# Monitoring linear accelerator beam with daily quality assurance phantom

**N. Dhoju*, A. Pudasainee*, B. Jha**, P. K. Yadav**, A. Pokharel**, K. Nyaichai*** and T. R. Lamichhane***

*Central Department of Physics, Tribhuvan University, Kirtipur, Kathmandu, Nepal.

**Bhaktapur Cancer Hospital, Dudhpati, Bhaktapur, Nepal.

***Kathmandu Cancer Center, Changunarayan, Bhaktapur, Nepal.

**Abstract:**This paper aims to analyze the output constancy of a medical linear accelerator using PTW, and to study the suitability as a daily quality assurance device. It is assumed that the device is sensitive enough to detect minor variations in central axis beam, flatness, symmetry, and beam quality factor. PTW, *QUICKCHECK*webline is the most efficient wireless device used in daily quality assurance. The measurements of output doses of photons ( 6MV and 15 MV) and electrons (6,9,12, and 15MeV) from a medical linear accelerator before the daily treatment have been graphically analyzed. This study assures the output stability of Varian Clinac iX 2100 CD linear accelerator at Bhaktapur Cancer Hospital, Bhaktapur, Nepal. The beam flatness, symmetry, beam quality factor, and central axis of photon and electron beam have been analyzed for 10x10cm$^2$ and 20x20cm$^2$ field size in separate ways. Among the measurements, observed parameters lie under the tolerance limit as recommended by American Association of Physicists in Medicine viz. ±3%. The outcomes of the measurements are in the acceptable range for the treatment procedure of patients.

**Keywords**: Linear accelerator; Quality assurance; Tolerance limit; Phantom.

## Introduction

In radiotherapy, ionizing radiation causes the ionization of malignant cells either in a direct or indirect way: directly through electrons or positrons and indirectly through x-rays or -rays[1]. A Linear accelerator (Linac) is a device that is used to deliver radiation for treating cancerous tissues in patients[2]. Photon beams are mostly applied for qualitative radiotherapy treatment. For maintaining effective treatment, accelerator's stability and quality control ability are required[3]. Based on the study performed on tumor control probability (TCP) and normal tissue complication probability (NTCP), it has concluded that more than 7% deviation in dose delivery shows clinically detectable effects on tumor and normal tissues[4]. The American Association of Physicists in Medicine (AAPM) task group 142 suggests a certain set of quality assurance (QA) test to be performed on a daily, weekly, monthly, and annual basis[5]. QA is the task of monitoring the performance of the machine to verify that it functions within the baseline values[6]. QA reduces uncertainties and errors of machines as well as complications and recurrence rates of tumors. It also expands the probability of identifying and rectifying the possible blunders or accidents as soon as possible so that fewer consequences occur during patient treatment Mcdermott *et al*. (2009) worked on the setup issue of daily output measurements for a Linac. PTW, *QUICKCHECK*webline (QCw) was concluded to be a more suitable, wireless device for daily QA measurement with good linearity and reproducibility results[7]. Maria *et al*. (2015) worked on utilizing data visualization techniques for trending photon and electron behavior using QA beam Checker Plus. Everyday observations and monitoring of Linac can be more efficient than frequently prescribed preventive maintenance techniques[8]. QCw is a device that consists

***Author for Correspondence***: Tika Ram Lamichhane, Central Department of Physics, Tribhuvan University, Kathmandu, Nepal.
Email: tika.lamichhane@cdp.tu.edu.np
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of inherent ionization chambers designed for routine reliability valuation of Linac beam parameters. It accesses dose output, flatness, symmetry, and radiation quality of Linac. Cable-free and truly wireless system with all indispensable elements makes it ready for daily use after a frame-up.[6,9].

