IMPLEMENTING A ROBUST QUALITY ASSURANCE PROGRAM IN AN LMIC CLINIC AFTER TRANSITIONING FROM CO-60 TO LINAC TELETHERAPY UNIT

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Abstract— **To provide emerging and existing radiotherapy centers in sub-Saharan Africa a blueprint to transition from Cirus Co-60 teletherapy units to Linac quality assurance (QA) tailored to the current availability of devices and equipment and to electronically track the data to trend and adjust when necessary. After 8 weeks of virtual training quality assurance (QA) documentation and the impact quality control (QC) and patient safety we instituted an electronic method of record keeping following AAPM TG 142 and 198 recommendations. Our clinic transitioned from a cirus cobalt-60 unit to a Varian Clinac iX with two photon energies (6 and 16 MV), four electron energies (6, 9, 12, and 16 MeV), an EPID, and a 120 millennium MLC installed. We developed an institutional QA program tailored to our institutional resources. The results demonstrate reproducibility in all quality assurance processes, with average daily radiation output constancy for 6MV and 16MV photons being (2.25%±0.25) and (2.61%±0.13) with a maximum deviation of 4.23% and 4.47% respectively whiles safety checks (door interlock and console, video monitors, beam on light indicator, and audio intercom system) and mechanical/optical checks (collimator size indicators, laser localization, distance indicator (ODI), collimator size indicator, gantry/collimator angle indicators, couch walk, collimator walk and treatment couch position indictors) were functional and within operational limits (1 mm, 2 mm and 1°). The average monthly radiation output constancy for 6 MV and 16 MV were 2.07%±0.45 and 2.185%±0.37 with a maximum of 2.32% and 2.63% respectively. This demonstrated that the beam is adjusted as the values are above the tolerance. The electronic data tracking has made it easier to track and trend our QA output values and as well as safety and mechanical checks for better record keeping. Through this, some new monthly QA tests (couch walk, collimator walk and treatment couch position indictors) have been added to the already existing ones. It was essential that centers similar to ours implement a robust yet simple QA program following recommendations from AAPM TG 142, 198 and MPPG 8a.**

Keywords— **Quality assurance, Co-60, Linac, low- and middle-income country.**

I. INTRODUCTION

Komfo Anokye Teaching Hospital is one of three radiotherapy centers in Ghana Equipped with a Varian Clinac iX which has two photon energies (6 and 16 MV), four electron energies (6, 9, 12, and 16 MeV), an EPID, and a 120 millennium multi leaf collimator. The Center offers 3-Dimensional conformal radiotherapy services and 2D treatments on a Cirus Co-60 unit.

Periodic quality assurance of the external beam radiotherapy device is essential for the device to function at a level needed for creating custom plans unique for each patient's treatment. Efficient and effective QA procedures are needed in radiotherapy centers to ensure the machines integrity is not compromised (i.e., machine characteristics do not deviate significantly from their baseline values acquired at the time of acceptance and commissioning). [3, 4, 5, 6, 7] This study was conducted to provide emerging and existing radiotherapy centers in sub-Saharan Africa a blueprint to transition from Cirus Co-60 teletherapy units to Linac quality assurance (QA) tailored to the current availability of devices and equipment and to electronically track the data to trend and adjust when necessary.

All QA protocols have been adapted from the American Association of Physicists in Medicine Task Group (AAPM TG) report numbers 142, 198 and Medical Physics Practice Guidelines 8a recommendations for periodic checks on the Linac.

A QA program takes into account the procedures necessary for checking the performance of radiotherapy equipment and for measuring the characteristics of the output as well. The program is designed to specify the method of testing equipment, the parameters to be tested and the frequency of testing, the responsibilities of different members of staff, the baseline values and tolerances for these values, action levels and documentation guidelines. A clinical linear accelerator must in all circumstances function within tolerances obtained during acceptance testing [9]. It is therefore expected that a QA program designed specifically for an institution will meet those standards.

