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International Corner

Lessons Learned From an Epic Transformation of a Radiation Oncology Department in Guatemala: Keys to Success

Edgar Ruiz, MD,[a,1] Hiram A. Gay, MD,[b,*,1] Milton Ixquiac, MS,[a] Angel Velarde, MD,[a] Baozhou Sun, PhD,[c] Jose García-Ramirez, MS,[b] Eric Laugeman, MS,[b] Benjamin Li, MD,[d,e,f] Jeff Michalski, MD,[b] Vicky de Falla, MD,[a] Geoff Hugo, PhD,[b] and Jacaranda Van Rheenen, PhD[g]

[a]Liga Nacional Contra el Cancer/INCAN, Guatemala City, Guatemala; [b]Department of Radiation Oncology, Washington University School of Medicine, St. Louis, Missouri; [c]Department of Radiation Oncology, Baylor College of Medicine, Houston, Texas; [d]Department of Radiation Oncology, Rayos Contra Cancer, Seattle, Washington; [e]Department of Radiation Oncology, University of Washington, Seattle, Washington; [f]Division of Radiation Oncology, Fred Hutch Cancer Center, Seattle, Washington; and [g]Global Health Center at the Institute of Public Health, Washington University in St. Louis, St. Louis, Missouri

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Purpose: We describe the radical modernization of a radiation oncology department in a developing country, Guatemala, from 2015 to the beginning of 2024. The Instituto de Cancerología y Hospital Dr. Bernardo del Valle S (INCAN) is the only public radiotherapy clinic serving patient referrals from the Ministry of Public Health and Social Assistance program.
Methods and Materials: We describe the state of the radiation oncology department in 2015 versus 2024 while chronicling its gradual transformation. This multifaceted collaboration involved academic centers, government agencies, International Atomic Energy Agency (IAEA), industry, and nonprofits and continues to this day. We analyze the infrastructure, staff, radiotherapy equipment, physics equipment, patient careCo-60 decommissioning, and educational initiatives.
Results: We graphically illustrate the impact of these changes in treatment delivery time, consults, follow-up visits, CT simulations, new patients treated in each linear accelerator, new patients treated with 2D, 3D, IMRT/VMAT, and superficial techniques, new patients treated with 2D LDR, 2D HDR, or 3D techniques, causes of linear accelerator downtime, and weekly patients on treatment. We provide a figure of the various sequential and parallel steps to modernize a radiation oncology department. We describe the complexities of radioisotope repatriation and safe disposal. We provide a comprehensive table of wisdom pearls regarding project governance, team, education, finances, culture, and language. We also discuss the impact of artificial intelligence in contouring
Conclusion: The transformation of the INCAN radiation oncology department in Guatemala is a testimony to many's hard work, vision, and perseverance for the betterment of Guatemalan patients while facing incredible financial hardship. We hope that what we have learned in the past nine years will help others achieve even greater success in a shorter time

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[1]E.R. and H.A.G. contributed equally to this work.

*Corresponding author: Hiram A. Gay, MD.; Email: hiramgay@wustl.edu

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Introduction

The National League Against Cancer (LIGA) in Guatemala created the Instituto de Cancerología y Hospital Dr. Bernardo del Valle S (INCAN) cancer center in July 1958. INCAN is the only public radiation therapy clinic serving patient referrals from the Ministry of Public Health and Social Assistance program. INCAN also provides cancer treatment for most of the indigent population in Guatemala and is 1 of 4 radiation therapy centers in Guatemala. The radiation therapy program started at INCAN on December 21, 1960, with a Co-60 teletherapy unit. In 1969, INCAN expanded to a 3-floor facility with a basement and a capacity of 80 hospital beds.

The Washington University in Saint Louis Department of Radiation Oncology and LIGA/INCAN initiated their collaborative relationship in 2015 when a radiation oncologist and medical physicist were sent to evaluate the radiation oncology department**.** This built on the preexisting relationship between Washington University's Department of Surgery, the Division of Public Health Sciences, the Institute for Public Health, and LIGA/INCAN. Here, we detail some lessons from this collaboration with LIGA/INCAN, focused mainly on the radiation oncology department.

Radiation Oncology Department Infrastructure

2015

The radiation therapy department had 8 bunkers, 4 of which were in use. The construction of the 2 most recent bunkers took place from 2010 to 2011 and was funded by both the Guatemalan government and LIGA. They housed an Elekta Compact with financial assistance from the International Atomic Energy Agency (IAEA) and a Varian Unique purchased by LIGA. The 2 older bunkers in use housed a Cirrus Co-60 teletherapy unit and a GE MaximaR 100 superficial kV therapy machine, the latter in use since 1968. The remaining unused 4 bunkers formerly housed a Theratron 780 Co-60 teletherapy unit (decommissioned in 2014), a Picker V90 teletherapy unit (decommissioned in 2012), a medium dose rate Cs-137 Curietron unit with 9 sources (decommissioned in 2008), and the last bunker was used for storage.

Additional spaces included male and female areas with a patient bathroom and dressing room each. Low-Dose Rate (LDR) brachytherapy patients received treatments in 1 of 2 wards, with 5 treatment beds in total. There was a physics workroom, 2 consult rooms, a computed tomography (CT) simulator room shared with diagnostic radiology and partially funded by the IAEA and LIGA in 2005, a conventional simulator room with a Huestis simulator, and a storage room for immobilization masks, and an LDR brachytherapy implant room.

2024

In 2024, the radiation therapy department has 8 bunkers. The Elekta Compact was decommissioned in February 2022, and now the bunker is used for storage and may house a future linear accelerator with stereotactic body radiation therapy, electron, and advanced technologies. The Varian Unique remains operational and was upgraded with a donated multileaf collimator (MLC) in 2022. Four bunkers have been repurposed: the Cirrus Co-60 teletherapy unit was decommissioned in 2019 and replaced by a Varian Halcyon installed in November of 2019, and the project has been previously described in detail.[1] The 2 bunkers formerly housing the Theratron 780 and Picker V9 were joined to create one for the new Varian Halcyon Elite linear accelerator installed in February 2023 and funded by LIGA. The bunker for the MaximaR 100 was decommissioned in October 2021, then modified with adequate shielding for a Varian GammaMed Plus Ir-192 high-dose rate (HDR) brachytherapy unit in use since 2022. One bunker had been used for HDR Co-60 brachytherapy since 2018 and was decommissioned in May 2023 to house a Varian Bravos unit in September 2023. Both Ir-192 units support CT-based 3-dimensional (3D) brachytherapy planning. The bunker that housed the Curietron is used as a surgical suite for HDR brachytherapy procedures. A small bunker previously housing a diagnostic mammography unit has now been used for a Sensus SRT 100+ (Sensus Healthcare) since September 2023 for treating superficial skin lesions.