**Materials and methods**

The measurements were carried out on the Varian Clinac iX 2100 CD Linear accelerator in Bhaktapur Cancer Hospital, Bhaktapur, Nepal. The baselines of the QCw device were reset during annual QA on the Linac after performing absolute calibrations on all energies. The device was calibrated weekly using two dimensional (2D) water phantom for evaluating the trend of measurement. Commissioned data and data obtained through 2D water phantom calibration were equivalent. QCw was normalized as per that data. Daily QA of Linac were performed for field size 10×10 $cm^2$ and 20×20 $cm^2$ for both electron and photon energies respectively.

QCw device consists of 13 vented ionization chambers each with a capacity of  cc. The chambers were used to measure the dose, dose rate, flatness, symmetry, central axis (CAX) beam, and index for beam quality factor (BQF). There was a predefined worklist on QCw device. The selection of the worklist is prior to each measurement. The measured data were resettled to a PC for storage and trend analysis.

CAX represents the central chamber of ionization. L10 indicates the ionization chamber at the left of CAX at a distance of  cm. Similarly, R10 indicates that at the right of CAX at the same distance. G10 and T10 are the ionization chamber on the gun to target (GT) direction from CAX respectively at a distance of  cm. Same applies to G20 and T20 at a distance of 20 cm. L20 and R20 are the ionization chamber on the left to right (LR) direction from CAX at 20 cm. The chambers located at the diagonals from the CAX are chambers that absorb energy. Updated guidelines set by the AAPM task group 142 was followed for setting limitations in our study action. The deviations of critical values are monitored so that the measurements will be within an acceptable tolerance. If the data is deviated beyond the guidelines, then the system needs to reset and rectify. Consequently, machine output is monitored and exposed to the treatment procedure.

Considering the importance of various parameters used during dose delivery and the AAPM recommendations, we decided to work with five variables during the study. The parameters are CAX, flatness of the beam, symmetry of the beam over GT and LR direction, and BQF.

Short-term reproducibility and linearity Short-term reproducibility and linearity of the device were checked to ensure the capability of QCw whether it enables to detect the small variation in output or not. Linearity was tested on the first day of the study. It was tested by delivering set monitor units (MU) to the QCw device with no additional build-up in the interval between  70 MU and  130 MU at  5 MU increments and standard 10x10 $cm^2$ at  100 SSD and  6 MV of energy, then input and output MU were compared to conclude the linearity of the device[3].

**Calculation of parameters**

Different parameters were used for calculating various parameters in QCw. Software automatically calculates the normalization factor through the normalization function. Each parameter has its own normalization factor which gets multiplied by each subsequent measurement.

**Flatness**

The ionization chamber and central chamber L10, T10, G10, R10 and CAX are used for measurement of flatness in  . Similarly, the central chamber along with T20, L20, G20, and R20 ionization chambers were used for 20x20 $cm^2$ . Utilizing the doses measured at these respective ionization chambers, we have calculated flatness using Equation 1 [10,11].

$$flatness(f) = 100(k_n)_{flatness} \times [\frac{D_{max}}{D_{min}}] \quad .....(1)$$

where $D_{max}$ indicates the maximum dose value delivered at the ionization chamber. $D_{min}$ represents minimum dose delivered at the ionization chamber. $(k_n)_{flatness}$ defines normalization factor for flatness.

**Symmetry**

The dose symmetry was analyzed for both GT and LT directions. For calculation of the dose symmetry delivered in 10x10 $cm^2$ , the ionization chambers T10 and G10 or L10 and R10 were used. The symmetry calculations are defined by Equations 2 and 3[9].

$$S_{GT} = 100(K_n)_{syGT} Max_{X=G10}^{X=G} \left[\frac{max(D_{-x}, D_x)}{min(D_{-x}, D_x)}\right] \qquad .....(2)$$

$$S_{LR} = 100(K_n)_{syLR} Max_{X=L10}^{X=L} \left[\frac{max(D_{-x}, D_x)}{min(D_{-x}, D_x)}\right] \qquad ......(3)$$

where $(k_n)_{syGT}$ defines normalization factor for symmetry in GT direction. Similarly, $(k_n)_{syLR}$ stands for normalization factor for symmetry in LR direction. $D_{-x}$ and $D_{-x}$ are the maximum dose delivered along the beam profile on either side. For measurement of symmetry dose in 20x20 $cm^2$ , we replace T10, G10 or L10, R10 with T20, G20 or L20, R20 respectively.

