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Monitoring Linear Accelerator Output Constancy and Overall Performance Using the PTW Quickcheck^{webline}

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ABSTRACT

Daily morning quality assurance (QA) for all available beams using conventional phantom measures only output and beam quality. PTW QUICKCHECK^{webline} (PTW QCw) is a compact movable light-weight dosimetry equipment used for daily QA, capable of measuring flatness, symmetry, beam quality and output constancy of a given beam in a single exposure. The purpose of this study was to analyze and monitor the output constancy of a medical linear accelerator using PTW QCw and assess the overall performance of the PTW QCw. The output parameters of 4, 6 and 15 MV photon beams and 4, 6, 8, 10, 12 and 15 MeV electron beams of the Elekta Synergy linear accelerator in Kathmandu Cancer Center were analyzed. It was found in the study that all the parameters were well within the recommended tolerance limit of ±3%. Some known modifications in the settings of the linear accelerator gantry, couch, and collimator were introduced separately during the exposures, and the percentage variations from the baseline values were noted to check the sensitivity of the PTW QCw using 6 MV photon beam. The PTW QCw was able to detect the deviations introduced to the external irradiation conditions for both photon and electron beams under daily testing conditions. The results from this study suggest that daily dosimetric consistency measurements using the PTW QCw helps to monitor the overall performance of the linear accelerator.

Keywords: Daily QA, Linear accelerator, Output constancy, QUICKCHECK, Radiotherapy, Sensitivity.

INTRODUCTION

With no national published quality assurance (QA) guidelines or protocols to follow, it has been difficult for the radiotherapy institutes to adopt international protocols [1-4] that suit the local scenarios. There are major hindrances in adopting some of the tests described in international protocols at radiotherapy centers, some of the dominant reasons being the absence or lack of human and technical resources, the parameter to be tested not available or not in clinical use. A clinically qualified medical physicist apply these international recommendations in a suitable manner in their local setup [5]. One of the key objectives of radiotherapy treatment is to achieve precise and accurate prescribed dose delivery to the specified target in patients. The QA of a linear accelerator plays an important role in precise tumor radiotherapy [6-7].

The machine status is updated by comparing the measured and analyzed results from periodic QA against referenced measurements obtained during commissioning and acceptance of the linear accelerator which had been acquired following international and company guidelines. Periodic QA can be performed on a daily, weekly, monthly, or annual basis. Guidelines for the specific acceptability criteria and tolerance levels used in the QA procedure are suggested by international protocols [1-4] and have to be established in country regulations. Periodic QA systems assess various measurements and setup uncertainties that are included in the analysis results. Daily QA, having the highest frequency, are used to evaluate radiotherapy machines prior to using them in daily practice of treating patients. Multiple systems are utilized to perform daily QA in clinical radiotherapy [8-17].

Daily morning QA are generally done with conventional phantom that, besides being time consuming, only measures beam quality via Tissue Phantom Ratio ($TPR_{20,10}$), for available photon beams. PTW QUICKCHECK^{webline} (PTW QCw) is a compact movable light-weight dosimetry equipment used for daily QA capable of measuring flatness, symmetry, beam quality and output constancy of a given beam in a single exposure. The purpose of this study was to analyze and monitor the output constancy of a medical linear accelerator using PTW QCw and access the overall performance of the PTW QCw. Reproducibility and linearity of the device with linear accelerator output were also analysed.

MATERIALS AND METHODS

All the measurements were carried out using Elekta Synergy Platform (Elekta Solutions AB, Kungstensgatan, Stockholm, Sweden) linear accelerator at Kathmandu Cancer Care Hospital for photon energies of 4, 6 and 15 MV, and electron energy 4, 6, 8, 10, 12 and 15 MeV for the field sizes 10 × 10 cm^2 and 20×20 cm^2 at Source to Detector Distance (SDD) of 100 cm. Linearity and output of PTW QCw readings against Farmer type ionization chamber were compared. PTW QCw was used as the measuring instrument for morning quality checks of the linear accelerator.

The PTW QCw utilizes 13 vented ion chambers with automatic air density correction for beam characteristic tests. The QCw uses one ion chamber at the center of the device to measure output constancy, four chambers along the central axis at the borders of the device to measure flatness and symmetry, and the remaining chambers are used to measure the beam energy for the photons and electrons. The measuring chambers, having measuring volume of 0.1 cc are placed at the depth of 0.57 cm where are the energy chambers E1, E2, E3, and E4 have measuring volume of 0.2 cc and are placed at varying depth of 5.3 cm, 3.7 cm, 2.8 cm and 1.5 cm respectively to imitate the varying depth measurements. A pass-fail system for the measurement is available in the device after a beam is delivered and trends can be viewed in the device software [17].