It is recommended that a QA committee should constitute professionals such as radiation oncologists, physicists, dosimetrist, therapists, engineers, and administrators, according to the American College of Radiology (ACR) [10]. Dosimetric accuracy, mechanical accuracy, safety, imaging, and unique Procedures, should all be included in the QA report. As a guideline for establishing the baseline for upcoming dosimetric studies of beam performance consistency, Acceptance Testing Procedure (ATP) Standards are established. This demonstrates that the apparatus is mechanically sound and functions within predetermined tolerances of accuracy.

According to their tolerance, three action levels are established and followed: level 1 (inspection), level 2 (planned activities), and level 3 (immediate/ stop treatment/ corrective actions) [7]. In this study we implement a quality assurance and an electronic method of tracking the data for a level 1, 2 or 3.

II. MATERIALS AND METHODS

The Clinac version 9.1 Linac system with 3D conformal treatment modality, Exradin A19 ionization chamber, Max 4000 Plus Electrometer, Designed A4 Sheet for collimator walk, Thermometer, Barometer, Blue Water PMMA Slabs, Front Pointer and Accessories, a Jig, a Leveler, and an electronic generated excel worksheet to keep track and record our QAs were used for the study. The linac has two photon energies (6, and 16 MV) with Flattening Filter Free (FFF) mode and four electron energies (6, 9, 12, and 16 MeV). The linac is equipped with a Varian Millennium MLC system comprising of 120 leaves

We performed x-ray output constancy, laser localization, distance indicator (ODI), collimator size indicator, door interlock, audiovisual monitor, radiation area monitor, and beam on indicator were performed on a daily, monthly basis and tracked the results for a total of 6 months setting action levels and making adjustments when needed.

Daily QA:

Prior to treating patients that day, the daily QA procedures were carried out. Mechanical checks, which included laser localization, distance indicator (ODI), and collimator size indicator were performed. Dosimetric checks, which includes photon and output constancy, and safety, which includes door interlock, audiovisual interlocks, radiation area monitor, and beam on indicator, are the three main categories into which these tests can be divided. In our clinic a certified medical physicist conducts such tests. For the dosimetric outputs we used Exradin A19 calibrated ionization chamber, a deviation of less than 3% is recommended, with errors of less than 2 mm for laser localization, distance indicator, and collimator size indicator being considered acceptable. Safety checks are done to check the functionality of, the door interlocks, audiovisual monitors, radiation area monitor, and beam on indicator. In our clinic, if any of these parameters are out of tolerance treatment is put on hold and issue is investigated and fixed. All daily check results must be within limits for the Linac to be approved for clinical use

Monthly QA:

More comprehensive tests of the mechanical, safety, and radiation dosimetry parameters were performed on a monthly basis. The mechanical system, gantry/collimator angle indicators, treatment couch position indicators, couch accuracy, localizing lasers, light/radiation field coincidence, door interlocks, optical distance indicator accuracy, photon output constancy and typical dose rate constancy, are among the things that are tested as part of the quality assurance approach.

1. ***Laser Localization***

This test was done with the jig aligned with the lasers installed and cross hair of the linac head. The surface of the jig was set to 100 cm SSD using the front pointer and the plate of the jig rotated through the angles of 90° and 270° to check deviations of the lasers from the cross marks on the plate. The deviation is then recorded.

2. ***Optical Distance Indicator or Distance Indicator (ODI)***

The front pointer and the jig were used for this test. With the gantry at 0°, the front pointer was set at 100 cm SSD and the jig moved till the flat surface touches the tip of the front pointer. The 100 cm SSD coincides with the radiation or machine isocenter as it grazes the surface of the illuminated field light. The pointer is removed and the ODI checked for 100 cm SSD. The value and its deviation were recorded.

3. ***Collimator Size Indicator***

This test was done with the jig set up on the treatment couch and set to 100 cm SSD. The field sizes are moved with the cross marks on the surface of the jig to fill the area. Various field sizes ranging from 5×5 cm to 20×20 cm was used, and the deviations recorded.