### Beam Quality Factor (BQF)

The central chamber and one of the four ionization chambers were used for calculating BQF as per the field. BQF was calculated through Equation 4.

$$BQF = 100(K_n)_{BQF} Poly\left[\frac{D_{Ei}}{D_{CAX}}\right] \qquad ....(4)$$

where refers to normalization factor for BQF index. denotes dose delivered at the ionization chamber. means dose at central chamber. Poly represents the polynomial expression established by the manufacturer.

### Central Axis Dose (CAX)

CAX was calculated by processing the dose exposed at the central chamber of QCw device.

$$CAX = (K_n)_{CAX} \times D_{CAX} \qquad ......(5)$$

where is the normalization factor for the CAX. is the Central chamber dose which is calculated by the QCw device itself as per the setup.

## RESULTS

### Short-term reproducibility and linearity

As clarified in the previous section, the short-term reproducibility of QCw was tested using a set of MU ranging from to for consecutive readings using at cm SSD. The relation between MU observed by QCw and input MU on Linac was obtained linearly as shown in Figure 1.

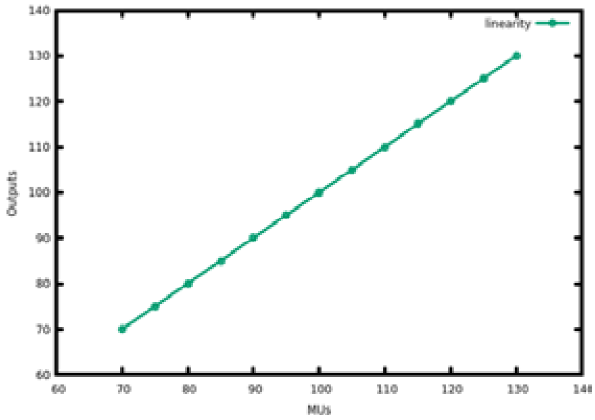
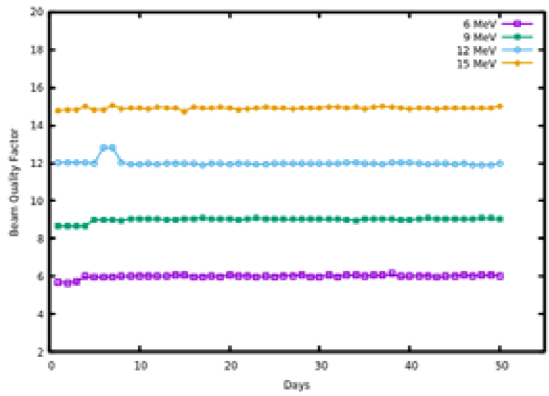
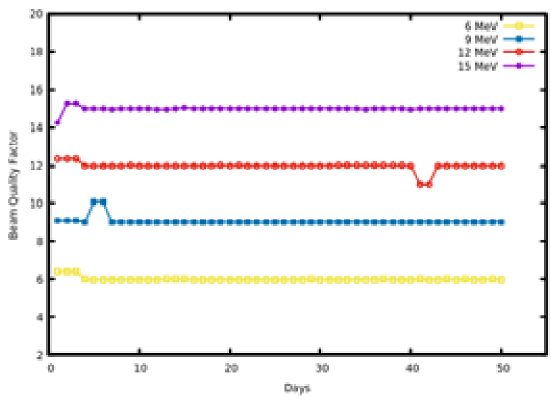


