate).

3. Belgium Cooperation

The Belgium Cooperation helps to send resident oncologists and radiation therapists abroad for training.

MAIN LESSONS LEARNED

1. Improved treatment

The great benefits result in better (1) quality dosimetry, (2) treatment process, (3) number of patients treated, and (4) radiation safety.

- ✓ ***Quality dosimetry***

  Co-60 gamma-radiation energy is 1.25 MV on average, with an approximate percentage depth of 55% at 10 cm that has a less defined penumbra. Its decaying dose rate limits its use in clinical situations compared to Unique (LINAC). IJC personnel noticed significant differences in grade 3 to 5 toxicities for certain head, neck and breast cancers. Previously, IJC did not treat prostate cancers with nodes due to the weak penetration potential of the beam, but now the hospital treats more prostate cases. In general, LINAC can treat a number of areas better than a Co-60 source.

- ✓ ***Treatment process***

  The improvement of current techniques in all areas of the workplace: patient throughput, patient setup, simulation, prescription, contouring, treatment planning, quality assurance, and general equipment functionality.

  The improvement of the adequacy and accuracy of the treatment planning system: calculating different doses for different patients as well as adapting the length of treatment.

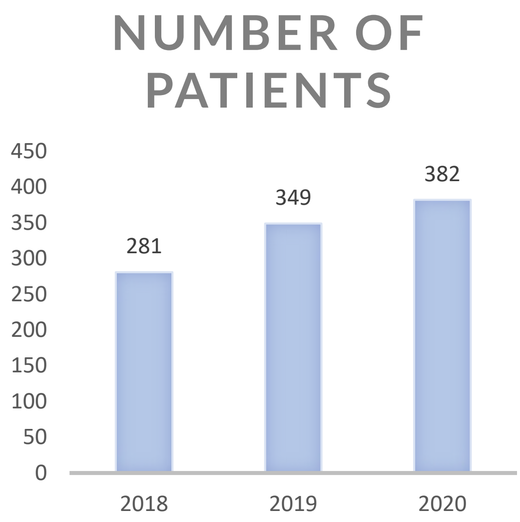


Figure 9: The number of patients treated per year.

The implementation of procedures and protocols by ensuring the appropriate establishment of second check systems for all areas of work to prevent "catastrophic" events.

✓ ***Number of patients treated***

LINAC has the potential to treat more than 60 patients per day with two shifts (rotations) of RTTs. Between March 2018 and the end of December 2020, 1,012 patients received external beam radiotherapy at the clinic (see Figures 9 and 10). The IJC began this process with 10 patients per day gradually as they gained experience and increased the number of patients treated daily. However, the number was limited in 2020 due to the limitations that resulted from the COVID-19 pandemic.

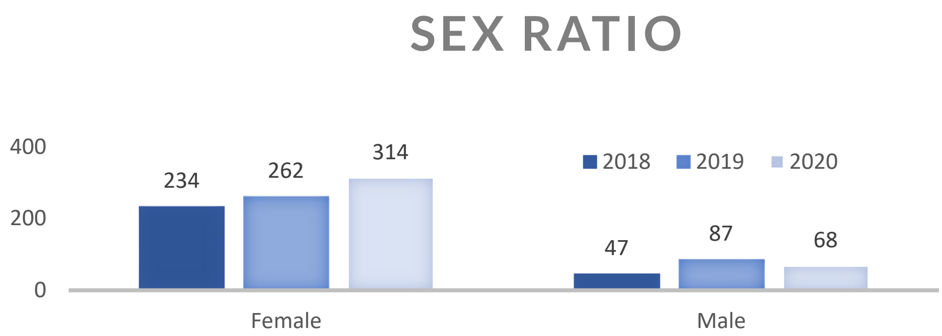


Figure 10: Patient sex ratio

✓ ***Radiation Safety***

A cobalt source always produces radiation, meaning there is high potential for the source to cause harm. Therefore, an adequate radiation safety framework was in place supported by gamma-time intensity recorders (GTIR) to be compliant with the safety standards set by the IAEA.

2. Prerequisites to successful implementation

Converting from cobalt to alternative techniques such as LINAC in a limited-resource setting is sometimes not easy but can be successful. It requires good assessment of needs and what already exists, a clearly defined project management structure and excellent coordination of various stakeholders involved in the project. The following list represents the steps the IJC recommends the following to successfully implement similar projects:

Assess the needs by reviewing the:

- ✓ Cancer registry
- ✓ Imaging
- ✓ Pathology
- ✓ Tumor board

Audit existing

- ✓ Regulations in radiation security and safety
- ✓ Human resources
- ✓ Equipment

Build a new facility, which requires:

- ✓ Conception
- ✓ Call for bids

Train the staff (end users). Training must be addressed before building a new facility. LINAC requires more staff than cobalt-based units, including positions such as:

- ✓ Radiation Oncologist (RO)
- ✓ Medical Physicist (MP)
- ✓ Radiation therapist (RTT)
- ✓ Oncology Nurse (ON)
- ✓ Mechanical engineer (ME)

Finance (Government)

- ✓ Evaluation of the costs
- ✓ Planning and budget
- ✓ Take opportunities (international organizations, fundraising)

Engage stakeholders. At the conception level of the project, involve key actors at all levels.

- ✓ National regulatory authority for safety and security for licensing and shielding requirements and audit
- ✓ Architects for facility design
- ✓ End users (RO, MP, a quality control specialist, the manager of an organization)

Get regulatory approval

Commission the LINAC

Start implementing the following

- ✓ Workflow tests
- ✓ Computerised medical reports
- ✓ Limit the number of patients
- ✓ 3D conformation radiotherapy before IMRT, VMAT
- ✓ Introduce the process on a step-by-step basis
  - Pelvis Tumors
  - Bone and Brain Metastasis

- Oesophagus
- Head and Neck
- Complex Technique (IMRT, VMAT, SRS)

✓ Delay brachytherapy

Operate the new system and gain experience

Address maintenance and achieve sustainability

✓ Investigate what service options are available to you and how each organization ensures proper training for service personnel

✓ Ensure the warranty duration and coverage is appropriate to your situation and your equipment

✓ Complement the warranty coverage with additional shared-risk insurance or other service contracts (natural disaster).

CONCLUSION

The transition from Cobalt to LINAC in Senegal proved to be a great success. The project emphasised the effective transition to LINAC, which requires good assessment, clearly defined management and excellent collaboration between the decision makers and key actors at all levels. The end users were involved at the very beginning, which allowed the manufacturer to quickly tackle any unforeseen issues, including obtaining licenses, handling Customs documents, and approving cobalt source removal. Assistance from international programmes helped to 1) support the hospital's efforts in establishing and strengthening radiotherapy, 2) build capacity through the long-term training of radiation oncologists and medical physicists, and 3) assist in the procurement of equipment and expert services.

LINAC machines are the most viable option and starting point for installing other radiotherapy centres inside the country to answer the call of millions of Senegalese citizens with no access to RT services. Sustainability was addressed to maintain the machines operational and continuous training for physicians and RT staff. Because they significantly improve the quality of treatment, LINACs are the future for developing countries. This system allows for medical personnel to efficiently customise radiation treatment to the unique anatomic characteristics of the patient, maximizing benefits while minimizing toxicity. LINAC machines also allow for hospitals and clinics to treat a higher number of patients. That said, introducing LINACs pose certain challenges that can be more easily tackled at the onset with adequate preparation. Our hope is that the main points outlined in this paper can serve as a resource and model for other underserved regions throughout Africa.

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