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Comparison of level-I, -II and -III dosimetry quality audits for MV-photon beams emitted from medical linear accelerators

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ABSTRACT

Background: Dosimetry audits have an important role to safely deliver the prescribed radiation dose to the cancerous area. It not only maintains and improve the treatment standards but also identify issues that are potentially harmful to the patients. This article presents the results of a comparative study of beam output measurements of a high-energy photon beam emitted from a medical linear accelerator. ***Materials and Methods:*** The measurements were performed by an International Atomic Energy Commission (IAEA) Quality Assurance/Quality Control survey mission (level-I dosimetry), a national Secondary Standard Dosimetry Laboratory (SSDL) experts (level-II dosimetry) and hospital physicists (level-III dosimetry). Glass dosimeters and cylindrical ionization chambers for level I and cylindrical ionization chambers for level-II and -III dosimetry were used in water by following IAEA TRS-398 protocol. ***Results:*** The level-I dosimetry results of glass dosimeters and ionization chambers were compared and percent deviations of -0.4 % and 0.3 % were found for 6 and 15 MV-photon beams, respectively. Similarly, level-II and -III dosimetry results with respect to level-I are in good agreement and within the optimum uncertainty level of ±5%. The annual level-II dosimetry quality audits (i.e., from 2010 to 2015) showed that only one dosimetry audit is out of the optimum level set for this study. However, it is within the tolerance level set for level-II quality audit programs (i.e., < ±5%). ***Conclusion:*** In conclusion, this article has demonstrated consistent radiotherapy radiation dosimetry results for MV-photons beams. It also showed quantitative information in-line with the currently achieved accuracy and precision of external megavoltage photon beam dosimetry. Furthermore, this study also established a baseline for current routine audits of radiotherapy dosimetry. Studies of this type are essential to appropriately follow the recommendations and procedures of the pertinent dosimetry protocols.

Keywords: *Radiotherapy; level-I, -II and -III radiation dosimetry; on-site dosimetry tours; quality audits.*

INTRODUCTION

Absolute output measurement of high energy beams produced by a linear accelerator under reference conditions (i.e., Level I dosimetry) has a vital role to determine uniformity of radiotherapy dose delivery to the patients (1, 2). Dosimetric comparative studies are important to assess uniformity and consistency of radiation dose delivery at radiotherapy facilities (3-7). Further, these studies are also helpful in the implementation of dosimetric calibration protocols and local standards [6-8]. In conjunction with Level III dosimetric measurements (those performed by local physicists at the hospital level), Level I and II dosimetric measurements (i.e., dosimetry performed by a national Secondary Standard Dosimetry Laboratory (SSDL) expert is termed as Level II dosimetry) not only indicate errors in machine output and its contribution in dose delivery but are also helpful in the prevention of accidents and treatment misadministration [8]. A uniform dose delivery to the patients can be achieved through an institutional quality assurance program (i.e., level III measurements). The last two types of audits are being performed to share the techniques being utilized for assessment/ calculations and comparison of results with level III measurements [2, 8-11]. The comparison of beam outputs at these multiple levels also demonstrates an assessment of uniformity in final radiation delivered dose to the patients [12]. To monitor the uniformity and accuracy of clinical dose delivery, various research groups continuously performed dosimetric inter-comparison studies which also include postal dosimetric audits (i.e. via mailed dosimeters). For many years, these audits have significantly contributed to the assessment of dose delivery to the patients. Postal thermo-luminescent (TLD) dosimetric audits have been conducted by International Atomic Energy Agency (IAEA) since the 1960's [1, 13-16]. The European Society for Therapeutic Radiology and Oncology (ESTRO) and European Organization for Research and Treatment of Cancer (EORTC) have also performed very wide-ranging audits [12, 17-19]. Similarly, the Radiological Physics Center undertakes such postal audits in addition to absolute chamber measurements during clinical site visits [20]. In Europe, at the national level, several audits, including Level I studies have been performed [21-24]. Earlier a national trial support center was established that provided dosimetric and general QA support for trials [21-24]. Level I dosimetry quality audits have been limited but the IAEA dosimetry audits are continued in Pakistan. On the other hand, Level II on-site dosimetry quality audits are regularly performed by the national Secondary Standards Dosimetry Laboratory (SSDL) at radiotherapy hospitals since 1989 [8]. The Institute of Nuclear Medicine and Oncology Lahore (INMOL) is one of the radiotherapy hospital which is regularly participating in level II dosimetry quality audits performed by SSDL. Along with these audits, a level I radiation beam quality audit was conducted by an IAEA survey mission at INMOL. The audit has been undertaken for radiation beam output measurements of high-energy X-ray beams from linear accelerators. Locally, radiation beam output measurements are regularly performed by following the IAEA dosimetry protocols (i.e., TRS 277 & 398) [3, 25]. The main objective of this study was to assess and review the results of these three levels of dosimetry audits/measurements (Level I, II and III) and to discuss the probable sources of error.