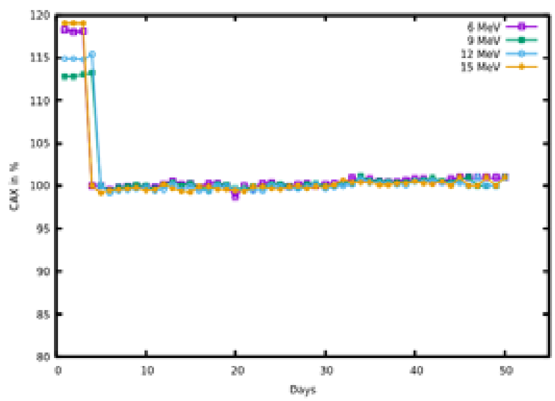

**Figure 1: Linearity of measurements observed by *QUICKCHECK<sup></sup>webline***



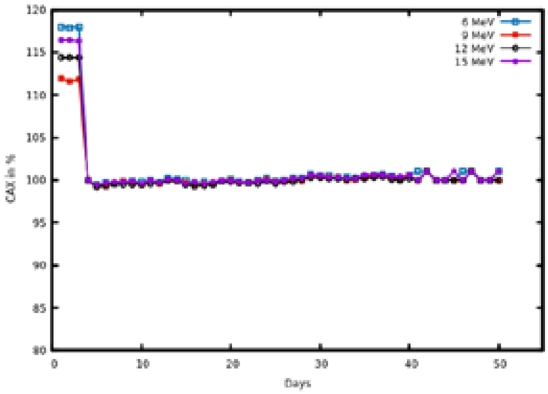

**(a) BQF in 10x10 $cm^2$**




**(b) BQF in 20x20 $cm^2$**

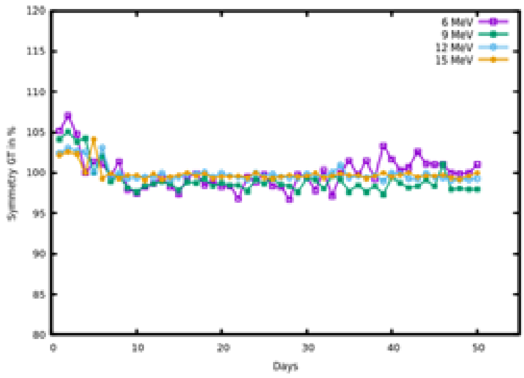



**(c) CAX in 10x10$cm^2$**

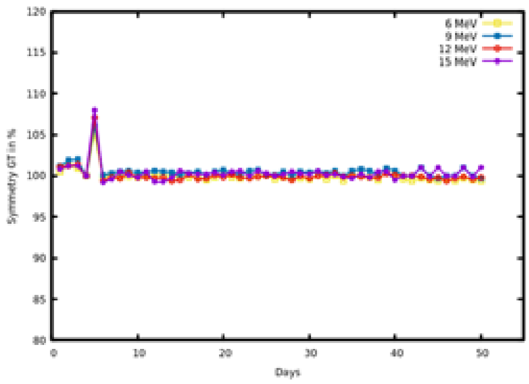



(d) **CAX in 20x20 cm²**

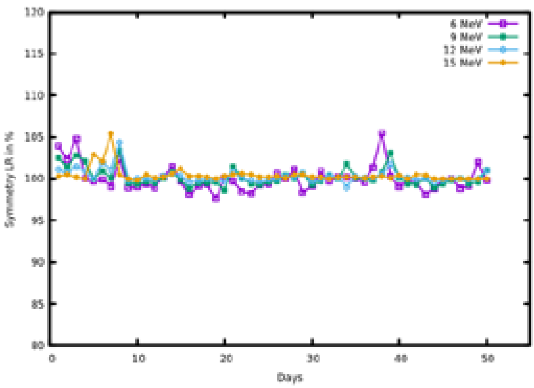
**Figure 2: Variation of beam quality factor (BQF) and central axis (CAX) for 6, 9, 12 and 15 MeV of electron beam.**