The physics room remains the same, but many other spaces have changed. The CT simulator (shared with diagnostic radiology) had remained operational until 2021 when it was replaced by a 36-slice-per-second Cannon CT for exclusive use by diagnostic radiology. Thereafter, the conventional Huestis simulator was decommissioned in November 2021 to make room for a new 16-slice-per-second CT simulator (Philips Brilliance Big Bore CT, Philips) with an indexed couch, 100-cm big bore, and exclusive for radiation therapy simulations. The conference room was modified to add a radiation safety office. The number of consult rooms was doubled from 2 to 4, with additional patient changing rooms that were formerly storage space. The bathrooms were remodeled, and the department was painted and cleaned. Signs were placed to highlight escape routes. Radiation-restricted and controlled areas were labeled. Patient waiting areas and consult rooms were improved.

Lessons learned

Increasing the capacity to meet patient needs was possible through better use of the existing space, including creative remodeling in some cases. The decommissioning of the 3 Co-60 bunkers freed 3 rooms that were repurposed. Washington University gave us a new vision of how modern technology could help us treat more patients with greater precision and accuracy while reducing side effects.

Staff

2015

The staff at LIGA/INCAN consisted of 5 radiation oncologists, 2 medical physicists, 12 radiation therapists, 3 practical nurses, 1 radiation oncology resident, 1 CT technician, 1 conventional simulator technician, 1 staff member in charge of masks and brachytherapy, and 1 secretary. All radiation oncologists divided their workday between LIGA/INCAN and private practice.

Effectively, there were 1.5 physicists, and 2 were obtaining their physics masters training in Italy. More physicists were needed, and physicists performed the dual role of physics and dosimetry.

Nursing had a morning and evening shift and was understaffed. Only 1 nurse covered each shift, and they performed multiple roles, from assisting the physicians to staffing the front desk, obtaining patient charts, and keeping patient records. The patient list was handwritten, without any electronic scheduling or record-keeping system.

There were 2 therapists per teletherapy machine, with therapists working 6-hour shifts. The chief therapist had a 12-hour shift excluding a 1-hour break. In addition, some therapists worked additional hours at a private practice.

A new residency program had begun training its first 2 residents. The residents had abundant clinical exposure at LIGA/INCAN but lacked exposure to advanced technologies and earlier-stage malignancies seen in private practices.

2024

The team has increased in size, albeit with some staff turnover, and new members have made significant contributions to benefit patients. Currently, there are 4 radiation oncologists (2 full-time and 2 part-time), 1 physician assistant, 3 radiation oncology residents, 3 medical physicists, 1 radiation safety officer, 4 dosimetrists, 15 radiation therapists, 5 practical nurses, 1 registered nurse dedicated to the department, 1 CT technician, 3 HDR brachytherapy technicians, 5 secretaries, and 1 department administrator.

The physicists' training was supported by the IAEA and LIGA. The radiation protection officer received his master's degree in radioprotection and dosimetry in Brazil and was the first in Guatemala to receive this training. There are 3 additional dosimetrists with medical physics training. One dosimetrist joined in 2022 with experience with advanced radiation therapy techniques at a private practice, and some training in the United States (U.S.).

Nurses continue with shifts in the morning, and their numbers have increased. Various secretaries in the radiation therapy department handle patient scheduling, customer service, and patient navigation. ARIA (Varian) is used to schedule all patients.

Lessons learned

Increasing the staff was critical to meeting patient needs and providing more efficient patient care. Additional roles were added to the department to better support patients and the rest of the team: physician assistants, radiation safety officer, dosimetrists, a registered nurse, and an administrator. Implementing electronic patient scheduling resulted in a more efficient workflow for consults, simulations, and treatment starts, eliminating the need for a written schedule notebook. Electronically scheduled appointments have significantly reduced patient wait times in the department. In the past, patients came early in the day and waited hours until their treatment time. Some staff changes were necessary to change the culture of the department. However, some of the changes resulted in some irreplaceable losses of talent that could have been avoided.

More radiation oncologists are needed to meet patient demand and ease the workload by transitioning to modern techniques like volumetric modulated arc therapy (VMAT) and intensity modulated radiation therapy (IMRT). In 2023, in collaboration with the University of San Carlos of Guatemala, the radiation oncology residency was reestablished, adding 3 R1 residents. In 2025 these residents will graduate from our three-year program. Transition to these newer technologies has required additional training for physicists, dosimetrists, physicians, and radiation therapists so that patients can fully benefit from this technological paradigm shift. Shifting to a model where LIGA fully pays radiation oncologists versus dividing their time between INCAN and a private practice has increased the commitment to the institution.

Radiation Therapy Equipment

2015

In 2015, the clinic had 2 linear accelerators that were installed in June of 2014: a Varian Unique and an Elekta

Compact generating 6 MV photons and no electrons. Both relied on standardized cerrobend blocks.

There was basic immobilization equipment, such as an assortment of headrests and breast boards. The entrances had warning signs and indicators when the radiation was active. Physical wedges were used instead of virtual ones. There was a severe shortage of cerrobend for creating customized patient blocks, and thermoplastic head and neck masks were reused for different patients.

The Unique was the most reliable of the linear accelerators and treated up to 70 patients per day. It had 2 therapist shifts, from 7 AM to 1 PM and 1 PM to 7 PM. It operated at a dose rate of 400 MU per minute but could go up to 600 MU per minute locked.

The Elekta Compact was the least reliable linear accelerator and treated about 50 patients per day. The Compact had 2 therapist shifts, from 7 AM to 1 PM and 1 PM to 7 PM. It operated at a dose rate of 200 MU per minute but could go up to 350 MU per minute.

The department had 3 Co-60 units: Cirus, Theratron 780, and Picker V90. Only the isocentric Cirus was functional with 2 shifts from 7 AM to 1 PM and 1 PM to 7 PM, treating approximately 25 patients. Treatment lasted about 35 minutes per patient due to the low activity of the old Co-60 source.

The department had 1 Huestis conventional X-ray simulator with localization lasers. The simulator was underutilized, with < 30 % of patients simulated. Treatment fields were mainly positioned based on external and palpable internal anatomy without anatomic imaging.

INCAN had a diagnostic CT scanner that was also used as a CT simulator. The CT scanner did not have a patient-marking laser system or radiation therapy software. Instead, reference "BB" markers for patient setup marks were used. The physics staff had equipped the CT scanner with a nonindexed flat tabletop to mimic the radiation therapy flat couch. When the CT scanner was operational, the unit was used 90% for diagnostic purposes and 10% for radiation therapy. Less than 5% of patients were 3D simulated.

The GE MaximaR 100 superficial kV therapy machine was used for treating skin cancer. The unit had provided many years of reliable service.

The department had 27 Cs-137 sources in use for at least 15 years, increasing treatment length. Of these, 24 sources were used to create 5 fixed-geometry Henschke tandem and ovoid treatment configurations. These sources were decommissioned in 2021. A medium dose rate Cs-137 Curietron unit needed decommissioning later in 2008.

2024

The implementation of the Halcyon in 2019 was a significant paradigm shift from clinical and 2-dimensional (2D) simulations to 3-dimensional (3D) CT-based simulations. Most patients are now treated with advanced techniques like VMAT/IMRT, followed to a lesser degree by 3D techniques. VMAT/IMRT with the Halcyon and 3D techniques using the donated MLCs with the Varian Unique installed in 2022 have shortened treatment delivery times from up to 48 minutes in the Co-60 era to as short as 8 minutes with VMAT increasing efficiency and patient comfort (Fig. 1). The Halcyon also changed another treatment paradigm because now image-guided radiation therapy is mandatory for all patients treated with it. A phantom with automatic 3D movements, Blue-Phantom (IBA), was acquired to perform the commissioning of all the linear accelerators.

