Estimation of absorbed dose in clinical radiotherapy linear accelerator beams: Effect of ion chamber calibration and long-term stability

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ABSTRACT

The measured dose in water at reference point in phantom is a primary parameter for planning the treatment monitor units (MU); both in conventional and intensity modulated/image guided treatments. Traceability of dose accuracy therefore still depends mainly on the calibration factor of the ion chamber/dosimeter provided by the accredited Secondary Standard Dosimetry Laboratories (SSDLs), under International Atomic Energy Agency (IAEA) network of laboratories. The data related to \( N_{\text{water}} \) calibrations, thermoluminescent dosimetry (TLD) postal dose validation, inter-comparison of different dosimeter/electrometers, and validity of \( N_{\text{water}} \) calibrations obtained from different calibration laboratories were analyzed to find out the extent of accuracy achievable. \( N_{\text{water}} \) factors in Gray/Coulomb calibrated at IBA, GmBH, Germany showed a mean variation of about 0.2% increase per year in three Farmer chambers, in three subsequent calibrations. Another ion chamber calibrated in different accredited laboratory (PTW, Germany) showed consistent \( N_{\text{water}} \) for 9 years period. The Strontium-90 beta check source response indicated long-term stability of the ion chambers within 1% for three chambers. Results of IAEA postal TL “dose intercomparison” for three photon beams, 6 MV (two) and 15 MV (one), agreed well within our reported doses, with mean deviation of 0.03% (SD 0.87%) \((n = 9)\). All the chamber/electrometer calibrated by a single SSDL realized absorbed doses in water within 0.13% standard deviations. However, about 1-2% differences in absorbed dose estimates observed when dosimeters calibrated from different calibration laboratories are compared in solid phantoms. Our data therefore imply that the dosimetry level maintained for clinical use of linear accelerator photon beams are within recommended levels of accuracy, and uncertainties are within reported values.

Key words: Absorbed dose, calibration factor for reference beam, dose delivery, uncertainties in dosimetry

Introduction

Accuracy of dose delivery in radiotherapy is stringent requirement for the expected outcome in patients. The dose delivery methods became very precise with digital linear accelerators, their monitoring electronics and automation in terms of use of record/verify systems. The measured dose in water at reference point in phantom is an absolute parameter for planning the treatment monitor units (MU), both in conventional and intensity modulated/image guided treatments. Therefore, traceability of dose accuracy depend mainly on the calibration factor of the ion chamber/dosimeter provided by the accredited Secondary Standard Dosimetry Laboratories (SSDLs), coming under the network of the International Atomic Energy Agency (IAEA) calibration laboratories. With the experience gained in maintaining an accredited laboratory elsewhere[1] in the past, an attempt has been made to scrutinize the database in terms of surveillance of dosimetry standards at our radiotherapy clinic in the present center. Objective of our present study, is referred to our earlier report[2] on status of beam level dose delivery, and correlate to realization of true absorbed dose in field conditions, in the user institution. As there is no telecobalt machine available for surveillance of dosimetry methods, an attempt was earlier made to study the efficacy of an extrapolation chamber as a ‘secondary standard’ for institutional use.[3] The IAEA dosimetry protocol (TRS 398)[4] highlights the uncertainties involved in various steps of dissemination of
measurement parameters. Another report\(^{(1)}\) emphasizes the overall uncertainty situation in megavoltage radiotherapy beam calibration. The present report evaluates our reference dosimeters in terms of reproducibility in absorbed dose standards.

Materials and Methods

The department has three reference class Dose-1 electrometers (IBA, GmBH, Scanditronix Wellhofer, Germany) used for absorbed dose calibration in linear accelerator beams and one Unidos electrometer (PTW, Germany) for high dose rate brachytherapy measurements with suitable chambers. All electrometers have calibration factor 1.00 as per certificates provided from accredited SSDLs, (IBA, Scanditronix Wellhofer, Nurenberg, Germany; PTW, Freiburg, Germany). Calibration factor for absorbed dose estimation in terms of Gray/Coulomb in water were obtained during 2003, 2009, and 2013 from the same SSDL (IBA chambers from IBA, GMBH calibration laboratory; PTW chamber calibrated by PTW, Freiburg).

