Technological Improvements in Low- and Middle-Income Countries (LMICs): A Review of the Literature and the "Sociedad de Lucha Contra el Cáncer" (SOLCA) Institutional Experience in Neuro-Radiosurgery During the Coronavirus Disease 2019 (COVID-19) Pandemic

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■ OBJECTIVE: **Neurosurgery is a medical field that requires specialized professionals and equipment, 2 important but scarce resources in low- and middle-income countries. Our goal was to report our experience with the replacement and implementation of linear accelerators with radiosurgery capabilities at "Sociedad de Lucha Contra el Cáncer" (SOLCA) Hospital in Quito, Ecuador, and give some recommendations for future technological replacements (TRs).**

■ METHODS: **Two surveys were performed in SOLCA's radiosurgery department, one before the TR was finalized and one after, consisting of an open and multiple-choice questionnaire. Questions focused on the performance of the new equipment, perceptions regarding the training, and the influence of the pandemic on the whole process. In addition, we share our experience regarding the difficulties and benefits of TR at SOLCA.**

■ RESULTS: **The most-reported limitation was lack of training (48%). By the time of the second survey, 95.2% of the staff had already treated patients or planned a radiosurgical procedure; 42.9% considered training to have been adequate, and 76.2% felt that the pandemic hindered the training process. Currently, 33 radiosurgeries have been done (26 for the central nervous system and 7 stereotactic radiation body therapies).**

■ CONCLUSIONS: **The TR in SOLCA had similarities with other experiences in low- and middle-income countries, but the pandemic brought additional limitations, mainly complicating the staff training. Nevertheless, those limitations can be resolved with a structured training program and international collaboration. Overall, the benefits obtained from a TR result in exponentially better medical care and accessibility to novel treatments.**

INTRODUCTION

Neurosurgery and neuroradiosurgery access are important worldwide health issues, both because of the number of cases requiring these kinds of procedures and their elevated cost.[1] It is estimated that 13.8 million cases needing neurosurgical treatment develop every year, and 80% of these cases are found in low- and middle-income countries (LMICs).[1] Therefore, the significant caseload causes disparities in access to neurosurgical resources in LMICs due to the limited technical and/or professional capacity available to attend the substantial

Key words
- Institutional experience
- Linear accelerator
- Low- and middle-income countries
- Neurosurgery
- Radiosurgery
- Radiotherapy
- Technological replacement

Abbreviations and Acronyms
COVID-19: Coronavirus disease 2019
HICs: High-income countries
IMRT: Intensity Modulated Radiation Therapy
LINAC: Linear accelerator
LMICs: Low- and middle-income countries
SBRT: Stereotactic body radiotherapy
SOLCA: "Sociedad de Lucha Contra el Cáncer"
SRS: Stereotactic radiosurgery
TR: Technological replacement
VMAT: Volumetric-modulated arc therapy

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number of patients needing a functional neurosurgical service.[1] Only 56% of neurosurgeons reside in LMICs, and there are at least 11 countries in which there is no access to any form of neurosurgical care.[1,2] For instance, the percentage of the population that has access to a functional service in the Sub-Saharan countries, the Caribbean/Latin America, and East Asia is 25.3%, 62.3%, and 29.6%, respectively; these numbers are even lower when the access to advanced microneurosurgery is considered.[3] Access to a stereotactic radiosurgery device is unequal between regions; one device is available for every 10 million people in Europe, North America, and Australia but in South America, there are 35 million people per device.[4] Furthermore, when neurosurgical services are available in LMICs, the proportion of people that have a 2-hour travel time access to any level of neurosurgical aid is low.[3]

To solve such disparities, an international collaboration between high-income countries (HICs) and LMICs is needed.[2] HICs can provide the technical and professional knowledge to bring functional techniques to LMICs through international programs.[2] Other solutions for LMICs are the establishment of standardized guidelines and the improvement of technological resources to offer a greater number of neurosurgical treatment options.[2]

There are multiple institutional experiences of technological replacements (TRs) in LMICs reported in the literature. However, the experience in the Oncological Hospital "Solón Espinosa Ayala," Quito, Ecuador, part of the society for the fight against cancer, "Sociedad de Lucha Contra el Cáncer" (SOLCA), was exceptional because it took place during the coronavirus disease 2019 (COVID-19) pandemic. The objective of this article is to report the institutional experience regarding technological improvement in SOLCA Hospital and to summarize the difficulties of the process as well as the potential benefits for the target population. In addition, we aim to summarize the available evidence of similar endeavors in the scientific literature to shed a light into a time-consuming and difficult process such as the implementation of new technology in resource-limited settings. Our goal is to share the observations and lessons learned from the process, successful despite the difficulties, so other LMICs can benefit.