MATERIALS AND METHODS

Level I, II, and III measurements were performed by the IAEA survey mission, SSDL experts, and local physicist, respectively. Two megavoltage X-ray beams produced by a SIEMENS ONCOR accelerator, having nominal energies of 6 and 15 MV, were selected for this study. A range of output measurements were performed for various configurations, including source to surface (SSD) and iso-centric (SAD) configurations. The measured outputs at the reference depth (Z_{ref}) were normalized to the depth of maximum dose (z_{norm}). For SSD setups, beam quality was determined from the conversion of the measured $PDD_{20,10}$ to $TPR_{20,10}$, using the following relationship (equation 1) [26].

$$TPR_{20,10} = 1.2661 \times PDD_{20,10} - 0.0595 \quad (1)$$

All three levels of dosimetry were performed in accordance with the reference conditions of IAEA dosimetry protocol (TRS-398) [25].

Level-I dosimetry

The dosimetry system for Level-I dosimetry was comprised of Farmer-type ionization chambers, PTW 30013, NE2571, and IBA 8273

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connected to electrometers, namely, Glass Dosimeter GD-302M (Reader FDG-1000), Type NE-2570/1 (Sr. No. 958), and IBA Electrometer (Sr. 12370), respectively. The dosimetry system was attached to Perspex water phantom (i.e., solid Water Phantom, 30 × 30 × 30 cm^3 and 10 cm depth). A barometer (i.e. Calibrated Precision Barometer) and thermometer (i.e., Calibrated UK brand) were also used for the temperature and pressure corrections to the ionization chamber readings.

To calculate the beam output of the stated photon beams, the beam quality, k_Q, for the respective chambers were determined according to the procedures outlined in the IAEA dosimetry report (TRS-398) [25]. Numerous demographic measurements were obtained to complement Level-I dosimetry, including institutional (local) estimate of accelerator output.

Level-II measurements

The dosimetry system used for Level-II dosimetry was comprised of a Farmer-type ionization chamber (NE2571) connected to a NE2570 electrometer. The dosimetry system was attached to a stationary water phantom having 30 cm × 30 cm × 30 cm dimensions, 10 cm ×10 cm window (i.e., 3 mm thick perspex sheet) and perspex inserter (i.e., 2 mm thick) for the thimble of farmer ionization chamber at the wall position. The system was calibrated in a Co^{60} radiation beam at SSDL, PINSTECH, Pakistan, following the IAEA TRS-398 dosimetry protocol. A duly calibrated thermometer and barometer from National Physical Standard Laboratory (NPSL), in Islamabad, were used for pressure and temperature correction to the NE2571 readings.

Dose absorbed in the water was measured for 6 and 15 MV X-ray beams at a field size of 10 × 10 cm^2. The depth of the ionization chamber was 5cm and 10cm in water for 6 and 15 MV, respectively, at a constant source to surface distance (SSD) of 100 cm. Source to ionization chamber distances (SCD) were 105 cm and 110 cm for 6 and 15 MV, respectively. The same alignment parameters as level I measurements were adopted.