The QCw was used for about two months to perform constancy checks of output, flatness, symmetry, energy and light field verification for all available photon and electron energies using 10 × 10 cm² and 20 × 20 cm^2 field size at a 100 SDD for 100 Monitor Units (MU). The annual QA data, fine-tuned to commissioning data of the linear accelerator was used as the baseline data for the study.

The calculations for flatness and symmetry are dependent on the modality and the evaluation protocol. The QCw contains preset major dosimetry protocols like AAPM TG-45, IEC 60976, Elekta, Siemens, Varian. The protocol is set when the worklists are created. For our study we used Elekta protocol.

Reproducibility and Linearity

For short-term reproducibility measurement, the PTW QCw was placed in a field size of 10 × 10 cm^2 at 100 SDD. The arrangement was irradiated 10 times with 100 MU of 6 MV beam. The PTW QCw and Farmer ion chamber readings were recorded.

For linearity measurement, all the arrangements were kept the same as that for short-term reproducibility. The QCw was irradiated with a 6 MV beam using monitor units of 70 to 130 with 5 MU increment. PTW QCw readings with Farmer ionization chamber readings were compared.

Output constancy

The central axis (CAX) chamber on the QCw device is primarily used for measuring the output of the required beam. The QCw readings were compared to corresponding baseline values.

Automatic Air density correction

The air density correction factor k_{TP} for QCw measuring chambers is calculated automatically using the following formula [17]:

$$k_{TP} = \frac{(273.2+T)*P_0}{(273.2+T_0)*P} \qquad (1)$$

Where, T is temperature in °C measured by QCw, P is atmospheric pressure in hPa measured by QCw, T_0 is temperature for calibration 20 °C and P_0 is the atmospheric pressure for calibration 1013.25 hPa.

Dose Values

The dose values Di for all measuring chambers are calculated according to the formula:

$$D_i = M_i \times N_i \times k_{TP} \qquad (2)$$

Where D_i is measured charge of measuring chamber i, M_i is ^{60}Co calibration factor of measuring chamber i and k_{TP} is a correction factor for air density correction.

Normalization factor k_{norm}

PTW QCw allows the user to normalize the evaluation values with the normalization factors k_{norm}. All the subsequent measurements will then be multiplied by this normalization factor.

Central Axis Dose, CAX

$CAX = (k_{norm})_{CAX} \times D_{CAX}$ .... (3)

Where $(k_{norm})_{CAX}$ is normalization factor for the central axis dose, and D_{CAX} is central chamber dose calculated using equation 2.

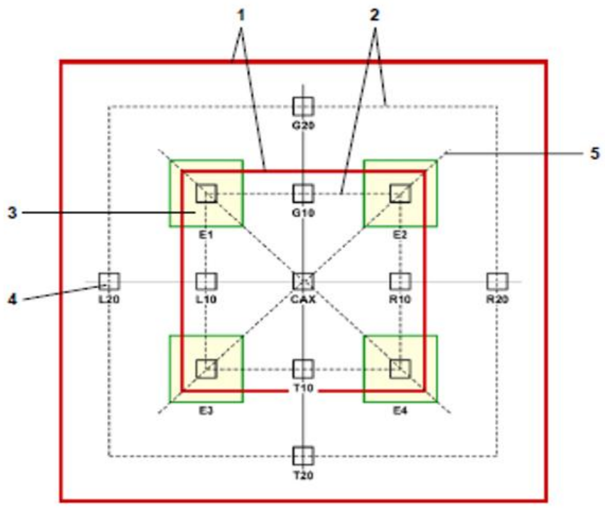


Fig. 1: The location and orientation of PTW QCw measuring chambers for dose measurements. 1 - Field size; 2 - 80% of the field size; 3 - Energy chambers with absorber (E1, E2, E3, E4); 4 - Measuring chambers (CAX, L10, R10, G10, T10; L20, R20; G20, T20); 5 - Diagonal of the measuring field. [17]

Flatness

The central chamber along with other ionization chambers is used in calculating the flatness. For the field size of 10 × 10 cm^2 the central CAX ionization chamber, T10, L10, G10, and R10 are used while for the field size of 20 × 20 cm^2 the central CAX ionization chamber along with T20, T10, L20, L10, G20, G10, R20, and R10 are used.