After seeing the increased number of patients being treated with greater quality and efficiency, LIGA decided to purchase in 2023 a new linear accelerator, Varian Elite. This equipment has kV imaging and improved cone beam CT (CBCT) imaging.

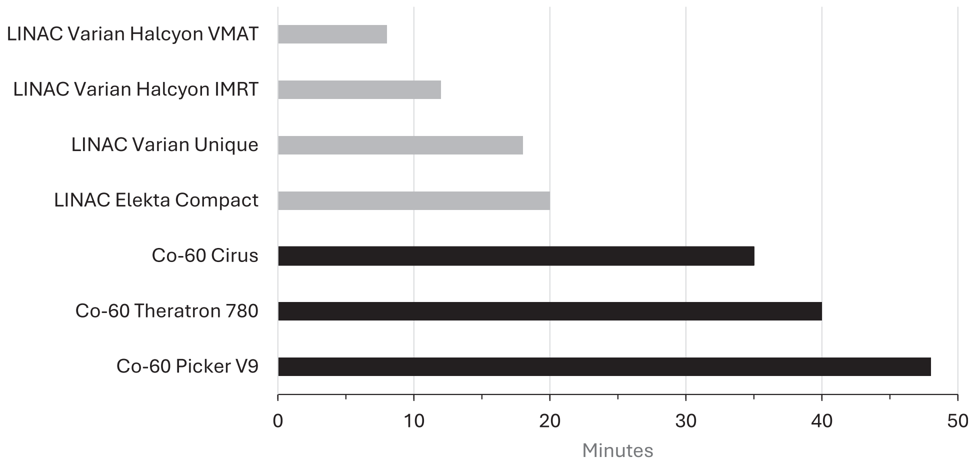

Figure 1 Average breast cancer treatment time depending on equipment and technique at National League Against Cancer (LIGA)/Instituto de Cancerología y Hospital Dr. Bernardo del Valle S (INCAN).

Another significant change was decommissioning the 3 Co-60 teletherapy units and 27 Cs-137 LDR sources. Only 1 Co-60 radioactive source was used until May 2023 in the SagiNova HDR unit. The HDR program started in 2018 with training sponsored by the IAEA. We transitioned from using a C-arm to obtain orthogonal images for brachytherapy planning to CT-based 3D treatment planning. New HDR quality control equipment was acquired, including a well chamber and a ruler for source position verification.

In 2021, a Varian GammaMed Ir-192 HDR unit was acquired with 3D CT-based planning. In 2023, when the Co-60 source from the SagiNova unit reached its half-life, the unit was decommissioned and replaced with a Varian Bravos Ir-192 HDR unit. The unit arrived in Guatemala in 2023. With this upgrade, 2D simulations were eliminated.

Along with the installation of the Halcyon in 2019 and Halcyon Elite in 2023, the Eclipse treatment planning system (TPS) and the ARIA oncology management system were commissioned. The Unique and Compact were commissioned in Eclipse to consolidate all treatment planning into 1 TPS. During commissioning, the Unique's dose rate was increased in 2021 from 400 MU/min to 600 MU/min for more efficient treatment delivery. Eclipse is also used for 3D CT-based HDR brachytherapy planning.

In February 2021, a donated MLC was installed in the Unique. The MLC makes it possible to deliver custom 3D treatments in a shorter time, eliminating the need to enter the treatment room and manually change the cerrobend blocks for each field. The MLC also eliminated manual labor in making custom cerrobend blocks in the mold workshop.

The use of a physical whiteboard to document the patient workflow from simulation to treatment plan approval has been substituted with electronic documentation and signatures using ARIA. Using notebooks for patient scheduling was substituted with electronic scheduling with ARIA.

A set of immobilizers was also purchased in 2020 for reproducible treatment setups: head and neck ± shoulders masks, Combifix for pelvis and lower extremities, and a breastboard (Civco). A new CT dedicated to treatment simulations was acquired at the end of 2020 and installed in April of 2021. The CT has allowed us to support more advanced treatment techniques (3D Conformal Radiation Therapy (3DCRT), IMRT, and VMAT). The wider bore allows treatment simulations with immobilization equipment. The CT has a laser system for marking the treatment isocenter, and the table is indexed and made of carbon fiber.

Lessons learned

The advent of the Varian Halcyon resulted in a significant radiation therapy paradigm shift, from 2D and few 3D treatments to IMRT/VMAT with some 3D treatments and eliminating 2D treatments. The Halcyon facilitated image-guided radiation therapy for all patients treated there. The disrepair of the Huestis 2D simulator forced the transition to CT-based simulations exclusively. The unavailability of the 2D simulator accelerated the shift to IMRT/VMAT. CT simulation has improved tumor targeting and sparing of organs at risk especially with IMRT/VMAT. Acquiring a dedicated CT simulator for radiation oncology with a flat indexed table and lasers has contributed to increased CT utilization, workflow efficiency, and more accurate setups to support IMRT/VMAT. The successful implementation of new techniques necessitated better immobilization devices and individualized immobilization like head and neck masks. The new equipment allowed 3D planning resulting in higher quality plans and reduction in side effects, and HDR allowed for faster and more convenient treatments for patients.

Hypofractionated treatments are now possible with IMRT/VMAT techniques. The reduced number of treatments is more cost-effective, more convenient for patients, and increases the capacity to treat more patients. Modern isocentric techniques require only 3 permanent tattoos versus at least 30 for a 2D 4-field pelvic box in the past.

There are still some technologies that are necessary for the department. None of the linear accelerators have electrons for treating superficial targets. Although the MaximaR 100 was used for very superficial targets, it was decommissioned in 2022 after failing. To fill this gap, a Sensus SRT 100+ has been used since January 2024 for treating superficial skin lesions.

Local engineering support is essential. The lack of local Elekta support contributed to its being down for months at a time significantly reducing the capacity to treat patients and ultimately resulting in being decommissioned. This was aggravated by the COVID-19 pandemic that limited support.

From the start of 2025 to September, the Halcyon up time was 95.14 % and for the Halcyon Elite 95.41%. The contract with Promed, who services Varian equipment in Central America, specifies an up time > 95 %. We have also purchased a magnetic resonance imaging device to serve both the radiology and radiation therapy departments in the future since we lack one at present. Next year we hope to have a new Varian TrueBeam linear accelerator increase capacity and to start a stereotactic radiosurgery and stereotactic body radiation therapy program which is only currently available in the private practice setting.

Physics Equipment

2015

The physics department had 7 ionization chambers: 2 0.6 cm^3, 1 0.3 cm^3, and 1 for kV X-rays, 1 Farmer chamber, 1 well chamber for LDR/MDR, and 1 well chamber for HDR. There were 4 electrometers for the ionization chambers. There were 4 phantoms: a beam calibration water tank (30 cm × 30 cm × 20 cm), a 1-dimensional motorized (depth) with no scanning acquisition software, a constancy phantom (20 cm × 20 cm × 20 cm), and an acrylic constancy phantom (40 cm × 40 cm). There was no beam scanning equipment to characterize the radiation field. There was a Huestis shielding block mold cutter for creating cerrobend blocks and a shielded workplace for handling Cs-137 radioactive sources.