Level-III measurements

The dosimetry system for level-III dosimetry consisted of a measuring assembly (Type NE-2570/1, Sr. No. 958) coupled with a Farmer-type ionization chamber (NE2571, Sr. No. 1905). The ionization chamber was placed in a water phantom having 30 × 30 × 30 cm^3 dimensions. A calibrated barometer and thermometer were used for pressure and temperature correction, respectively. This system was calibrated at SSDL, PINSTECH in a Co^{60} radiation beam. The reliability and consistency of the dosimetry system was ensured prior to measurements by SSDL through reference check source (i.e., Sr^{90} check source) measurements. The same measuring setups were adopted as level-II for dosimetry of stated photon beams. The alignment parameters were kept the same in all three types of measurements.

Uncertainty analysis and comparison of the results

The uncertainties should be taken into account to estimate overall errors in measurement [27-36]. The estimation of uncertainties in all three types of measurements was calculated by following the procedures and methodologies described in TRS-398 [25]. The dosimetric measurements and cross-calibration of the chambers are main source of these standard uncertainty. In absolute dose determination and cross-calibration of chambers, the uncertainty is approximately 0.2% [25]. An uncorrelated uncertainty (additional) is also observed from the measurement of either $TPR_{z_{ref}, z_{norm}}$, or $PDD_{z_{ref}, z_{norm}}$ which can be expected in dose determination as analyzed by Castro *et al.* [37].

After completing level-I and –III measurements/calculation for the beam output measurements, the results were inter-compared. These results were also compared with annually performed level-II measurements from 2010 to 2015.

RESULTS

Prior to the study, action levels were

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established for immediate assessment of output measurements with the mutual understandings of three teams (table 1). The results of level-I dosimetry for ionization chamber and glass dosimeters are summarized in table 2. The results of glass dosimeters and ionization chambers were compared with the results of manufacturer configuration factor, MCF (1.0 cGy/MU, here, MU is monitor unit). A $\Delta_{MCF/GD}$ (percent deviation in output measured through glass dosimeter OP_{GD}, with respect to MCF) of -0.7 % and 0.4 % was found for 6 and 15 MV-photon beams, respectively. Similarly, a $\Delta_{MCF/IC}$ (Percent deviation in output measured through ionization chamber, OP_{IC} with respect to MCF) of -0.3 % and 0.1 % was recorded for 6 and 15 MV-photon beams, respectively. These values are within the above stated optimum level of uncertainty. Similarly, table 3 shows the summary of the measured outputs of level-II and -III dosimetry at Z_{ref}. The Δ were calculated with respect to the output measured through level-I dosimetry at Z_{ref} using ionization chambers. These values are within the optimum uncertainty level (i.e., ± 5 %) and also within inter-comparison tolerance level (i.e., ±2 %) [28].

Figure 1 shows annual level-II dosimetry quality audits (i.e., from 2010 to 2015) of same medical linear accelerator as stated earlier. During the audit, the percentage deviation ($\Delta_{II/III}$) amongst the absorbed doses determined by the level-II and level-III was determined as shown in figure 1. A minimum Δ of 0.08 and 0.07 were observed for both 6 and 15 MV-photon beams respectively, in 2013.

Table 1. Action limits for ratio of accelerator output measurements to account for expected uncertainty [40, 41].

Type of level	Deviation (Δ)	Action
Optimum level	≤ ±3%	No. action is required
Tolerance level	≤ ±5%	Within tolerance but Measurement repeated once
Out of tolerance level	±5% < Δ < ±10%	Outside tolerance. Investigate until resolved
Accident level	≥ ±10%	

Table 2. Summary of Level-I dosimetry measurements at reference depth (Z_{ref}). Here, $\Delta_{MCF/I}$C and $\Delta_{MCF/G}$D means percentage deviation of ionization chamber output (OP_{IC}) and glass dosimeter output (OP_{GD}) with respect to manufacturer configuration factor (MCF), respectively.