The evaluation algorithm for flatness is

$F = 100 \times (k_{norm})_{FLAT} \times \frac{D_{max}}{D_{min}}$.................................(4)

Where

$(k_{norm})_{FLAT}$ is normalization factor for flatness

D_{max} is maximum dose value of the 5 or 9 ionization chambers

D_{min} is minimum dose value of the 5 or 9 ionization chambers

This algorithm shows the deviation of the flatness F in %.

Symmetry

Symmetry for the gun-target direction and right-left direction are analyzed separately. The peripheral ionization chambers are used for the evaluation of the symmetry: ionization chambers, T10 and G10 or L10 and R10 for the field of 10 cm × 10 cm; T20 and G20 or L20 and R20 for the field of 20 cm × 20 cm. The evaluation algorithm for symmetry used is:

$$S_{LR} = 100 \cdot (k_{norm})_{SymLR} \cdot {}_{X=L10}^{\;\;L}\mathrm{Max}\left[\frac{\mathrm{Max}(D_{-x}, D_x)}{\mathrm{Min}(D_{-x}, D_x)}\right] \quad (5)$$

$$S_{GT} = 100 \cdot (k_{norm})_{SymGT} \cdot {}_{X=G10}^{\;\;G}\mathrm{Max}\left[\frac{\mathrm{Max}(D_{-x}, D_x)}{\mathrm{Min}(D_{-x}, D_x)}\right] \quad (6)$$

Where

$(k_{norm})_{SymLR}$ is the normalization factor for symmetry in the left-right direction

$(k_{norm})_{SymGT}$ is the normalization factor for symmetry in the gun-target direction

D_x, D_{-x} are the dose values for the ionization chambers at the chamber positions x or –x. the chamber positions x and –x are symmetrical to the central beam. (Examples: if x = L10, then –x = R10, if x = G20, then –x = T20)

Index for the radiation quality, BQF

Beam Quality Factor (BQF), the index for the radiation quality was determined for photon on a field size of 10 cm × 10 cm and for electron on a field size of 20 cm × 20 cm on an open field. The central ionization chamber and one of the four ionization chambers for radiation quality are used for radiation quality BQF. The BQF is calculated using following formula:

$BQF = (k_{norm})_{BQF} \times \mathrm{Polynom}(\frac{D_{Ei}}{D_{CAX}})$..................... (7)

Where,

$(k_{norm})_{BQF}$ is normalization factor for the index for the radiation quality,

D_{Ei} is dose of the corresponding ionization chamber for radiation quality,

D_{CAX} is central chamber dose.

Statistical analysis

The data were transferred to an excel sheet where all the necessary statistical analyses were performed. If p-values< 0.05, the differences were considered statistically significant.

RESULTS

Reproducibility and Linearity

Short-term reproducibility of the PTW QCw was tested applying 100 MU of 6 MV beams using 10 x 10 cm^2 field size at 100 SDD and repeated 11 times. In addition, the output readings for 23 days were analyzed to check its reproducibility. The readings had a good coefficient of variance, way less than the tolerance value of 0.02.