There was 1 well chamber for brachytherapy source calibration. Only about 25 radiochromic films were in the department, and the Duoscan HiD scanner did not work. There was one Linacheck for daily radiation therapy machine output check. One homemade 3-point beam flatness and symmetry device used small volume diodes (Eivd system). There were 4 survey meters for radioactive sources.

Brachytherapy planning was performed in one of 2 Theraplan Plus workstations. 2D and 3D planning was performed in a donated XIO 4.4 workstation. The Theraplan and XIO workstations had exceeded their end-of-life and ran on outdated Pentium 5 processors that were too slow to perform more complex treatment planning. The department had an independent MU calculation software for external beam. There was no secondary check methodology for brachytherapy verification. The physics workroom is the same but with modern equipment.

2024

In 2020, with the support of the IAEA, LIGA acquired a TPS, PCRT 3D (Tecnicas Radiofisicas S.L.) version 6.2.0.0, with an external radiation therapy module and virtual simulation, installed on February 3, 2020. Due to the treatment planning needs for LDR brachytherapy, a brachytherapy module was added on February 6, 2020.

The PCRT 3D TPS was widely used for LDR with Cs-137 sources until June 2021, when LDR brachytherapy was finally decommissioned to fully transition to HDR brachytherapy. Finally, in May of 2022, the IAEA donated an Acuson NX2 ultrasound system for brachytherapy (Siemens).

In 2023, new dosimetry daily quality assurance (QA) (myQA Daily) and IMRT/VMAT patient QA (MatriXX Resolution) equipment were acquired from IBA. A CT phantom to calibrate the Houndsfield Units (HU) linearity of the radiation oncology dedicated CT, and a 1-dimensional water tank for commissioning, QA, output calibration and beam modeling (percent depth dose and output factor) measurements were obtained.

INTContour (CARINA AI), a web-based tool using deep learning algorithms for auto-segmentation[2] was implemented to automatically generate contours for different anatomic sites in LIGA/INCAN since 2022. The CT images were imported to INTContour for automatic contour generation within approximately 2 minutes. The structure file in digital imaging and communications in medicine (DICOM) format is downloaded from INTContour and imported to Eclipse TPS. Radiation oncologists then review the contours generated from INTContour and make necessary edits. As most contours need minor edits or do not need editing at all, the artificial intelligence-based auto-segmentation tool significantly improves the efficiency of normal tissue contours.

Lessons learned

With the implementation of HDR, acquiring a well chamber for the HDR source QA was essential. The TPS transition to Eclipse was necessary to utilize all the Halcyon capabilities. Implementing a quality control program is essential to verify the linear accelerators' performance. Acquiring adequate equipment to implement the quality control program is indispensable to meet international and protocol guidelines.

Patient Care

2015

There were 2 large consult rooms with basic examination equipment. Some physicians typed their notes with a mechanical typewriter. In 2014, 1263 new patient consults and 3573 follow-ups were seen, of which 80 % and 81.5 % were women, respectively. On average, physicians saw 5 consults and 14 follow-ups per day.

Approximately 3/4 of the patients treated were women, with cervical cancer being the most common, followed by breast cancer. Most cervical cancer treatments were stage IIB and above.

2024

There are 4 consult rooms with basic equipment and computers with ARIA to write progress notes. The electronic notes are also printed for the patient's paper hospital chart. Figures 2a, b show the monthly radiation oncology consults and follow-ups from 2018 to 2023, respectively. Figure 2c shows the rapid transition to CT-based simulations in mid-2020. Figure 3a depicts the increasing monthly new patients receiving teletherapy or external beam radiation therapy from 2017 to 2023. Figure 3b shows an increasing shift to VMAT/IMRT and a reduction in 3D plans after the installation of the

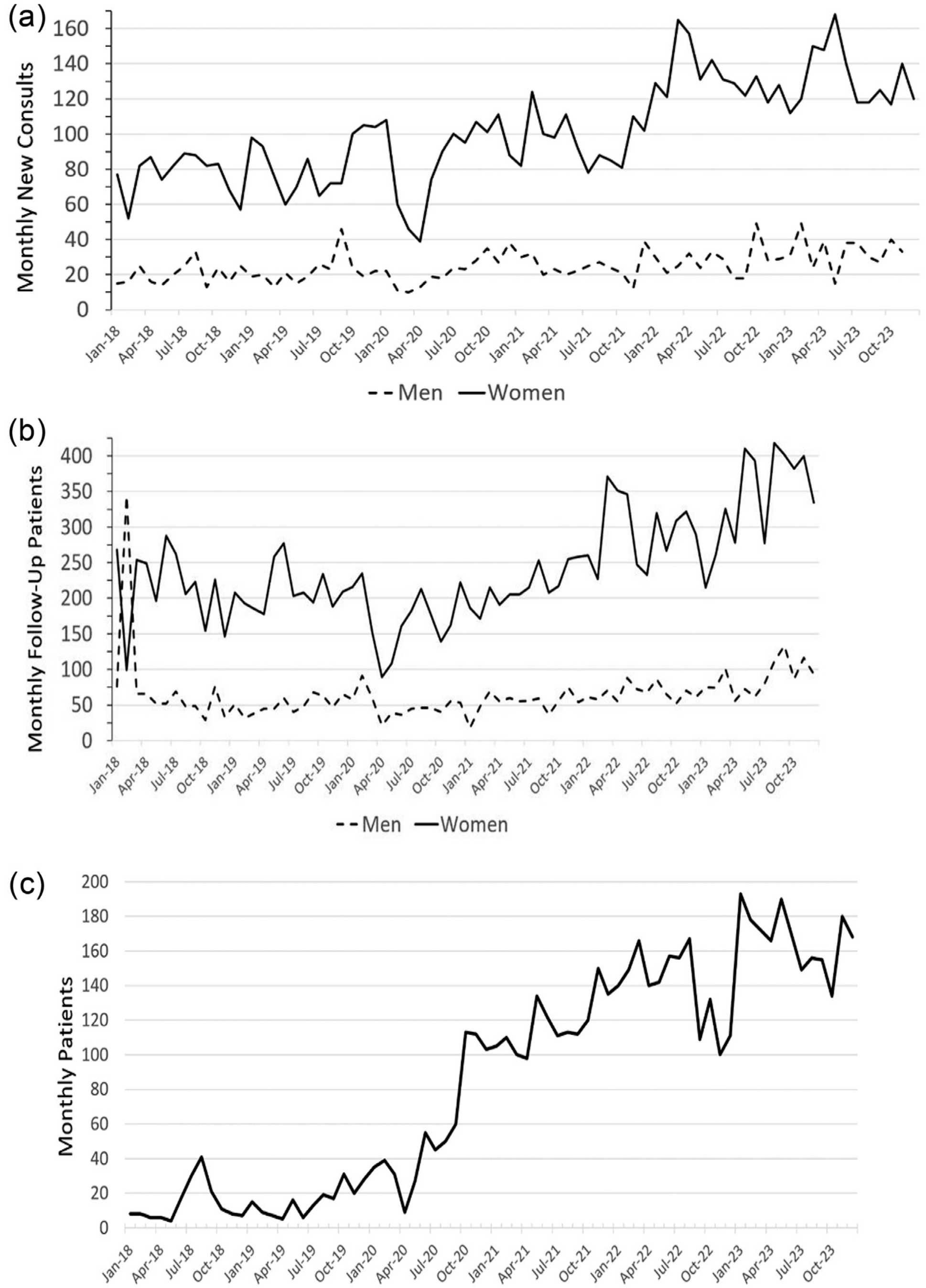

Figure 2 (a) Monthly radiation oncology consults at Instituto de Cancerología y Hospital Dr. Bernardo del Valle S (INCAN) by sex from 2018 to 2023. (b) Monthly radiation oncology follow-up visits at INCAN by sex from 2018 to 2023. (c) Monthly computed tomography (CT) simulations from 2018 to 2023.