S. No.	Energy (MV)	MCF (cGy/MU)	OP_{IC} (cGy/MU)	$\Delta_{MCF/IC}$ (%)	OP_{GD} (cGy/MU)	$\Delta_{MCF/GD}$ (%)
1.	6.0	1.0	1.003	-0.3	1.007	-0.7
2.	15.0	1.0	0.999	0.1	0.996	0.4

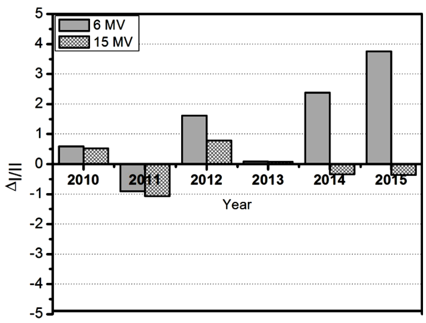

Figure 1. Percentage deviation ($\Delta_{II/III}$) between the absorbed doses determined by the level-II and level-III at reference conditions for 6 and 15 MV-photon beam from 2010 to 2015.

Table 3. Summary of Level-II and Level-III dosimetry m easurements at Z_{ref}. Here, $\Delta_{I/III}$ and $\Delta_{I/II}$ means percentage deviation of Level-II Output (OPII) and Level-III Output (OP_{III}) with respect to Level-I Output (OP_I), respectively.

S. No.	Energy (MV)	Level-I OP_I	Level-II OP_{II}	Level-III OP_{III}	$\Delta_{I/II}$ (%)	$\Delta_{I/III}$ (%)
1.	6.0	1.003	1.014	1.023	-1.07	-1.99
2.	15.0	0.999	1.007	1.017	-0.77	-1.85

DISCUSSION

A summary of three types of audit results with an overview of methodologies employed and lessons learnt is reported here. Amongst these audits, Level-II dosimetry quality audits are more convenient and cost-effective to reduce the uncertainties [8, 38, 39]. In this article, the authors have reported that the radiotherapy radiation dosimetry results for photon beams in MV range were consistent. Further, quantitative evidence on the currently achieved accuracy in tele-therapy photon beams dosimetry in MV range is observed from previous Level-II audits by showing that only one dosimetry audit result (as shown in figure 1) is outside the optimum level set for this work. However, it is still within the tolerance level set for level-II quality audit program (i.e., < ±5%).

The results presented here are the outcome of the many measurement sessions. At each session, methodologies, measurement

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techniques, and calculations were discussed in detail to identify the causes of deviation [8] in the dosimetry. Further, the possible remedies were also discussed to remove causes were rectified and brought these deviations in the tolerance limits. This study has established a baseline for a routine audits of radiotherapy dosimetry. In the future, this type of periodic practices can maintain quality of the treatment standards and by benchmarking the centers with same equipment, it can facilitate the understanding of common issues related to dosimetry. It is also helpful for the improvement and implementation of complex techniques. This is why dosimetry quality audits are considered very important in delivering radiation to cancer patients.

In the future, more complex audits are expected for recent advanced treatment techniques, regular external dosimetry audits will be a source of motivation to modernize existing techniques and develop and test the feasibility of new treatment techniques.

CONCLUSION

The dosimetric results compared to the IAEA audit are below the optimum uncertainty level. Studies of this type, if possible, are very useful to comply with the recommendations / procedures of the pertinent protocols in an appropriate manner. Furthermore, the five years of level-II dosimetry audit results have also shown the radiation beam output consistency. This study also highlighted the importance and relevance of a properly organized ongoing quality assurance program. The precise, consist and uniform radiation absorbed dose to the patient can only be achieved by following the recommendations of the followed dosimetry protocol and proper ongoing quality assurance program.

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