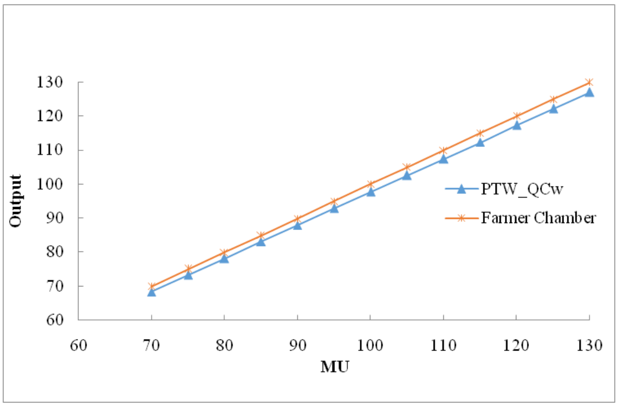


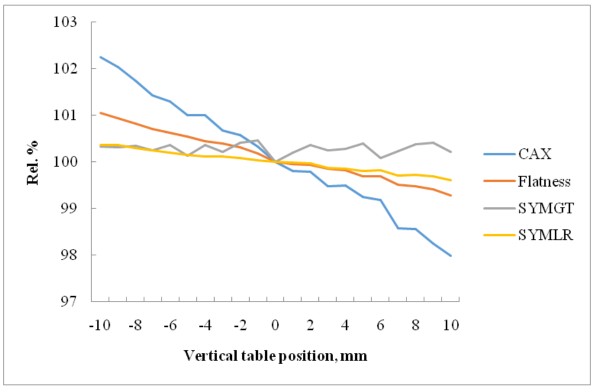
Fig. 2: Linearity measurements of PTW QCw and Farmer Ionization chamber for the same MU range.

The linearity of PTW QCw was checked using a set of MUs ranging from 70 to 130 MU at 5 MU increments. 6 MV photon beam is used with 10 x 10 cm^2 field size at 100 cm SDD. The QCw readings were compared with set monitor units (70-130 MU) with the Farmer chamber readings. The two curves are almost parallel as shown in figure 2.

Sensitivity of the PTW QCw detector

Some known errors were introduced in the QCw by altering the external irradiation conditions and the percent variations from the baseline data were noted. The gantry angles and collimator angles were changed in treatment head, some deviations were introduced in the couch movement in vertical, longitudinal (gun-target direction) and lateral (left-right direction) directions. The radiation quality BQF, beam flatness, symmetry, and output energy 0f 6 MV of photon energy were statistically analyzed.

Along Vertical direction: The couch movement was deviated with a 1 mm increment from -10 mm to 10 mm and the output of PTW QCw was studied whose results are shown in figure 3.



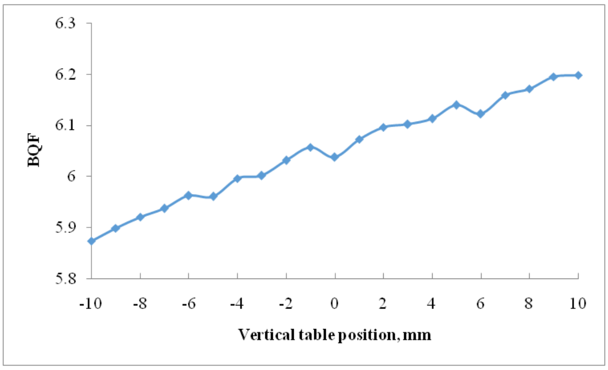
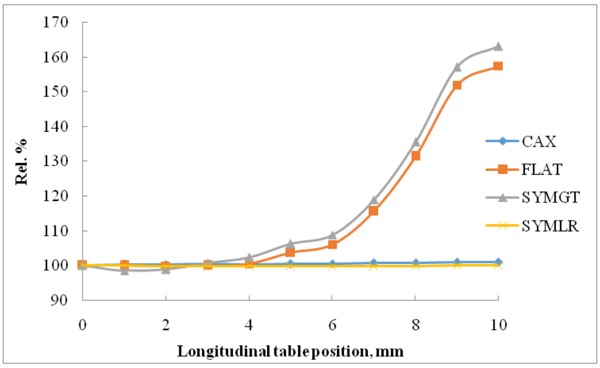


Fig. 3: PTW QCw outputs with change in vertical direction.



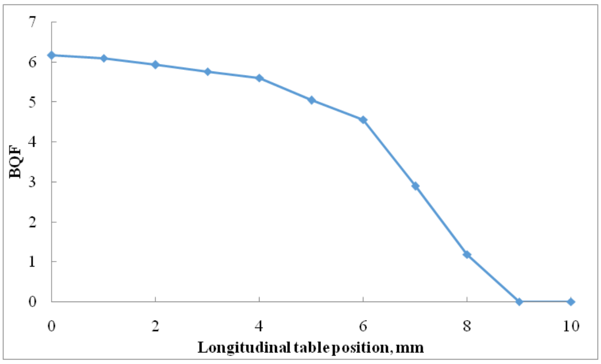


Fig. 4: PTW QCw outputs with change in longitudinal (gun-target) direction.

With deviation in vertical direction the CAX was more sensitive with over-response below the zero position and under-response above the zero position. Opposite was the response of the BQF values.

Along the gun-target direction: In the gun-target direction, a 1 mm increment deviation was introduced and the result is shown in figure 4.