A strontium-90 check source (QSA Global GmbH, Germany) of nominal activity 50 MBq (0.8 mCi) is used to periodically check the sensitivity variations of the 0.6 cc Farmer Chambers (FC 65) routinely. This provides a dose rate of about 1.25 mGy/s at the position of the chamber; requiring about 400 s for an accumulated reading of 500 mGy.

Postal dose TL intercomparison program of IAEA, Vienna, started in our Hospital in 2008, after (Sultanate of) Oman became a member state. and started participating in postal dose TL intercomparison program since 2008. So far we participated in three intercomparisons, for three high energy photon beams 6 MV (two), 15 MV (one). The procedure followed here was to measure the absorbed doses in water (10 cm depth) on the day of TL irradiations, and use the dose/MU for calculating the MU required for 2 Gy dose. The stated dose by the user institution and IAEA dose estimates in their dosimetry laboratory at Seibersdorf, Austria, validate existing dosimetry at the hospital.\(^{(8)}\) The method of maintaining a constant cGy/MU in our linac photon and electron beams was explained in a previous report.\(^{(9)}\) When the daily check of output/MU showed drift beyond ±2% limits retuning is carried out by the local service personnel.\(^{(10)}\)

The agreement of measured absorbed dose using three chambers/electrometer combinations was checked using a 5 cm depth Perspex, isocenter test tool (Sun Nuclear, USA) in 6 MV X-ray beam from Clinac 600 CD linear accelerator (Varian, USA). This was carried out after recent recalibration of the ion chambers (2013). This tool has adaptation insert for the FC 65 chamber. 100 MU with 10 × 10 cm field size at 100 cm FSD were delivered. Absorbed dose/MU was calculated from the charge measured, multiplied by \(N_{d,w}\) calibration factor, corrected for temperature pressure. The doses were not converted into dose to water, and compared as it is. Three FC 65 chambers are connected one by one to different electrometers, their response and measured values were compared. The extent of agreement between dose estimates at the same reference point under constant geometry by two different ion chambers calibrated at different laboratories (A and B) is also checked.

Results

Table 1 lists the \(N_{d,w}\) values of four dosimeters during first and subsequent calibrations. Three chambers calibrated in one laboratory and another one in some other laboratory. Slight changes in the \(N_{d,w}\) factors in Gray/Coulomb are observed, effective on different dates of calibration. Overall about 0.2% increase was observed for the IBA chambers (one to three), but the PTW chamber showed a nearly consistent response. Table 2 highlights the results of chamber response to a Strontium-90 beta check source, indicating the long-term stability of the ion chambers to the constant geometry beta source. The mean variation of the chamber response with corresponding electrometer, remained well within 1% for all three chambers used for beam level measurements.

It could be observed from Table 3, that the results of IAEA postal TLD intercomparison for three photon beams agreed well with our reported doses, over the period 2008-2012 representing the status of beam level dosimetry in this institution. Tables 4 and 5 show the measured absorbed doses in phantom at constant geometry, using chambers and electrometers which obtained calibration factors from same accredited laboratory. It is observed clearly that all the chamber/electrometer calibrations had an agreement of 0.15% standard deviations in realized absorbed doses. From Table 6 it could be appreciated that \(N_{d,w}\) factors obtained from two different calibration laboratories (in contrast to Table 5 inference) do not realize the absorbed dose exactly, but agree within 0.6% (in Perspex cylindrical phantom) and with deviations as high as 1.5-2.0% in solid water, water equivalent phantom.