4. ***Gantry Angle Indicator***

The test was done with mechanical movement of the gantry at 0°, 90°, 180°, and 270°. The angles moved were verified by attaching a digital leveler to the head of the linac. This test is necessary for checking couch and machine isocenter. The measured or readout values were recorded.

5. ***Collimator Angle indicator***

The test was done with mechanical movement of the collimator at 0°, 45°, 90°, 135°, 180°, and 315° with the jig set up and aligned with the laser and the cross hair in the head of the linac. The angles moved were verified from the digital readings on the gantry of the linac. The readout values were recorded and well documented in the developed excel spreadsheet.

6. ***Iso Walk***

a. Couch walk

Couch is kicked to various angles as indicated on the base plate. Couch rotation angle indicated on the base plate is compared with the angle indicated on the in room monitor. The deviations were recorded.

b. Collimator walk

Set the sheet with the field markings on the couch and align cross hairs. Move collimator through various selected angles. (30, 60, 90, 200, 315, etc.). Check at

what point the center of the cross hair move from the center of the markings. The deviations were recorded.

7. Safety Checks

These checks are paramount to the safety of the patient and people authorized to work within the radiation area. Patients are monitored and communicated with through the audiovisual monitor. Staff and authorized people are warned of radiation beam on or off with the functionality of the beam light indicator. The door interlock also helps prevent unnecessary exposure to staff as treatment is in session as one attempts entering the treatment room.

The data taken were well documented and analyzed in the developed electronic excel spreadsheet which will also help track data of all QA tests performed for the future.

8. Photon Beam Output factor

The output factor for the two photon energies of the energy were measured. The blue solid PMMA slabs phantom was arranged on the treatment couch and aligned with the lasers. An SSD of 90 cm using the front pointer, a reference field size of 10×10 cm and a depth of 10 cm were set. The electrometer was switched on and warm up done. The A19 ionization chamber was connected to the electrometer. Series of five readings were taken for the 6 and 16 MV photon energies. Initial and final temperature and pressure readings were recorded as well. The deviation in the output was calculated using the equation:

$$\frac{measured\ reading - reference\ reading\ (nC)}{reference\ reading\ (nC)} \times 100 \quad (1)$$

9. Couch Position Indicators

For couch position indicators, the couch vertical and longitudinal were done. For couch vertical, a 30 cm rule was held to the couch with a cellotaph. The 15 mark was used as the zero mark with the corresponding value on the in-room monitor and ODI recorded. Series of values were taken in steps of ±5 cm and the corresponding digital values on the in-room monitor and ODI noted as well.

For couch longitudinal, a 100 cm rule was held to the couch with a cellotaph. The 50 mark was used as the zero mark with the corresponding value on the in-room monitor recorded. Series of values were taken in steps of ±10 cm and the corresponding digital values on the in-room monitor recorded as well.

III. RESULTS

A. Photon Beam Output factor

The output factor is a field size–dependent correction for the output of the linear accelerator. It is the ratio of absorbed dose of a particular field size relative to the dose at a reference field size. Field size is determined by choice of collimator size and SDD. In the measurements carried out, the reference field size was 10×10 cm with additional field sizes (5×5 cm, 15×15 cm, 20×20 cm) and the depth of measurement was 10 cm. The results for the daily and monthly output are presented in the Table 1.

Table 1: Photon Beam Output for 6 MV and 16 MV with average daily and monthly deviations

	6 MV	Deviation (%)	16 MV	Deviation (%)	Tolerance (%)
Monthly	16.82	2.32	20.00	2.88	3
Daily	16.78	2.07	19.44	2.40	2

B. Laser Localization

The laser alignment for patient setup was done for the angles 90° and 270°. This helps to set up patients per treatment planning parameters to deliver the right dose to patients. The results for the test are presented in Table 2. Tolerance ± 1 mm.

Table 2: Laser Alignment with average deviations

	Horizontal	Vertical
Left	0	0
Right	0	0
Sagittal	0	0

C. Optical Distance Indicator or Distance Indicator (ODI)

The 100 cm SSD test was done using the ODI at a gantry angle of 0 and collimator angle of 0. The average result for the test is summarized in Table 3.