The FLAT, SYMGT and BQF were more sensitive with deviation in the longitudinal (gun-target) direction. The relative variation of the FLAT values from the zero position were within 1% till 4 mm deviation which then increased almost exponentially with increase in the distance. Similarly, SYMGT values, symmetry along the gun-target direction, were within 2% till 4 mm of table movement and the deviation was more pronounced with increase in the table deviation following the trend of the FLAT values. The BQF values decreased to 0 when the deviation reached 10 mm.

Along the left-right direction: Similar to the gun-target direction, a 1 mm increment deviation was introduced in the lateral direction, and the result is shown in figure 5.

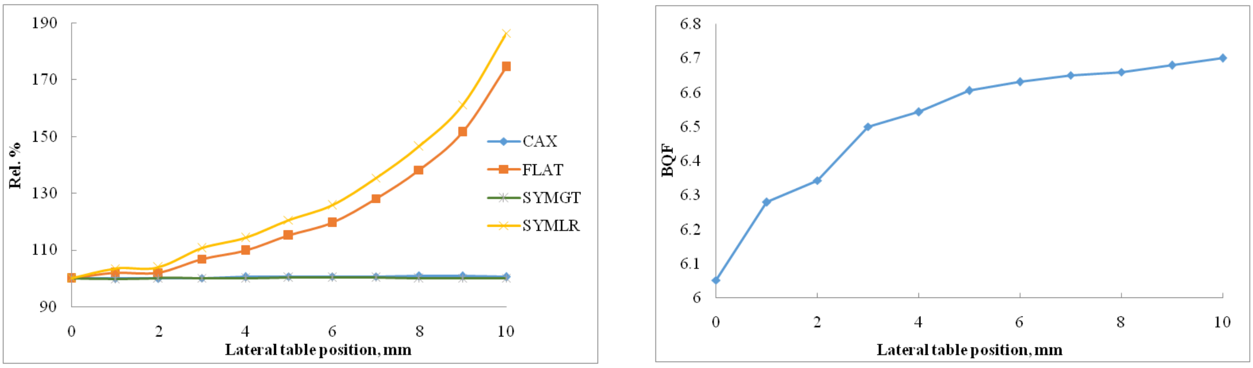


Fig. 5: PTW QCw outputs with change in lateral (left-right) direction.

Similar to the deviation introduced in gun-target direction, the FLAT, SYMLR and BQF were more sensitive to the deviation introduced in the lateral (left-right) direction. The flatness was within 2 % for 2 mm deviation which increased to about 75% when the couch was deviated by 10 mm. SYMLR, the symmetry around left-right direction deviated by 3% with the 1 mm error whilst the deviation reached 86% with 10 mm error in couch lateral position. The trend for the BQF values in lateral deviation is different from the longitudinal deviation in the couch position. In the gun-target direction, BQF decreased significantly with increase in the distance whereas the BQF increased with the distance from the center in the left-right direction.

Effect of the gantry angle

Some errors were introduced in the gantry angle rotation 1 degree increment from 0° to 10°. The results are shown in figure 6.

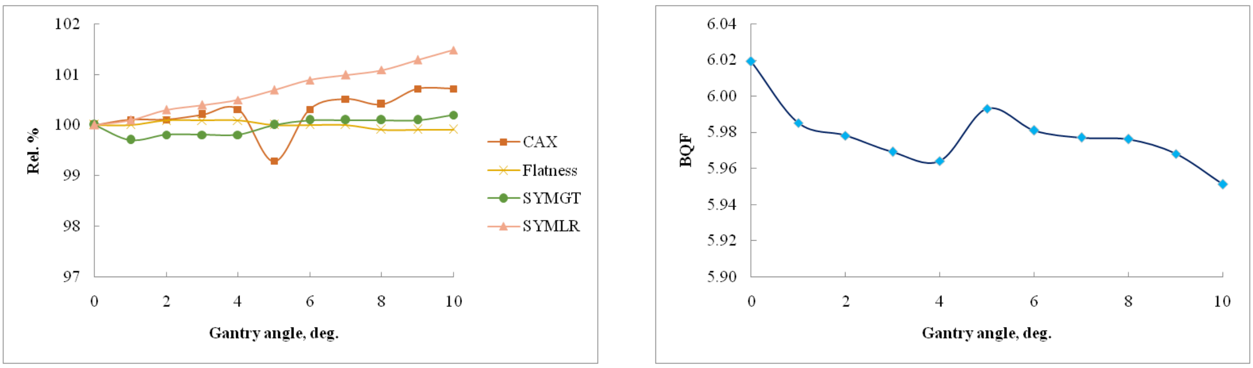


Fig. 6: The effect of gantry angle in the PTW QCw measurements.