Discussion

The above report enumerated calibration factor, \(N_{d,w}\) variability over a 9 year period, as is typical at the user level, and the extent of agreement/disagreement in application of \(N_{d,w}\) factor in realizing dose were described. Comparison of calibration factors for all dosimeters showed an upward trend in the \(N_{d,w}\) factors [Table 1] which indirectly imply that they show slight under-estimation of dose, as the time progresses. Though it is negligible percentage per year, the slight change in effective volume of ionization is not
Table 1: Calibration factors $N_{d,w}$ for thimble (FC 65) chambers from different laboratories

| Chamber ID | Ionization chamber $N_{d,w}$ factor; $\times 10^7$ Gy/C and dates | Magnitude of consistency % in intercalibrations |
|------------|---------------------------------------------------------------|-----------------------------------------------|
| IBA 749    | 4.793 (Nov, 2003) 4.852 (Sept, 2009) 4.899 (Feb, 2013)       | +1.23 +0.97 +2.21                             |
| IBA 750    | 4.780 (Nov, 2003) 4.820 (Sept, 2009) 4.837 (Feb, 2013)       | +0.84 +0.35 +1.19                             |
| IBA 854    | 4.757 (May, 2005) 4.840 (Sept, 2009) 4.855 (Feb, 2013)       | +1.74 +0.31 +2.06                             |
| PTW 395    | 5.376 (April, 2005) 5.348 (Sept, 2009) 5.364 (Feb, 2013)     | -0.53 +0.30 -0.13                             |

Table 2: Strontium-90 check source, chamber response for reading $\int 500$ mGy

| Period     | % Deviation 854/8763 | % Deviation 750/8740 | % Deviation 749/8736 |
|------------|----------------------|----------------------|----------------------|
| 2006-2009  | 0.48±0.62 ($n=23$)   | -0.14±0.83 ($n=27$)  | -1.1±1.18 ($n=25$)   |
| 2009-2012  | 0.99±0.73 ($n=10$)   | 0.61±0.82 ($n=23$)   | 2.33±0.91 ($n=18$)   |

Table 3: Absorbed dose estimates by IAEA postal TLD intercomparison

| IAEA TLD ID | Dosimeter | Energy (X) | RH stated dose (Gy) | IAEA mean dose (Gy) | % deviation |
|-------------|-----------|------------|---------------------|---------------------|-------------|
| June 2008   | IBA 854   | 6 MV, 600 CD | 2.003               | 2.000               | -0.15       |
| 195; 9513, 9514, 9515 | IBA 854 | 6 MV, 2300 CD | 2.003               | 2.020               | +0.85       |
| June 2010   | IBA 750   | 6 MV, 600 CD | 1.998               | 1.970               | -1.40       |
| 215; 10803, 10804, 10805 | IBA 749 | 6 MV, 2300 CD | 2.002               | 2.030               | +1.39       |
| June, 2012  | IBA 750   | 6 MV, 600 CD | 1.991               | 1.990               | -0.06       |
| 2IR23501, 12072, 73 | IBA 749 | 6 MV, 2300 CD | 2.002               | 2.010               | +0.39       |

Table 4: Dose estimate in cylindrical perspex phantom with $N_{d,w}$

| FC chamber no. and $N_{d,w}$ | Dose 1 Electrometer | Charge/$100$ MU ($\times 10^8$ C) | Dose cGy/MU |
|------------------------------|---------------------|----------------------------------|-------------|
| IBA 854 4.855$\times 10\,$ Gy/C | IBA 8763 | 1.9126 | 0.9454 |
| IBA 749 4.899$\times 10\,$ Gy/C | IBA 8736 | 1.9120 | 0.9451 |
| IBA 2554 4.815$\times 10\,$ Gy/C | IBA 8740 | 1.9270 | 0.9446 |

Table 5: Corrected dose value from electrometers on Gy display for different ion chambers

| Dose 1 Electrometer | Chamber used | Correction factor | Reading Gy | Dose Gy |
|---------------------|--------------|-------------------|------------|---------|
| 8763 20.87          | 8763         | 20.597            | 1.01325    | 0.9164  |
| 8736 20.61          | 8740         | 20.412            | 1.02243    | 0.9053  |
| 8740 20.61          | 8763         | 20.576            | 1.00063    | 0.9277  |
| 8740 20.61          | 8740         | 20.412            | 1.00970    | 0.9168  |