Halcyon and Halcyon Elite, with the abandonment of 2D and hand calculations at the beginning of 2022.

In 2020, despite the impact of COVID-19 (first case March 13, 2020), there were 1271 consults and 2646 follow-ups, of which 80% and 77% were women, respectively. On average, radiation oncologists see 5 new consultations per day and 11 follow-up visits each day. The follow-up intervals were increased to reduce patient numbers in the clinic due to the COVID-19 pandemic.

New consults were approximately 40% stage IIB and higher cervical cancer, 22% breast, 11% head and neck, 7% gastrointestinal (gastric, rectum), 6% bone or brain metastases, 4% skin, 3% genitourinary (prostate, bladder), 3% sarcomas, 2% lymphomas, and 2% others.

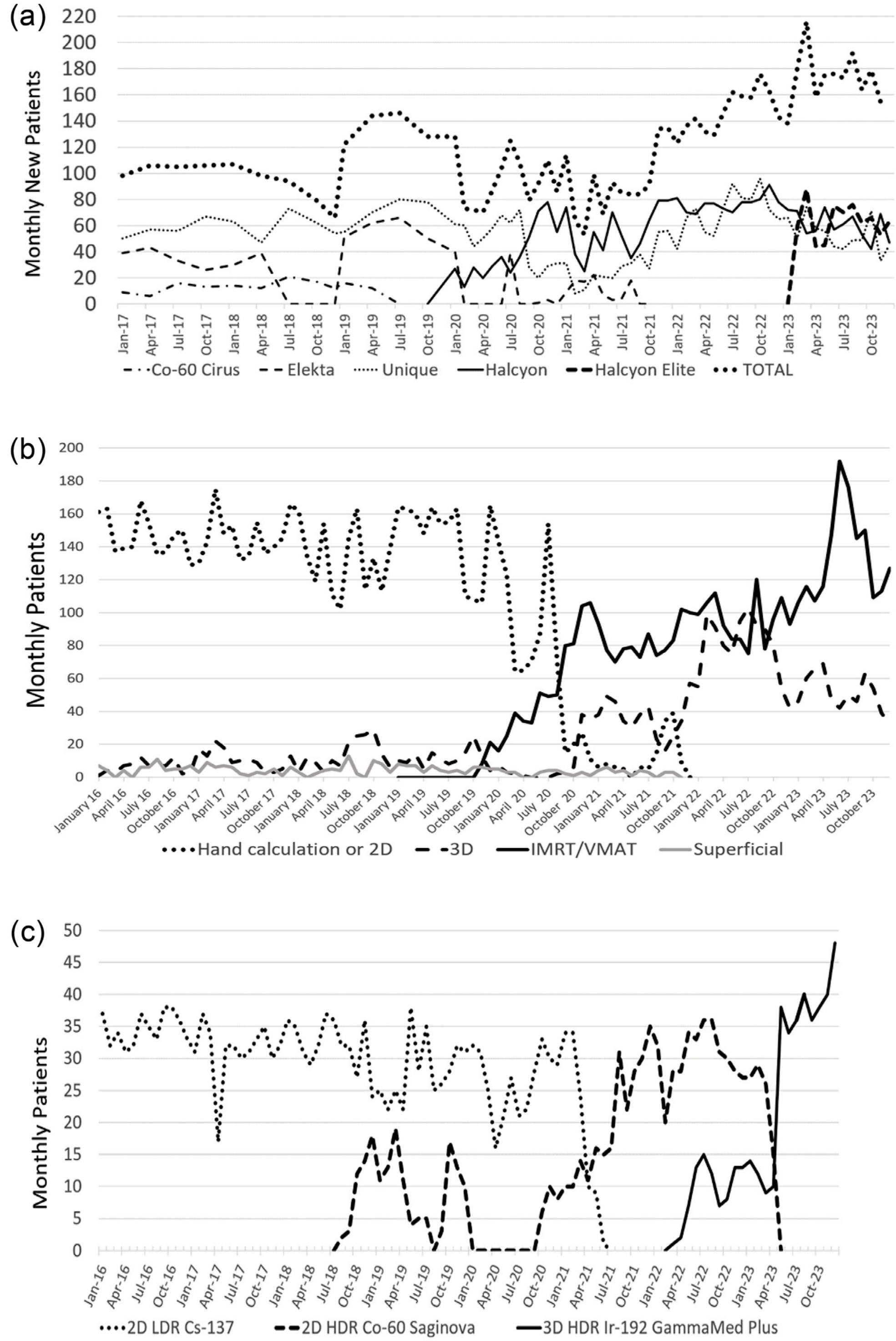

Figure 3 (a) Monthly new patients receiving teletherapy (Cirus) or external beam radiation therapy (Elekta, Unique, Halcyon, and Halcyon Elite) from 2017 to 2023. (b) Monthly new patients receiving 2-dimensional (2D), 3-dimensional (3D), intensity modulated radiation therapy (IMRT)/volumetric modulated arc therapy (VMAT) or superficial radiation therapy from 2016 to 2023. (c) Monthly patients receiving low-dose rate (LDR) or high-dose rate (HDR) brachytherapy from 2016 to 2023.