The SYMLR and BQF values seemingly varied with the baseline values with change in gantry angle. The SYMLR deviated by almost 2% when the gantry angle was changed by 10° while the BQF decreased by around 1% with increase in the gantry angle.

Effect of the collimator angle

Errors were introduced in the collimator angle rotated from 0° to 10° keeping gantry angle 0°. The results are shown in figure 7.

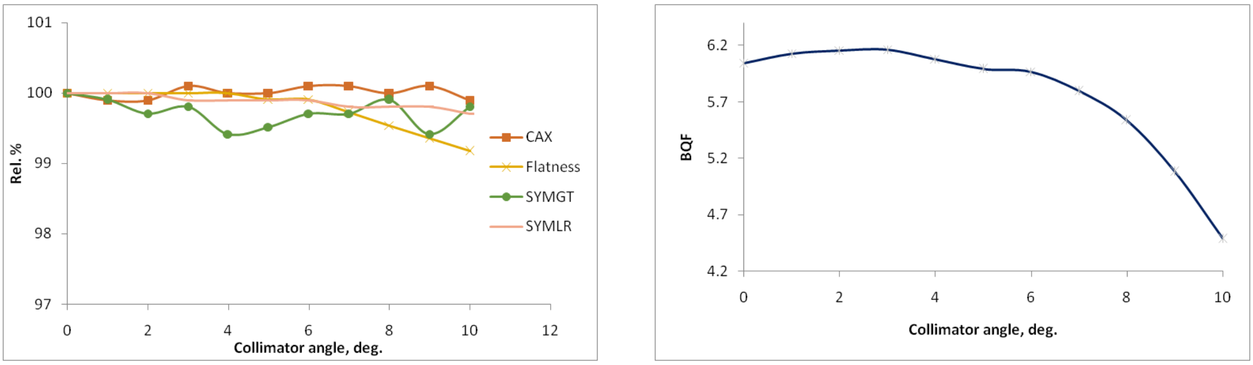


Fig. 7: The effect of collimator angle in the PTW QCw measurements.