INSTITUTIONAL EXPERIENCE

The oncological hospital "Solon Espinosa Ayala" in Quito is one of the most-recognized specialized centers for the management of cancer in Ecuador. As a reference hospital, it has one of the largest radiotherapy units in the country.

In 2018, an update for the Radiation Oncology Department was proposed. At the time, that service had 2 linear accelerators (LINACs), the EX-21 (Varian, Palo Alto, California, USA), capable of 3-dimensional conformal radiation therapy, both machines being approximately 15 years old. There was also access to a 10-year-old LINAC Varian Unique, capable of intensity-modulated radiation therapy (IMRT). In this context, a TR was undertaken by mid-2018 as an institutional challenge with the objective of offering more advanced therapies, such as volumetric-modulated arc therapy (VMAT) and radiosurgery of the central nervous system (stereotactic radio surgery [SRS]) and other structures (stereotactic body radiotherapy [SBRT]).

The acquisition of a Radixact System with TomoTherapy (Accuray, Sunnyvale, California, USA) took place in early-2019. This machine can perform a helicoidal IMRT, SRS, SBRT, hypofractionated radiation therapy, and many other advanced techniques. This acquisition already offered the possibility of performing new radiosurgical techniques; however, by the end of 2019, the institution decided to replace the 2 Varian EX-21 LINACs with 2 TrueBeam (Varian) LINACs (Figure 1). With the TrueBeam, the options for radiation therapy and radiosurgery diversify, as this machine can perform SRS, SBRT, VMAT, HyperArc and RapidArc radiotherapy, IMRT, and image-guided radiotherapy. The idea of both the acquisition of equipment and the TR was not only to increase the radiotherapy options for the population but to treat a greater number of patients in less time by having machines that provide faster treatment compared with the ones that were previously in service.

The first TrueBeam device was installed by the end of 2019, and it started functioning in early 2020. However, the COVID-19 pandemic delayed the complete installation of the device, hindering its ability to perform more advanced techniques. Therefore, the first months it was only used for IMRT and VMAT. In addition, because of the delay on staff training, the advanced techniques on this device could be only delivered 6 months ahead of schedule. The first cerebral radiosurgery took place in October 2020 and the first lung SBRT in December 2020.

The institution originally planned to have the second TrueBeam in service by January 2021, but the pandemic affected the liquidity of the funds as well as the transportation logistics for the acquisition. The second TrueBeam was finally acquired and used 7 months later, in August 2021. In Figure 2, a complete timeline of the TR chronology at SOLCA is shown.

Figure 1. TrueBeam linear accelerator machine in "Sociedad de Lucha Contra el Cáncer" (SOLCA) Quito.

Staff Training

In a TR endeavor, the staff training is essential to ensure that novel technologies or the upgraded techniques are put to good use.[5-11] The type of training reported in different institutional experiences consist mostly of fellowships, educational missions, local trainings, and online education. A fellowship is a collaboration between institutions in which staff from a LMIC travel to a health care facility in a HIC to learn from more experienced professionals; an educational mission is the opposite—the staff from the HIC go to the LMIC to provide training.[5,7-9]

In SOLCA, the training strategy had to change due to the COVID-19 pandemic. At first, the plan was to include an initial local training on how to operate the device, management of the software, quality control, and to complement these with fellowships. The fellowships were designed to included multiple local staff visits to more-experienced foreign centers. However, once the pandemic began, fellowships were impossible to maintain, and only a small part of the team could benefit from this kind of training. The only method available at the time to pursue the program consisted of training imparted by more experienced coworkers who went on the original fellowships abroad before the pandemic.

Due to the disruptive nature of COVID-19, a first survey was conducted in September 2020 to determine the perception and opinions of the radiotherapy department staff, composed of 31 people. The survey included questions regarding the limitations of the TR before any patient was treated with the TrueBeam. The radiotherapy team consisted of 8 radiation oncologists, 6 medical physicists, 12 radiation therapists, and 5 resident physicians, from whom 22 responses were obtained (from 5 radiation oncologists, 2 medical physicists, 12 radiation therapists, and 3 resident physicians). This first survey consisted of an open question: "What has been the main limitation during the TR so far?" The most common answers were counted and categorized for analysis, and the results are reported in **Figure 3**. The main concern, reported by 48% of the staff, was the lack of training. In response to the survey results, the department decided to correct the reported deficiencies by implementing teleconferencing with audiovisual learning tools. Therefore, every Tuesday and Thursday, teleconferences took place to present clinical and dosimetry protocols to the staff and to provide training on the new technologies. Those lectures were not only given by the most experienced hospital staff on SRS and SBRT but also by international specialists from Argentina, Chile, Spain, and El Salvador. In addition, the staff was also offered free access to virtual congresses and webinars on advanced radiotherapy techniques, including radiosurgery.