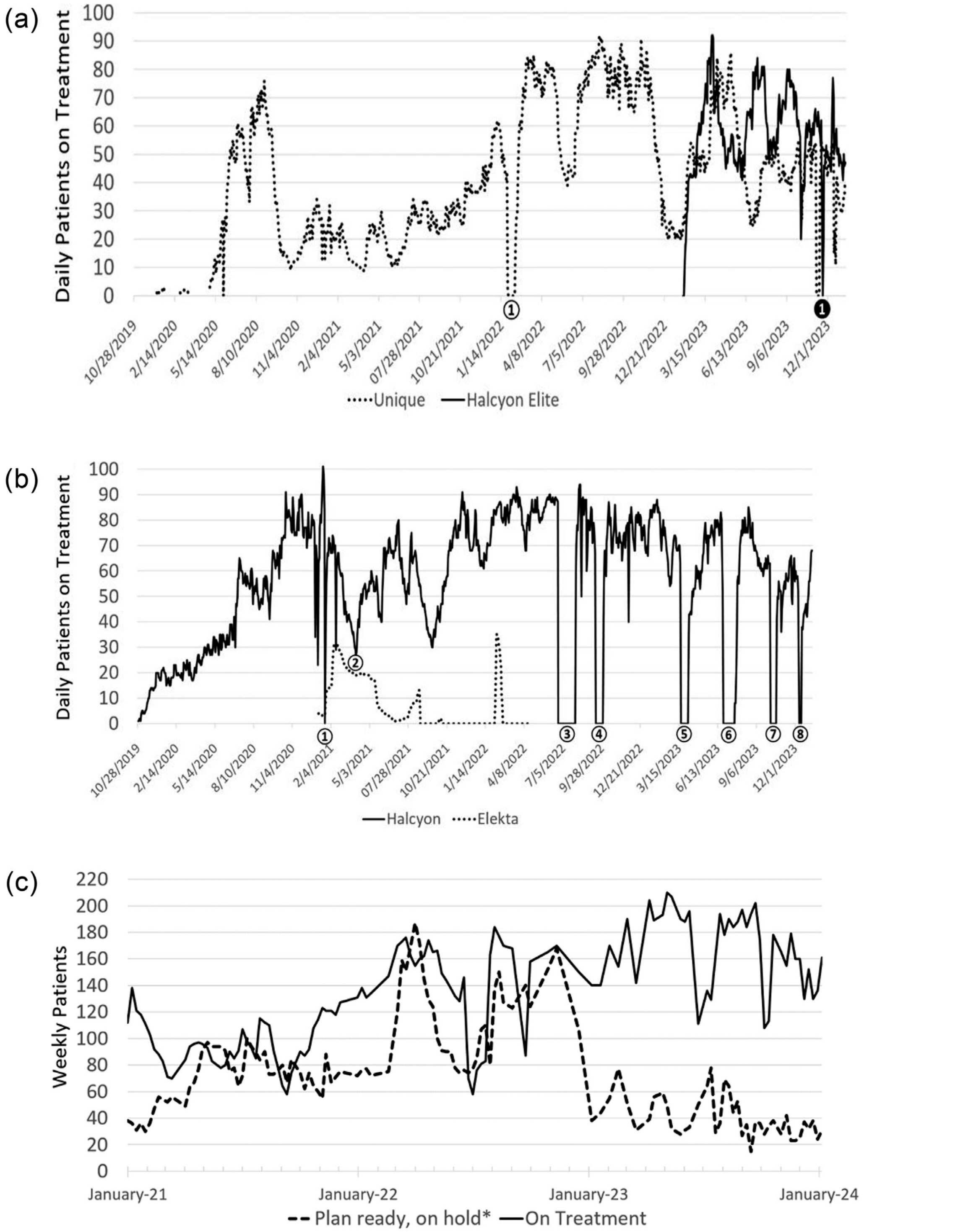

Figure 4 (a) Varian Unique and Halcyon Elite daily patients on treatment from 2019 to 2023. Reasons for interruptions in treatment: ① Unique multileaf collimator (MLC) change, and ❶ Halcyon Elite kV communication problem. (b) Varian Halcyon and Elekta Compact daily patients on treatment from 2019 to 2023. Reasons for interruptions in Halcyon treatment: ① modulator, ② uninterruptible power supply, ③ bunker construction and first magnetron, ④ electric transformers, ⑤ second magnetron ⑥ lightning and third magnetron ⑦ Central processing unit (CPU), and ⑧ cooling system. Note that the Elekta Compact was nonoperational during most of this period due to the difficulty servicing it in Guatemala. (c) Weekly patients on treatment and patients with plans ready but on hold due to lack of government or patient funding, patient, or other issues. Note the increase in the weekly patients on treatment and a significant decrease in patients on hold.

Figure 3c shows the discontinuation of LDR brachytherapy in July 2021 and Co-60 HDR brachytherapy in May 2023, with a shift to Ir-192 3D-based HDR brachytherapy. Figures 4a, b show the daily patients on treatment on the 4 linear accelerators from 2019 to 2023, as well as the reasons for treatment interruptions. Figure 4c shows the weekly patients on treatment and patients with plans ready but on hold due to lack of government or patient funding, patient, or other issues. Note the increase in the weekly patients on treatment and a significant decrease in patients on hold.

Lessons learned

Electronic charting has facilitated the radiation oncology staff's access to patient documentation and legibility of notes. Thanks to the increased efficiency of the Halcyon (up to 100 additional patients per day), the waiting list was significantly reduced. Patients were treated faster than anticipated, and the Guatemala government's yearly budget to treat patients for the year was depleted by April 2021.[3] By October of 2021, 65 patients had been evaluated and in need of a CT simulation, and another 200 who were referred to INCAN but could not be evaluated due to lack of funding. LIGA could not secure additional funding from the Ministry of Health for the remainder of 2021. On October 15, 2021, LIGA decided to deliver free radiation therapy patients for the remainder of 2021.[4,5] As of 2025 all eligible patients with cervical cancer receive HDR brachytherapy.

Since we have consistently demonstrated our increased treatment capacity to the Ministry of Health, our main contractor, our yearly budget has been increasing. The larger budget has allowed us to gradually increase the number of low-income patients we treat each year and improve the institution in general. Our current challenge is that we can treat more patients than government funding allows which is 150 patients per month.

Lessons Learned: Decommissioned Co-60 and Other Radioactive Isotopes

The logistics of decommissioning and ultimately disposing of Co-60, Cs-137, and other radioactive sources can be challenging, and work on this should start from day 1. The COVID-19 pandemic hindered the process. Organizations like the National Nuclear Security Administration (NNSA), the World Institute for Nuclear Security, and the IAEA are excellent resources for advice regarding the decommissioning process.

The disposal of radioactive sources depends on the country of origin. The Picker and Theratron Co-60 sources were repatriated to the U.S. through the Off-Site Source Recovery Program (OSRP). OSRP implemented the project and is a U.S. government activity sponsored by the NNSA's Office of Radiological Security, and is managed at Los Alamos National Laboratory through the Nuclear Engineering & Nonproliferation Division. The Department of Energy's NNSA (DOE-NNSA) planned and coordinated the expatriation of these 2 sources. The Defense Threat Reduction Agency assumed the leadership role in logistics planning, including establishing funding mechanisms to expedite military airlift assets.[6] The U.S. embassy in Guatemala provided mission support. The U. S. Air Force Air Mobility Command transported the sources to Los Alamos National Laboratory.

The Cirus Co-60 source originated in France and cannot be repatriated to the U.S. Instead, OSRP will send the source to the disused radioactive source central storage facility, CENDRA, in Guatemala.

Lessons Learned: Education

Rayos Contra Cancer)

INCAN radiation oncologists and medical physicists participated in a Rayos Contra Cancer (RCC) sponsored longitudinal 28-session telehealth curriculum in Spanish with interactive didactics and a cloud-based platform for case-based learning. According to RCC methodology, the program included 1- to 1.5-hour live video conferencing sessions held 1 to 2 times weekly for 4 months from December 2020 to March 2021.[7,8] The RCC educator team included 10 medical physicists and 3 radiation oncologists from 11 institutions, and INCAN participated along with a cohort of 14 other Latin American centers. This program was well-received and successful, according to significant improvements in self-confidence and knowledge-based assessments.