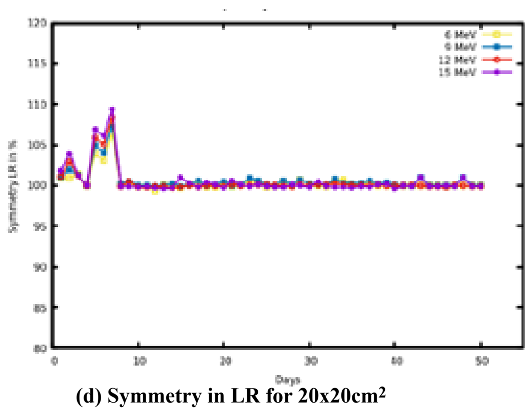

**(a) Symmetry in GT for 10x10cm²**




**(b)Symmetry in GT for 20x20cm²**




**(c) Symmetry in LR for 10x10cm²**




**(d) Symmetry in LR for 20x20cm²**

**Figure 3: Symmetry in gun to target (GT) and left to right (LR) direction for 6, 9, 12 and 15 MeV of electron beam.**

## Calculation of parameters of electron beam

QCw device uses five ionization chambers to check the electron beam. These ionization chambers include a central chamber and chambers at the corners located at  cm from the center in the diagonals. Thus, single exposure of the electron beam allows the measurement at five different points. The change in energy is measured with respect to the central chamber, i.e. the ratio of each energy chamber reading to the CAX chamber reading. Hence, changes in setup or other factors show a direct impact on the CAX.

Variation of BQF according to respective days of measurement was observed as shown in Figure 2(a) and (b). There seems to be the presence of certain peaks of variations in the graph but it lies within the tolerance as recommended by AAPM ((±3%). The graph in Figure 2(c) and (d) shows the variation of CAX on respective days of measurement. About the first three days of measurement, there seems to be some unusual deviations of CAX value but the rest are within the tolerance level and can be neglected.

The deviations of measurement of symmetry in the GT direction were observed and shown in the graph in Figure 3(a) and (b). In 10x10 cm², there seem to be rapid variations in the level of symmetry in GT directions but most of the deviations lie within the tolerance level, so it does not affect the treatment procedure. All data are under accepted level except one so it can be neglected for 20x20 cm² (Figure 3(b). It is due to the misalignment of the device over the couch.

Similarly, the deviations seen in the graph of symmetry in LR direction over measurement days are shown in Figure 3(c) and (d) that also follow the identical reason. Electron applicators of respective field sizes must be used to monitor electron beams in the Linac. These electron applicators are supported by a secondary collimator that produce uniform electron distribution across its output end. The purpose of these applicators is not only to limit the field size but also to provide good flatness of the dose profile. Thus, calibration of flattening measurement for electron beam profile can be neglected in the Linac.

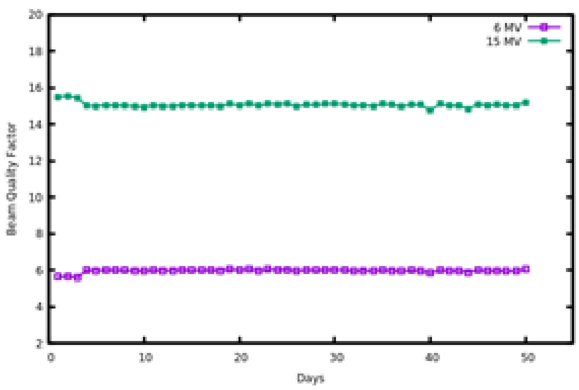
### Calculation of parameters of photon beam

For evaluating the photon energies, QCw device uses five ionization chambers including a central chamber and chambers at the corners (located at a distance of 11.3 cm) from the center in the diagonals. Parameters measured by the Linac device must be within the acceptance level for qualitative production of photon beam. Here, we have calibrated MV and MV of photon energies. The BQF of photon beam for field sizes is obtained as in Figure 4(a) and (b). The deviation occurs only for certain days. Later, the measurement is consistent and under uniform level.