The first brain radiosurgery performed with the TrueBeam was in October 2020, and by April 2021 most of the staff had already been involved in at least one radiosurgery procedure. At this point,

Figure 2. "Sociedad de Lucha Contra el Cáncer" (SOLCA) Hospital timeline on the implementation of technological replacement. VMAT, volumetric-modulated arc therapy.

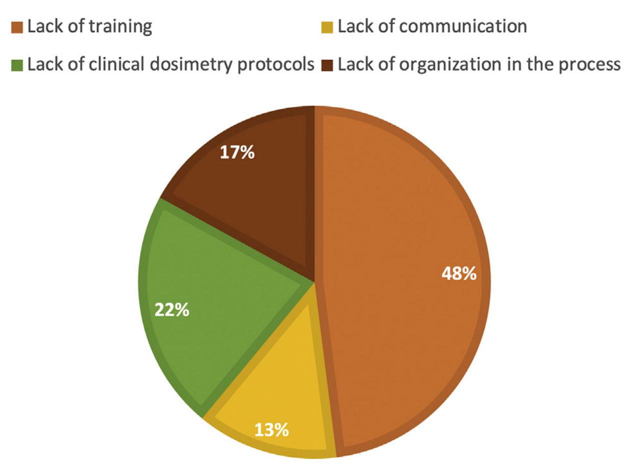

Figure 3. Results of the first open-question survey: perception and opinions of the radiotherapy department.

a second survey was performed with a multiple-choice questionnaire (Table 1). The second survey was submitted to the same 22 members of the staff who responded to the first survey, and all of them responded. In total, 95.2% of the staff had already planned or performed radiosurgery, or simulated one, from which 49.2% felt very confident during the procedure. In terms of training, most of it was done at the center by experienced colleagues (52.4%), and 47.6% of the staff felt that it was insufficient, whereas 42.9% marked it was adequate.

Even though our international fellowship program was discontinued due to the pandemic, the support from foreign specialists was maintained through teleconferencing. Those specialists in radio-oncology, physics, and radiotherapy had vast experience in using our newly acquired technology, which made their online interactions with the SOLCA staff essential to the training process. The lack of training was partially resolved by the time of the second survey, with only 4.75% of the staff still untrained (Table 1).

Table 1. Second Survey Applied on the Radiation Oncology Staff About Their Opinion on the Technological Exchange

Have you had the opportunity to treat/plan/simulate, SBRT/radiosurgery patients?	
Yes	95.2%
No	4.8%
If you have trated/planned/simulated radiosurgery/SBRT patients, how confident do you feel about performing the procedure?	
Very confident	49.2%
Somehow confident	42.9%
Not confident	14.3%
How do you evaluate your training regarding these new technologies?	
Very appropriate	4.75%
Adequate	42.9%
Poor	47.6%
None	4.75%
How was the training conducted?	
On-site in foreign countries	23.8%
On-line	19%
At the center itself by experienced colleagues	52.4%
At the center itself by invited foreign professionals	4.8%
Do you consider that the pandemic hindered the process of training in the use of these technologies?	
Yes	76.2%
No	0%
Maybe	23.8%

SBRT, stereotactic body radiotherapy.

Difficulties and Limitations

The difficulties experienced in SOLCA were like the ones other LMICs experience in a TR; however, our hospital staff also had to cope with the limitations brought by the COVID-19 pandemic. In the second survey, 76.2% of the staff considered that the pandemic affected the TR process (Table 1). The structural remodeling needed for the installation of the machine took longer and so did the training of the oncology radiation team, due to the impediment of face-to-face training (Figure 3). This led to a 6-month delay in the inauguration of the first TrueBeam and the first procedure, that ended-up being in October 2020. The second TrueBeam was planned to be operational on January 2021, but due to the pandemic, it could only be deployed by September 2021, 8 months later.