Staff feedback helped RCC personalize the training program to fit clinic needs, and subsequently, an IMRT training program in Spanish for radiation therapists consisting of 18 weekly 1.5-hour training sessions was provided for INCAN and other Latin American centers from May 2021 to September 2021. The RCC educator team included 9 radiation therapists, 3 medical physicists, and 1 radiation oncologist from 11 institutions.

These efforts were part of a longitudinal partnership between INCAN and RCC, which began with a site visit in 2017, assistance with a more than 300-lb. cerrobend donation in 2018, and assistance with MLC installation negotiations in 2019, ultimately leading to successful installation in 2020, in time for IMRT training. After the aforementioned IMRT training programs from 2020 to 2021, INCAN staff have continued to participate in RCC training programs, including an Advanced IMRT program (July 2022-October 2022) for centers with

Table 1 Wisdom pearls

Category	Lesson learned
Governance	
Vision and mission	A leader with a vision of the project and, most importantly, an overarching team mission that, ultimately, the project is for the betterment of cancer patients will help the team persevere through seemingly insurmountable challenges.
Institutional governance	Understanding institutional governance is essential to the successful completion of joint projects. For this partnership, the OSI is governed by 2 entities: the league (LIGA), which manages the finances, and INCAN (hospital), which runs the radiation oncology department.
Listen	It is imperative to listen to the needs of the OSI before initiating any project and during the project's progress. The goal is to help solve the highest priority needs of the OSI without forcing what the U.S. institution thinks would be a good project.
Clear objectives	Specifying clear objectives and timelines is critical for assessing the project's progress and success. This way, parties can be objectively accountable for assigned responsibilities.
Overseas institution visit	Before initiating any project, a thorough evaluation of the OSI through an in-person visit, in this case, the radiation oncology department, is critical to understand the problems and challenges. Photographing is very useful to help document the visit and illustrate the scope of the situation to others. Native language speakers are more likely to obtain significantly more information since English and foreigners may be intimidating for some. The initial OSI visit resulted in a 25-page comprehensive report.
Project manager	An experienced and energetic project manager is essential for success. The manager should understand any grant mechanisms very well, keep track of deadlines, organize the member subtasks for grant applications, and organize the agenda of weekly meetings necessary to gain any traction. Ideally, this person should be well networked at their institution to reach out to talent in different departments, have charisma, and maintain an optimistic attitude.
Regular, clear communication	Regular communication, ideally weekly, will keep the momentum of the project. The project manager usually orchestrates this. Having bilingual members will facilitate communication when necessary.
Identify need, match with expertise and technology	Matching the needs of the OSI with optimal technology and experts will yield an optimal solution platform.
Well-defined roles	Creating clear roles for each project member based on expertise will help avoid confusion and make everyone accountable for their roles and objectives.
Team	
Patients	At the darkest moments, the team can never lose perspective that the ultimate goal is the benefit of the patients. Keeping this in perspective will help the team overcome the most challenging obstacles.
Continued commitment	The successful completion of the project is just the beginning. A successful project requires ongoing commitment from all parties to overcome new challenges threatening its success.
Institutional leader commitment	At least 1 leader with decision-making ability and authority over others should be involved at each collaborating institution. Their role is to support the project, get team members involved, and solve problems at a macro level. These leaders should be energetic, skilled at team building, have a clear vision of the final goal, and be realistic but, at the same time, aim high.
Team buy-in	When team members at each institution buy into the project, progress is smoother and more efficient. Alternatively, pushing the project through authority is sometimes necessary at the OSI due to reluctance to change, lack of financial incentives, or existing workload.
Local champions	Having at least one local champion at each institution working on a specific task is necessary. These individuals will help find solutions at a micro level, engage additional local team members, provide valuable problem insights, and help each other reach out to leadership (both local and at the collaborating institution) to help with problems that require intervention at a higher leadership level. Sometimes emails are necessary for specific situations, but the ability to message or talk using WhatsApp or Signal at short notice can be very effective. The OSI local champions should be 100 % paid by the institution with a competitive salary and not have conflicts of interest with private practices, which is often a necessity in low-income countries. This should minimize conflicts of interest and maximize the investment into the institution's success.

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Table 1 (*Continued*)

Category	Lesson learned
Effecting change efficiently at OSI	OSI leadership buy-in is critical to the successful transition of the institution to a center of excellence. The leader needs to be motivated and able to bring the team together to make a culture shift. Otherwise, the transition is unlikely going to succeed.
Culture shift	Shifting the focus of the work culture to improving the process is critical for a project's success. Employee satisfaction is vital to creating a motivated team and moving a project forward.
Avoid demotivation	Collaborative projects like these are voluntary, take incredible time and effort, and although societally invaluable, depending on the activity, may not necessarily bolster academic careers. Collaborators should respect each other's time, and both institutions should make the collaborative process as painless as possible through efficient and competent collaboration.
Carpe diem	Always be ready when an opportunity arises. Institutional priorities can change, staff turnover, financial challenges may arise, and others. The initial report from 2015 was shelved. It was not until the grant opportunity with USAID arose that Sasa Mutic connected the dots with the Halcyon and the BJC warehouse for donations.
Human resources (HR)	HR is critical to any successful organization. A transparent and fair policy of employee responsibilities and expectations should be well established and discussed at the onset of any employment. Processes should be in place to protect both the institution and the employee.
Cancel culture	High turnover in staff can strongly jeopardize the success of a project and the willingness to continue working with the institution. Specialized personnel with limited availability in a given country should be retained and valued.
Unconscious bias	Unconscious bias may affect the perception of team member's competence or expectations. Addressing this issue will increase the team's success.
Education	
Well-defined training plan	Deployment of advanced technologies will require a robust educational program to ensure the technology is optimally and correctly used.
Education/collaborative learning/mentoring	The collaborating institution should be ready to support educational initiatives with the OSI to facilitate the transition to new technologies and treatment paradigms. Rayos Contra Cancer is an excellent resource with online resources and continuous educational offerings that can be customized to the local needs of the institution. Mentors should be identified to team up with members of the OSI and be accessible outside the scheduled team meetings for addressing new issues and providing support efficiently. Email and applications like WhatsApp or Signal can be helpful.
Advocating	Sometimes it is difficult or uncomfortable, but keeping the goal in mind is critical to success, such as advocating for patients and team members in the OSI.
Patience and persistence	The obstacles low-income countries face can be challenging to solve. In some cases, institutional chronic problems like financial or suboptimal work culture require years of patience and persistence to make minor incremental improvements. Sometimes, progress can happen in dramatic short bursts followed by long periods of inactivity, sometimes dictated by funding availability and changes in government administration.
Finances	
Financial sustainability	Before embarking on a project, there should be a clear path to sustain the project financially. Unfortunately, financial obstacles can be challenging to overcome in low-income countries. The OSI should invest in a solid financial and fundraising team to make the project sustainable.
Currency fluctuations	Sadly, the cost of high-technology equipment can be sometimes prohibitively expensive for a low-income country, having a similar cost as in a high-income country. Currency fluctuations can further aggravate this challenge, and the financial plan should mitigate this problem.