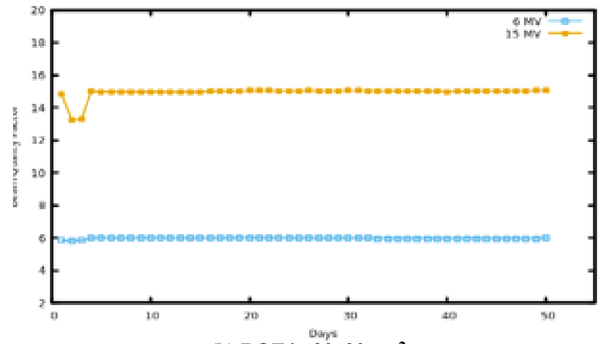
Similarly, variations of CAX beam according to the respective measurement days were observed as presented in Figure 4(c) and (d) that shows CAX variation in 10x10 $cm^2$ and 20x20 $cm^2$ respectively. There is no major issue with the deviation observed as it is due to mispositioning of the ionization chamber with the center of scattering foil.

Variations of symmetry for MV and MV energies of photon beam in the GT and LR direction were observed within the tolerance limit. Figure 5(a) and (b) indicate variation of symmetry in GT direction and Figure 5(c) and (d) in LR direction for respective field size. Normally, Flatness is defined at depth of cm in tissue. Flatness of the photon beam is extremely sensitive to change in the energy of the incident beam. Minor change in the penetrating quality of photon beam shows very large variation in beam flatness. Photon beam penetrates more on the surface because the beam is hardened at the center. Variations in the flatness of the photon beam in respective measurement days were obtained as Figure 6. It seems to be more sensitive in field size 10x10 $cm^2$ (Figure 6(a)) in comparison to 20x20 $cm^2$ field size (Figure (b). Deviation seen in the graph of flatness lies within the tolerance level. So, the dose delivered to the patients are effective.

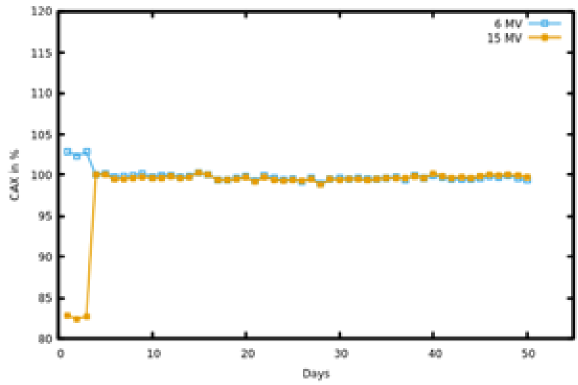
Many scholars have studied and performed research work on different aspects of QCw and claimed that it a suitable device for the daily QA of Linac. This work motivates the researchers to explore the efficient mechanism of QCw and analyze various parameters of the Linac.