IAEA: International atomic energy agency, TLD: Thermoluminescent dosimetry
The international dosimetry protocol\[^4\] (TRS 398, IAEA) indicates relative standard uncertainty in dose estimates using \(N_{d,w}\) for cobalt reference, a value of 0.9% for telecobalt beams, and 1.5% for high energy linear accelerator photon beam, calibrated at an user institution. Another report\[^5\] indicate uncertainties 0.8% for Standards Laboratory, total user beam level 2% with an overall uncertainty of 2.2% for the application of \(N_{d,w}\) calibration factor. The status of beam level dosimetry is highlighted in Table 3 for period 2008-2012 indicate a mean of 0.03%, maximum of +1.4%, minimum of −1.4% for three photon beams for nine irradiations. Oman became a member country in IAEA only in 2007. Therefore in the year 2008 only first TL postal dose intercomparison was possible. However, beam output and energy stability have been evaluated since patient treatment with linacs began in 2005, and have been documented in a previous report\[^2\].

Table 1 has significance in a user clinic of megavoltage beams for treatment, as the \(N_{d,w}\) factors form the basis for status of calibration over a long period of time. The drift in the calibration factor with a long time (8-10 years) observed in Table 1 is in agreement with the values indicated by Tomas Kron\[^5\] viz. a drift of 0.6% for the \(N_{d,w}\) calibration. An experience in a previous institution cited elsewhere\[^1\] showed that the departmental secondary standards showing about 1-1.5% variations in 10 years period. The calibration factor RDM-1F dosimeter was \(0.551 \times 10^{10}\) R/C in 1986 drifted to \(0.544 \times 10^{10}\) R/C in 1998. The present report shows similar magnitude of differences in repeat calibrations.

It was indicated by us earlier\[^2\] that a constant value of linear accelerator beam output cGy/MU is used in the department, and continuous monitoring of the beams are carried out to quantify routine variations. If changes beyond acceptable limits are observed, the original cGy/MU is restored such that dose delivered to patients are within 2% limits from the MU point of view.

All the three dosimeters (IBA, Germany) in Table 1 are reference class dosimeters, and therefore the changes in \(N_{d,w}\) factor should be realized as genuine changes representing some response change in chambers, as electrometer calibration remained same. The realization of dose in terms of cGy/MU is within 0.13% standard deviation for different chamber/electrometer combinations by taking Gray/Coulomb calibration, and within same 0.13% standard deviation by taking Gray/reading calibrations [Tables 4 and 5]. A careful scrutiny of strontium-90 check source response for these three chambers could not exactly correlate to the actual drift observed in \(N_{d,w}\) factors over many years. It was highlighted that \(N_{d,w}\) factors obtained from different laboratories (three chambers calibrated by IBA compared with PTW calibrated chamber) [Table 6] did not estimate absorbed doses with good agreement, exactly in solid water phantoms (in contrast to Table 5 inference) with deviations as high as 1.5-2.0%. But agreement was seen (within 0.6%) in Perspex cylindrical phantom and in water phantom (last four entries) [Table 6].

In Oman, we do not have an SSDL at present, though there are efforts to establish one in the university hospital, with IAEA assistance. Even then, our center will continue to be the only institute where high energy photons/electron sources are available. Therefore, this type of database is necessary to establish standards. This overview has highlighted the point that about 2% uncertainty limit exist in maintaining patient dosimetry from medical physics point of view; which is the achievable limit as per international standards.

**Acknowledgements**

Authors thank the Director General, Royal Hospital and Head, Radiation Oncology for the permission to publish this work.

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How to cite this article: Ravichandran R, Binukumar JP, Davis CA. Estimation of absorbed dose in clinical radiotherapy linear accelerator beams: Effect of ion chamber calibration and long-term stability. J Med Phys 2013;38:205-9.

Source of Support: Nil, Conflict of Interest: None declared.