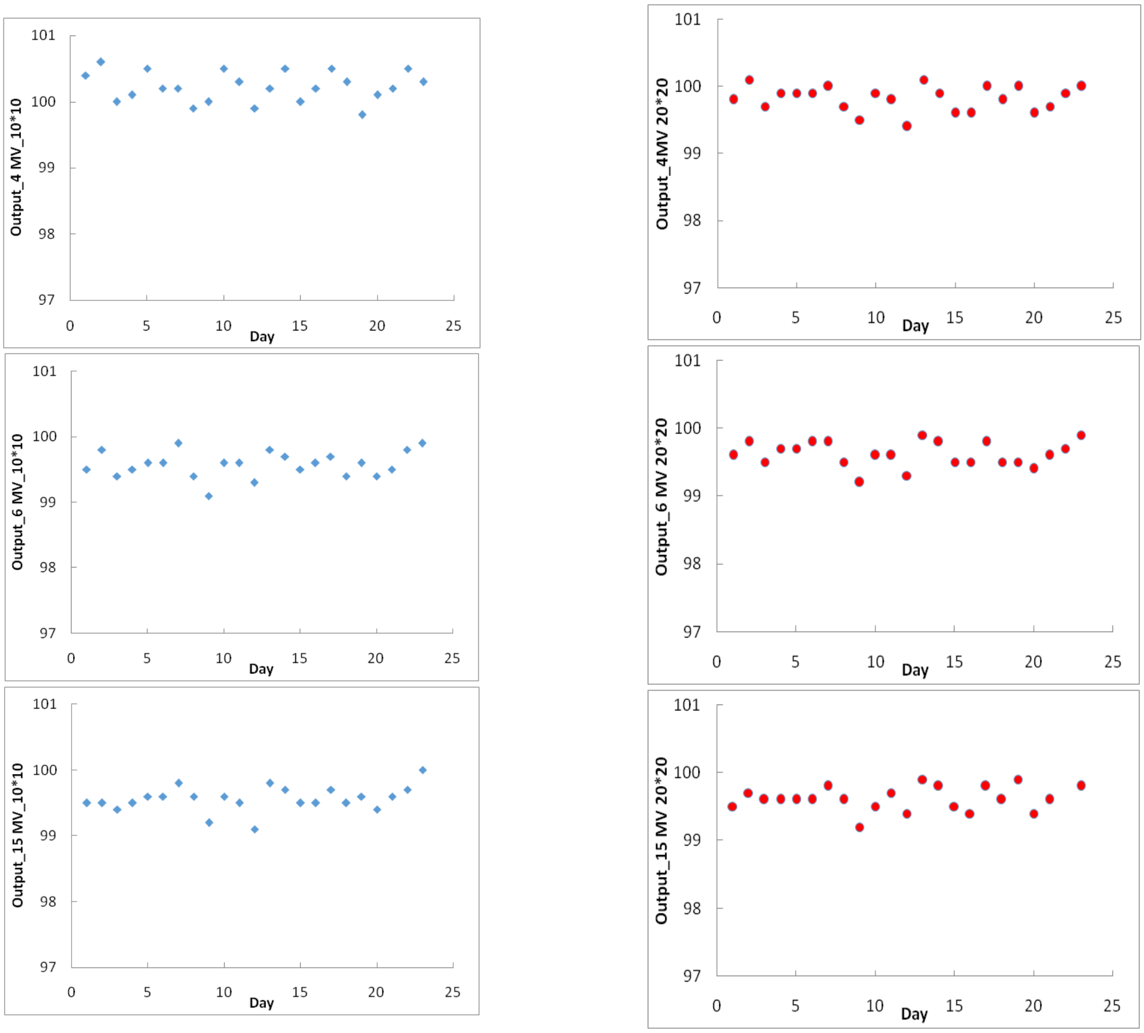


Fig. 8: The dose output of available photon energy of the accelerator.

The FLAT values were consistent with the baseline data till the collimator angle of 4°, beyond that collimator angle the values changed however within 1%. The SYMLR, SYMGT, and CAX values were seemingly unchanged with change in collimator angle. The BQF value was significantly affected by the change in collimator angle. The BQF value changed by around 25% with the change of collimator angle by 10°.

The PTW QCw was used for its daily QA purpose in the hospital for the photon measurements and for electron measurements for about two months. Some problems were encountered in the electron beam which led to the electron beam measurements taken comparatively lesser than for the photon beam measurements. The results are illustrated in figure 8 for the photon measurements and figure 9 for the electron measurements.