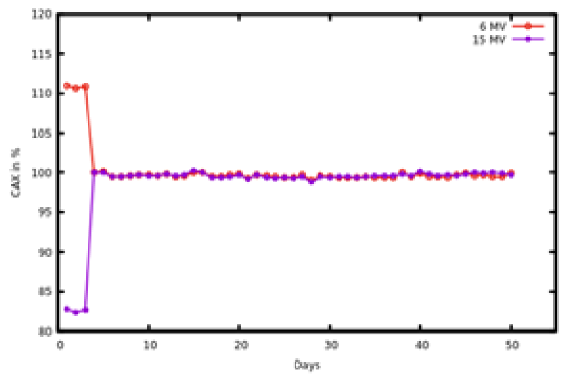

**(a) BQF in 10x10 $cm^2$**




**(b) BQF in 20x20 $cm^2$**

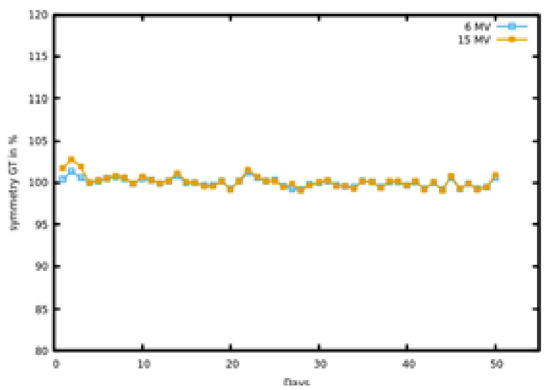



**(c) CAX in 10×10 $cm^2$**

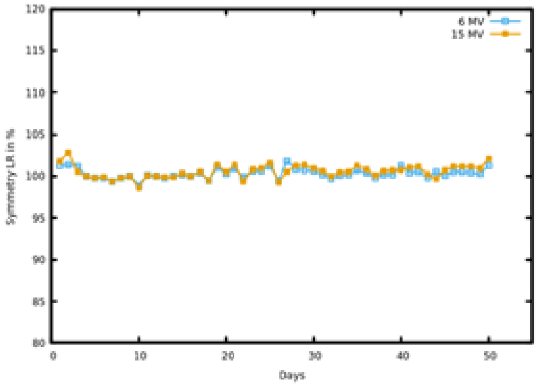



**(d) CAX in 20×20 $cm^2$**

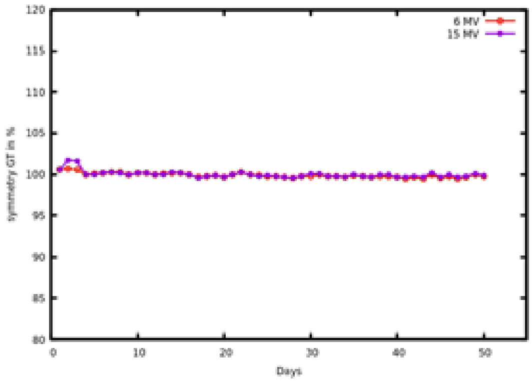
**Figure 4: Fluctuation of beam quality factor (BQF) and central axis (CAX) for two energy values(6 MV and 15 MV) of photon beam.**