However, the biggest problem faced by SOLCA was the lack of in-house protocols for the application of new therapies, as well as the lack of adherence to well-established international protocols (Figure 3). Therefore, priority should be given to the creation and implementation of an appropriate mandatory protocol to ensure the proper use of the equipment. Furthermore, based on our experience and the information we have gathered, each LMIC and its health care facilities need to use and implement the new technology in a way that makes sense for their institution. Trying to adhere to international protocols, that often require the infrastructure and assets of a HIC, will result in elevated prices and nonefficient allocation of available resources. This can hinder the acquisition of more technology in the future.

Benefits

Based on the SOLCA experience, it is evident that the benefits of these changes improve the therapeutic options and provides previously non-existent therapeutic alternatives, especially in the case of brain tumors. Thanks to the TR plan, there are currently 4 radiotherapy machines on use, the 2 TrueBeams, the Radixact System with TomoTherapy, and the Varian Unique LINAC. Until

November 2021, 33 radiosurgeries were performed between the 2 TrueBeams and the Radixact System with TomoTherapy. The CNS has been the most-favored system, with 26 radiosurgeries: 18 performed on the brain and 8 on the spine. Ten of the brain tumors were metastatic, 4 from the lungs, 5 from the breast, 2 from the cervix, and 1 melanoma. Six tumors were primary, 3 were high-grade gliomas, 1 hemangiopericytoma, 1 recurrent pituitary adenoma, and a recurrent glioma. The spine tumors were metastatic, 6 from prostatic cancer, and 2 from breast cancer. In addition, 7 SBRTs have been performed: 4 in the prostate, 2 in the lungs, and 1 in the retroperitoneum. These radiosurgeries could not be performed before de TR; the technological upgrade and the involvement of a multidisciplinary team, consisting of neurosurgeons, radio oncologists, imaging specialists, and medical physicists, made these procedures possible and benefitted a wider population.

DISCUSSION

The types of TR in the neurosurgical field that take place in LMICs can be classified in 3 groups: when a new device to perform novel techniques is acquired, when an old device is replaced by a newer one to improve a technique, or when a previously owned equipment is adapted to perform better or newer techniques.

The implementation that usually has a greater impact is the one in which a new technology that was not available before is implemented. Examples of this kind of TR took place at the neurosurgical services from EsSalud Hospital in Trujillo and María Auxiliadora Hospital in Lima, where the first microneurosurgery services in the region were implemented, and it provided the population with a variety of new procedures that were not available before.[10,11] To picture the magnitude of this kind of TR, we consider an institutional experience from Pakistan, in which they comment on the benefits of implementing new imaging equipment, consisting of computed tomography imaging devices for the diagnosis of Pott disease secondary to tuberculosis by computed tomography—guided biopsies.[12] The study reported 91 cases, from which 75.8% tested positive and responded well to therapy. Pakistan has the fifth-highest prevalence of tuberculosis.[12] In fact, in 2012, 8.6 million people were diagnosed with tuberculosis, and 1.3 million died of it; therefore, the impact of this TR is certainly significant.[12]

Another type of TR involves the replacement of old devices for newer ones to improve procedures that were already performed in the center or to perform different ones. This type of TR occurred in our hospital, SOLCA. Similar to SOLCA's case, a report from Guatemala describes the replacement of a Cobalt-60 equipment for a Varian Halcyon LINAC device for radiosurgery—a more versatile, manageable, simple, and economic device that allows to perform more complicated surgeries in less time, with less radiation toxicity, and without the concern of operator expertise dependence.[9] Another case from Nigeria describes an unusual implementation of electrocauterization for neural tube defect repair with the objective of reducing blood loss to less than 10%.[13] The authors obtained a 92% rate of success on the 48 reported cases.[13]

As seen with the previous examples, the core idea of TR in LMIC is getting the maximal benefit from the equipment and the available budget, in the intent of helping the greatest number of people possible. Other experiences describe the adaptation of previously owned equipment when the acquisition of new ones is not possible. An example of this phenomenon took place in Tanzania, where ultrasound transducers from the radiology and anesthesia departments were modified to be used on neurosurgical procedures to offer intraoperative neuronavigation.[7] This allowed guidance and assessment of the procedure in real time for the 24 reported cases.[7] The outcomes were that 18 tumors (75%) were completely resected and 6 (25%) were partially resected.[7] No postoperative hematomas were reported, which is one of the most common complications.[7]

No matter the kind of TR and the limitation of the process, they always bring more benefits than complications for LMIC, as they improve the accessibility to neurosurgical services, and they upgrade the variety and safety of the procedures. Table 2 shows a summary of different TR characteristics and difficulties in medical institutions on LMIC.