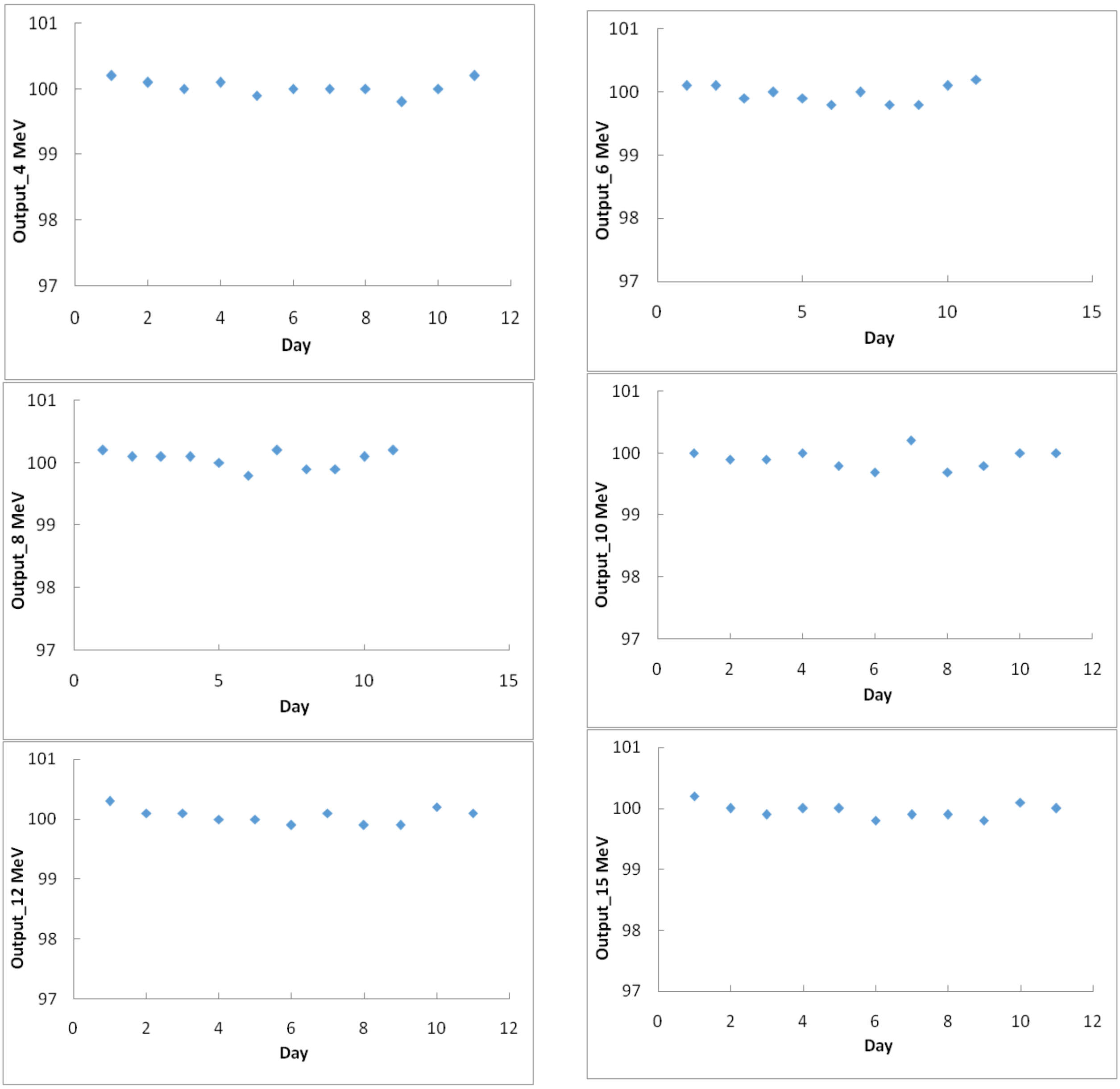


Fig. 9: The dose output of available electron energy of the accelerator.

The output deviation of the accelerator was within a small range of 1% near the standard value indicating the relatively stable performance of the PTW QCw.

DISCUSSION

The PTW QCw was used in this study to monitor the dosimetric parameters of the linear accelerator before the daily treatment of patients. In addition, its sensitivity to slight difference in the treatment couch or/and gantry positions was also checked. However, due to scheduling problem and some mechanical problems in the linear accelerator, the QCw could not be irradiated regularly. The sensitivity check of the QCw was done only with the 6 MV photon beam as this beam energy is more frequently used in radiotherapy treatments in this center. The light field verifications were done manually before any exposure by coinciding the light field of the linear accelerator with the field size outlines on the QCw. The variation in measurement data during the daily morning examinations for all the available photon beam energies of 4, 6 and 15 MV and electron beam energies 4, 6, 8, 10, 12, and 15 MeV were well within 1 %, shown in figure 8, indicating the consistent output of the accelerator. It is recommended [18] that the output deviation should be less than 3% and all of the measured data were within this tolerance near the standard value of the linear accelerator. Other parameters like flatness, symmetry, the beam quality, etc., should be tested properly when the output from the morning QA is consistently greater than 2% [18]. An established daily output dose monitoring mechanism and an effective routine (daily/ weekly/ monthly) measurement system should be an essential part of radiation therapy linear accelerator system quality assurance [1, 2].

Similar study have been performed elsewhere [9,10,12,14,19,20] where various dosimetric parameters of the linear accelerator were studied with the help of different daily QA equipment. Nicewonger D et. al [12] and Jiang D. et. al [20] performed the evaluations with PTW QCw for the Varian linear accelerator while our study is performed on a Elekta Synergy linear accelerator. Even though the orientation of some of the graphs were different than that of the referenced studies [12,20], the final results expected from the daily QA equipment is in agreement with the previous studies.

CONCLUSION

Suitability of the PTW QUICKCHECK^{webline} device was verified with this study for routine quality assurance of the medical linear accelerator which checked the machine output constancy, energy, flatness and symmetry. The device produced fitting linearity and reproducibility with compare to the Farmer ionization chamber readings. The convenient use of this device overcame the conventional daily morning QA phantom with its perk of single exposure requirement to evaluate the different dosimetric output parameters.

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CONFLICT OF INTEREST

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