Table 3: Optical Distance Indicator or Distance Indicator (ODI) with deviations

SSD (cm)	ODI (cm)	Deviation (%)
100	100	0

D. Collimator Size Indicator

During patient treatment, the radiation beam which is defined by field size results from the closing and opening of the collimator jaws to an extent. The results of the collimator size indicator for 5×5 cm to 20×20 cm is summarized in Table 4. Tolerance ± 2 mm.

Table 4: Collimator Size Indicator with average deviations

Jaws (mm)		Expected (mm)		Measured (mm)		Difference (mm)	
X=5	Y=5	5.0	5.0	5.0	5.0	0.0	0.0
X=10	Y=10	10.0	10.0	10.1	10.0	0.1	0.0
X=15	Y=15	15.0	15.0	15.0	15.1	0.0	0.1
X=20	Y=20	20.0	20.0	20.0	20.0	0.0	0.0

E. Gantry Angle Indicator

During the treatment of patient gantry moves through various planned angles to deliver the right dose to patients during the process. The results of the test done from selected angles are summarized in Table 5. Tolerance ± 1°.

Table 5: Gantry Rotation with average deviations

Level	Digital	Mechanical	Difference
0	0.0	0.0	0.0
90	90.1	90.0	0.1
180	180.1	180.0	0.1
270	270.0	270.0	0.0

F. Collimator Angle indicator

Collimator rotation is key in treatment planning as better dose coverage and sparing of critical organs is concerned. A summary of the test done on various collimator angles is presented in Table 6. Tolerance ± 1°.

Table 6: Collimator Rotation with average deviations

Level	Digital	Difference
0	0.0	0.0
45	45.1	0.1
90	90.1	0.1
180	180.0	0.0

G. Couch Position Indicators

A quality control test on the movement of couch necessary since patient setup and treatment is dependent on this as well. This is done to maintain the integrity of the couch. A summary of the results from the tests performed is shown in Tables 7 and Table 8. Tolerance ± 0.2 cm.

Table 7: Couch Position Indicators (longitudinal)

Ruler	Digital (cm)	Mechanical (cm)	Difference (cm)	Deviation (cm)
0	0.0	0.0	0.0	0.0
-10	133.0	123.1	9.9	-0.1
+10	113.1	123.1	10.0	0.0

Table 8: Couch Position Indicators (vertical)

Ruler	Digital (cm)	Mechanical (cm)	Difference (cm)	ODI (cm)
0	0	N/A	N/A	100
-5	-5.1	5.0	-0.1	105
5	4.9	5.0	0.1	95
-10	-10.1	10.0	-0.1	110

H. Iso Walk

Couch and collimator isocenter tests are important quality control tests performed on the machine since one has to make sure of reproducing the same baseline isocenter settings attained during acceptance. The results are summarized in Table 9. Tolerance ± 1 mm.

Collimator	0.1	0.18
Couch	0.1	0.16

I. Safety Checks

The safety check is very key to the safe and comfortable treatment delivery to patients undergoing radiotherapy. This also helps warn and prevent staff and authorized people of any unnecessary radiation exposure. The summary of the results obtained is found in Table 10.

Table 10: Safety checks with operational status.

Check	Status
Door interlock and console	Functional
Video monitors	Functional
Beam-on light indicator	Functional
Audio intercom system	Functional

Eighty percent (80%) of the measured dosimetric data was below ±2% tolerance,10% above ±2% and with 10% above the tolerance value of ±3% from the commissioning value from fig.1. Daily measurements over the period shows an average percentage difference of 1.39% and 0.83% for 6 and 16 MV photon energies as compared to the values obtained during commissioning.

The monthly photon output had four of values within the ±3% of the reference values and the one above the tolerance value fig.2. Output measurements over the period show an average percentage difference of 2.16% and 2.18% for 6 and 16 MV photon energies as compared to the values obtained during commissioning.