(*continued on next page*)

Table 1 (*Continued*)

Category	Lesson learned
Hidden costs	Careful consideration should be given to unforeseen additional hidden costs. For example, to take advantage of all the advanced treatment capabilities of the Varian Halcyon included additional investments like improved patient treatment immobilization devices (pelvis, breast, head and neck), a dedicated CT scan for patient simulations with an indexed flat tabletop and isocenter laser system, new TPS, and improved quality assurance processes.
Equipment maintenance/maintenance contracts	High-technology projects can ultimately fail due to a lack of funding for equipment maintenance or local technical support. This should also be considered when donating medical equipment. Maintenance contracts should be negotiated carefully based on the needs and budget of the OSI. Depending on the project, hardware or software maintenance options may need to be prioritized. For a linear accelerator, hardware maintenance is essential for its continued reliable operation. Software contract options should include essential security updates and bug fixes and support for an adequate number of licenses to avoid bottlenecks, especially in treatment planning. For limited budgets, the high cost of having the latest software version, which may not necessarily offer new functionality, may be avoided.
Infrastructure	The existing local infrastructure should be considered when implementing any project, especially a high-technology one. Several questions should be addressed: Is the power grid stable? Is a backup generator or uninterruptible power supply necessary to protect against blackouts, voltage sags, voltage surges, over-voltages, and temperature and humidity control through reliable cooling from an air conditioning system? Internet reliability and sufficient bandwidth? Is the water quality and supply adequate, especially if the equipment requires water cooling?
Culture	
Cultural intelligence	Understanding each other's culture can make a difference between a project failing or succeeding. For the Halcyon project, when key collaborators left the OSI institution, we had to get buy-in from the new OSI partners. The project was stonewalled, and we could not proceed with the collaborative agreement. Familiarity with the culture helped to identify that the OSI's problem was a lack of trust and concern for corruption. Realizing this and clarifying that the grant would not pay any individual but only the linear accelerator completely brought things back on track, and the agreement was signed, and a close partnership ensued.
Language	At least 1 team member should be fluent in the local language. This minimizes misunderstandings and helps build trust more quickly, and collaborators at the OSI are more likely to feel comfortable sharing vital information for the success of the project.
Trust	Having trust and transparency is key to any successful partnership. Not only is it important between institutions, but also for the team members collaborating locally.
Transparency	Transparency is essential to foster trust between institutions and ensure awareness of ongoing and potential problems and challenges. Culturally, the OSI may want to give a good impression to others by hiding ongoing challenges, and ultimately, this is detrimental to trust and the success of the project.
Flexibility	Flexibility with alternative solutions, sources of funding, and sources of education will allow for better adaptation to ongoing challenges.
Humility	Humility is essential for all institutions involved. An OSI with limited resources may be embarrassed to share all the critical problems that need to be addressed to move forward. However, sharing these concerns may lead to potential solutions.
Socializing and humor	Socializing and having fun are important to help bring the team together and build trust, friendship, and success for the project. Humor was especially essential during the pandemic.

Abbreviations: CT = computed tomography; INCAN = Instituto de Cancerología y Hospital Dr. Bernardo del Valle S; LIGA = National League Against Cancer; OSI = overseas institution; TPS = treatment planning system; US = United States.

established experience and a hypofractionation training program (March 2023-June 2023). In total, 29 INCAN staff have engaged in RCC training, representing nearly 100% center participation.

Washington University

As part of the USAID grant for the Halcyon project, we had regular Zoom meetings with LIGA/INCAN. Since the

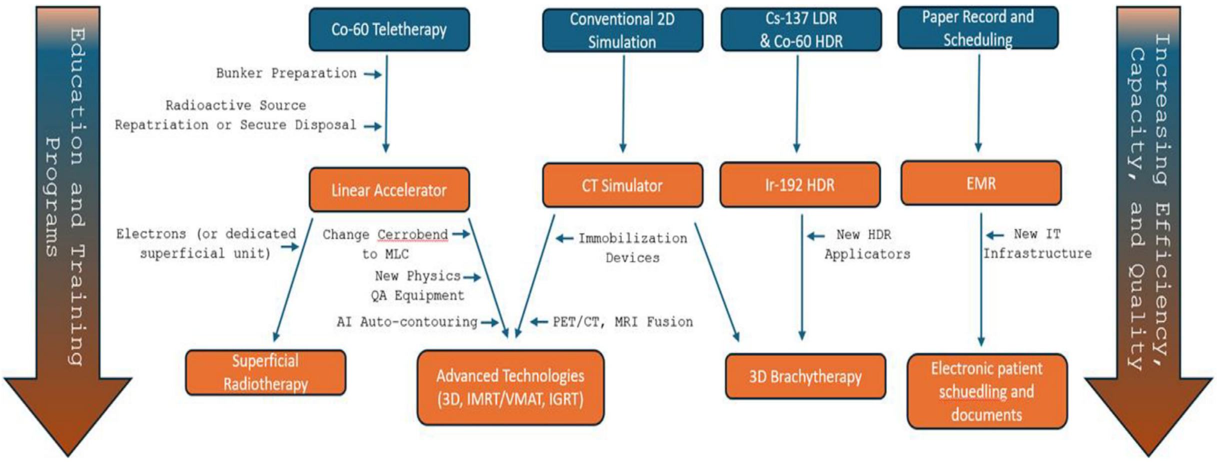

Figure 5 Gradual transformation of a radiation therapy department to increase efficiency, capacity, and quality with the support of education and training.

completion of the project in September 2020, we have held weekly meetings with LIGA/INCAN to discuss the project's continued progress, research projects, publications, future grants, and several other initiatives.

In preparation for the Halcyon, a radiation oncologist and medical physicist visited the Department of Radiation Oncology at Washington University in St. Louis, Missouri, for a 2-week training on the TPS Eclipse to practice contouring and planning and get familiarized with ARIA.

Washington University radiation oncology physicists and radiation oncologists have given lectures through Zoom on topics like head and neck contouring, lattice radiation therapy, and prostate HDR brachytherapy. Dr Baozhou Sun provided guidelines and training on machine-specific and patient-specific QA to the Guatemala medical physicist group. He has developed an automated QA tool to streamline their QA workflow. INCAN also participated in a 12-week online IMRT training.[9]

Conclusions

The transformation of the INCAN radiation oncology department in Guatemala is a testament to collective hard work, vision, and perseverance for the betterment of Guatemalan patients while facing incredible financial hardship. Although there are challenges a specific institution may face, many of the fundamental keys to success are universal and rely on the project's governance, team, education, and financial aspects. Table 1 summarizes wisdom pearls from this collaboration, which will be of use to other similar collaborations. Figure 5 shows a blueprint of a radiation oncology's technological transformation supported by education and training programs. We hope that what we have learned in the past 9 years and our detailed account of this process will help others achieve even greater success in a shorter time. Finally, Dr Edgar Ruiz, chair of the Radiation Oncology department at LIGA/INCAN, gives us his perspective:

"The most difficult thing has been working with people who resist change. Staff is used to doing things one way, but little by little, they realize that changes are necessary, and in the end they get on board and everything flows better."

Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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