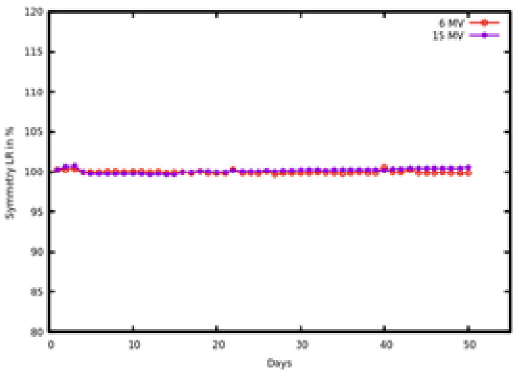

**(a) Symmetry in GT for 10×10 $cm^2$**




**(b) Symmetry in GT for 20x20 cm²**

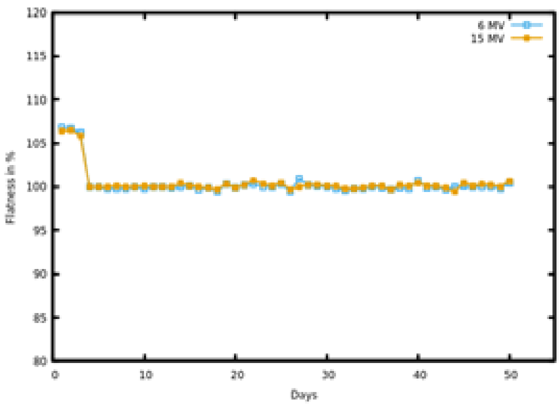



**(c) Symmetry in LR for 10x10 cm²**

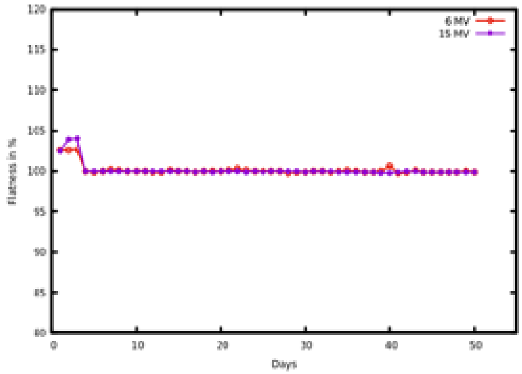



**(d) Symmetry in LR for 20x20 cm²**

**Figure 5: Symmetry in gun to target (GT) and left to right (LR) for two energy values (6 MV and 15 MV) of photon beam.**




**(a) Flatness in 10x10 cm²**




**(b) Flatness in 20x20 cm²**

**Figure 6: Flatness deviation for 6 MV and 15 MV of photon beam.**

## Discussion

The basic purpose of radiation therapy is to deliver appropriate amount of radiation dose to the affected tissue without creating adverse irreparable damage on other normal tissues as much as we can. For that, we analyze the output of Linac using QCw as a constancy check device to monitor if the Linac can deliver the recommended dose of beam precisely. We reached the conclusion similar to the Mcdermott *et al*.. We believe that the daily morning QA test of Linac helps to monitor output stability of various parameters. QCw gives good linearity and reproducibility.

Chan *et al*. also analyzed measured data and displayed it in a graphical technique that gives ideas to the scientist about the change in the trend of parameters of Linac over time. A constancy check device was used to monitor output and various parameters of beam before daily treatment of patients. Whenever the outputs are beyond the tolerance limit as shown in Figure 3(a) and (b), 4(b), 5(a) and (b), 7(a) and (b) and 10(b), the physicist uses ionization chamber to calibrate the absolute dose of the Linac output in time, which is consistent with the findings reported by Binny *et al*.. Though we calibrate the absolute dose using ionization chamber, measured variation may be beyond the tolerance limit like in the above-mentioned figures. This occur either due to calculation of parameters of Linac according to previously normalized data inspite of newly normalized data or some set-up error.

Stability of medical Linac output is the major aspect of tumor radiotherapy that ensure effective treatment of cancer patients. Physicist must carefully test the parameters of Linac like flatness, BQF, CAX, symmetry every morning before the patient treatment and calibration of dose should be performed at the time of need immediately. The deviation in measured parameters is within which gives similar conclusion as mentioned by Jiang *et al*..

Nicewonger *et al* used two daily QA phantoms (PTW and Sun Nuclear Corporation) to evaluate consistency of the dose output, beam flatness, symmetry and BQF of 23EX Varian Linac. Photon of and MV energies for daily basis and electron of and MeV energies for weekly basis were measured using conveying MU. They concluded that QCw can be used as suitable phantom for daily QA.

## Conclusion

This research has supported the suitability of QCw for regular quality tracks of Linac output along with CAX, flatness, BQF and symmetry in GT and LR direction. Data visualization is the most effective trend in radiation oncology research. Beam monitorization following quality assurance protocol improves quality of exposed beam during treatment procedure of patients. The variations observed during the data measurement of different parameters of Linac over long period of time mostly lie within the tolerance limit as recommended by AAPM. Sometimes the data shows variation beyond the tolerance limit because of misalignment of ionization chamber with the center of the scattering foil. We should be more focused while performing the quality assurance task of respective machinary equipmet.

## Data availability statement

Data will be available upon request to the corresponding author.

## Conflict of interest

There is no ethical issues related to this research.


## Funding information

There is no funding available for this research.

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