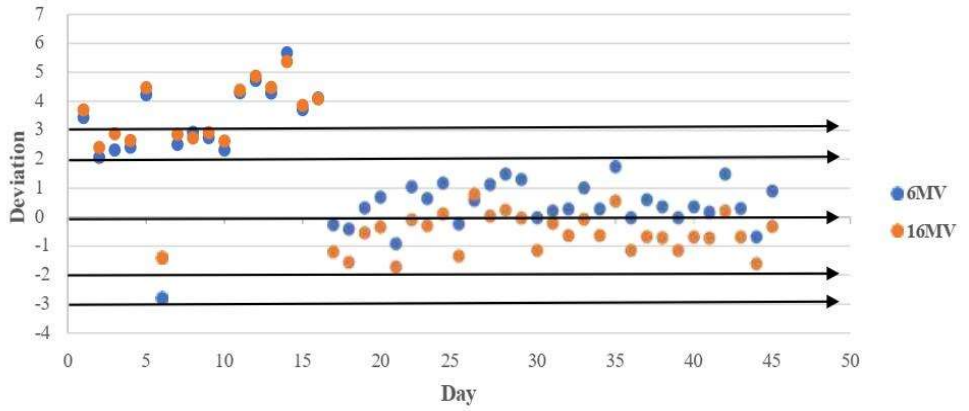

Fig.1 A graph of daily photon output deviation

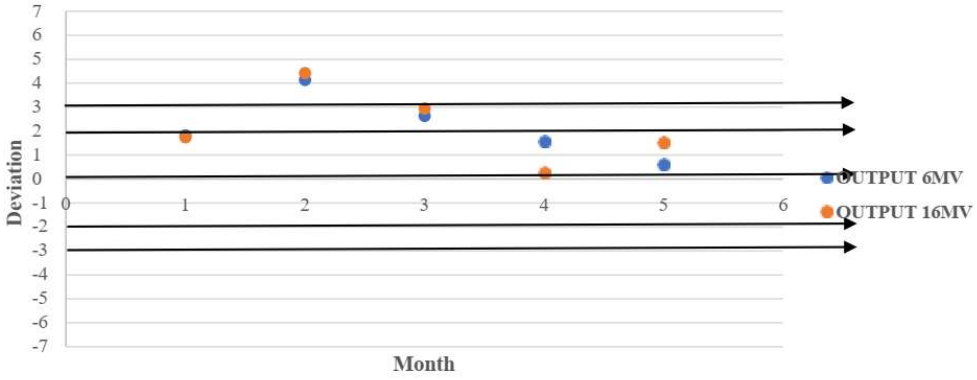

Fig.2 A graph of monthly photon output deviation

IV. DISCUSSION

The output value above the tolerance might be due to power fluctuations, procedural errors and concentrated charges at the effective point of measurement of the ionization chamber. These will be adjusted to meet the tolerance value for better treatment outcome. For daily QA tests, these parameters could seriously affect patient positioning and therefore the registration of the radiation field and target volume (collimator size indicators, lasers, ODI) and safety (Door interlock and console, video monitors, beam on light indicator, and audio intercom system) were carried out. From tables 4, 2, 3 and 8 all these parameters checked were within the acceptable limits and in good working condition.

The monthly mechanical tests which include laser localization, distance indicator (ODI), collimator size indicator, gantry/collimator angle indicators, couch walk, collimator walk and treatment couch position indictors were all within the tolerance values of ±2 mm, ±2 mm, 1°, ±1 mm, 1° and ±2 mm respectively.

The daily safety checks were done and were found to be within tolerance (functional). The audiovisual monitor functioning proves that patient can be monitored whiles treatment is in session and communicated to ensure safety and comfortability. The beam on indicator being functional keeps the staff or authorized people in the known of whether the radiation is on or not.

V. CONCLUSION

A comprehensive QA program is essential for the safe delivery of radiation and the quality of treatment received

by patients. It was essential that centers transitioning from Cirus Co-60 units to modern Linac treatment implemented a robust QA program and have a system of tracking to verify any out of tolerance data to improve the quality of radiotherapy care that patients receive in their clinics.

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