Limitations

Our surveys rely on the perceptions of the staff exposed to the TR. We have not used any specific criteria to guide the respondents or to define the adequacy of training. Therefore, answers will be strongly influenced by each respondent's perception.

CONCLUSIONS

Technology replacement processes in LMIC are necessary, as the benefits for the patients in terms of therapeutic possibilities and treatment safety justify the costs generated by the investment in such replacements. Staff training was the most relevant determinant in our technology-replacement process, including not only the attending physician, but all the multidisciplinary team that takes part in radiosurgery. This element of the process always carries difficulties. Outside of the pandemic, the economic aspect is the greatest limitation, whereas during the pandemic the limitations were the inability to have a face-to-face training, and the delay on the equipment delivery. Those limitations can be resolved with a structured training program and with international collaboration through online teaching sessions or courses. The installation of the machines should only take place after clinical, dosimetry, and quality control protocols are well stablished and well known by every member of the staff.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Pamela Ochoa: Conceptualization, Investigation, Writing – original draft, Visualization. **Raul Puente-Vallejo:** Conceptualization, Investigation, Resources, Writing – original draft, Supervision. **Felipe Loza:** Investigation, Writing – original draft. **Fiorella Cueva:** Investigation, Writing – original draft. **Jose E. Leon-Rojas:** Methodology, Writing – review & editing, Visualization, Project coordination.

Table 2. Characteristics of the Institutional Experiences of TR in LMICs

Location	Type of Experience	Duration of the Experience	Staff Training	Limitations
University College Hospital, Ibadan, Nigeria[13]	Use of material nonspecialized for a procedure[13]	24 months to test the material[13]	None[13]	The use of this kind of material could cause post-chirurgical complications[13]
Aga Khan University Hospital, Karachi, Pakistan[12]	Learning a new technique with an equipment previously owned[12]	7 years of observation of the technique[12]	Not mentioned[12]	The success of the procedure is operator dependent[12]
Muhimbili Orthopaedic and Neurosurgical Institute, Dar es Salaam, Tanzania[14]	Adaptation of the owned equipment to perform a new technique[14]	1 month[14]	Fellowships[14]	The equipment is not ideal for the technique[14]
University of Botswana Academic Hospital, Gaborne, Botswana[8]	Acquisition of new equipment to perform a new technique[8]	5 years from development of the project to the first patient treated[8]	Fellowships Educational missions[8]	Difficulties to obtain training, mistrust from part of the population[8]
Public sector institute, India[15]	Adaptation of the owned equipment because of the lack of specialized material[15]	Not specified[15]	None[15]	Lack of precision of the used material[15]
María Auxiliadora Hospital, Lima, Perú[10]	Acquisition of new equipment to perform a new technique[10]	3 years[10]	Educational missions[10]	None[10]
Several health care centers, Tanzania[16]	Adaptation of the owned equipment because of the lack of specialized material[16]	Not specified[16]	None[16]	Lack of precision of the used material[16]
Kenyatta National Hospital, Nairobi, Kenya[17]	Acquisition of new equipment to perform a new technique[17]	Not specified[17]	Local training[17]	Lack of budget to get material that makes the procedure more precise, and lack of neurosurgical practitioners[17]
Vivekanand Hospital, Lucknow, India[18]	Adaptation of the owned equipment to perform a new technique[18]	Not specified[18]	None[18]	The material does not reach the quality that specialized equipment would[18]
Instituto de Cancerología, Guatemala City, Guatemala[9]	Acquisition of new equipment to improve a technique[9]	5—6 months[9]	Local training[9]	Need to readapt a room for the new equipment[9]
EsSalud hospital of Trujillo, Trujillo, Perú[11]	Creation of an area for a neurosurgical subspecialty[11]	4 months[11]	Educational missions[11]	Differences in languages spoken, inefficient coordination[11]
Kijabe Hospital, Kijabe, Kenya[19]	Acquisition of new equipment to improve a technique[19]	12 months[19]	Not mentioned[19]	Economic limitations forced the use of single-use pieces, multiple tomes[19]
SOLCA Hospital, Quito, Ecuador	Acquisition of new equipment to perform a new technique	3 years	Fellowships Local training Online education	Delay on the implementation plan because of the pandemic, lack of standardized protocols

TR, technological replacement; LMICs, low- and middle-income countries.

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