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Some steps towards establishing a tertiary standard dosimetry laboratory at a radiotherapy department

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▸ ***Technical report***

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ABSTRACT

Background: In order to deliver the precise dose to the target in radiotherapy, absorbed dose to water at the reference point should be assessed. When the calibration procedure is performed for a reference dosimeter in the ^{60}Co beam of a Secondary Standard Dosimetry Laboratory (SSDL), the total uncertainty in absorbed dose to water (D_w) is estimated to be approximately 1.5%. This study attempts to re-measure the $N_{D,W}$ factors for all available field chambers at Reza Radiotherapy & Oncology Centre (RROC). ***Materials and Methods:*** Consistency and linearity checks were performed for a range of available chambers using a check source. The $N_{D,W}$ factors were also measured for the ionization chambers. All cylindrical chambers have been cross calibrated at 6 MV photon beam using a Siemens Primus Plus Linac. The Plane Parallel Chamber has been cross calibrated at the highest available electron beam and the $N_{D,W}$ factor has been measured. ***Results:*** The tolerance of consistency and linearity checks has been reported to be within 0.3%. The $N_{D,W}$ value for field Farmer chamber was found in agreement with certificate within 1%. In contrast for small active volume chambers, the deviation from the SSDL reports was 2.3%. For the plane parallel chamber, the difference between SSDL and Home measurements are found to be 12%. ***Conclusion:*** Although the calibration of reference chambers used for absolute dosimetry through a Primary Standard Dosimetry Laboratory (PSDL) or SSDL is recommended, for field chambers this can be done at home department as a Tertiary Standard Dosimetry Laboratory (TSDL).

Keywords: *Cross calibration, ionization chamber, radiation dosimetry, radiation therapy.*

INTRODUCTION

The most important aim of radiotherapy is to deliver a prescribed dose to a target while the dose to the surrounding normal tissues should be kept as low as possible. According to international standards for radiation units and measurement (ICRU24) [(1)], the delivery of the prescribed dose to the target volume supposes to be within ± 5%. This percent is related to the dose received by the patient at the end point of all steps in the radiotherapy process including machine output fluctuation, patient localization procedure, beam data acquisition, uncertainty of radiation dose calculation using a treatment planning systems and the implementation of the accepted plan at each treatment section over the course of the treatment. At the first step, to be assure of delivering the precise and accurate dose to the target, the absolute quantity of absorbed dose to water should be measured at the reference point and the machine should be calibrated through this measurement.

The basis of dosimetry protocols have been changed from air kerma to absorbed dose to air and then to water [(2-7)]. This change is able to reduce the uncertainty in dose measurement up to 0.8% which is related to chamber to chamber $N_k/N_{D,W}$ differences. There are different parameters that enter into formalism for determination of absorbed dose to water recommended by various protocols [8-11]. To reduce the total uncertainty of the absorbed dose process one should determine each parameter as accurate as practically possible. Absorbed dose to water should then be carefully determined to achieve the uncertainty of ±1.5% - 2% or better [8].

For photon absolute dosimetry the cylindrical ion chambers are recommended by the most of standard protocols. For Electron beam calibration, the use of plane-parallel chambers is recommended especially for low energy beam where the scattering is increasing significantly [7-11].

The absolute dose for photon or electron beam can be measured either by a reference or a field ion chamber. The reference chambers are routinely calibrated by PSDLs or SSDLs using standard ^{60}Co gamma ray beams [4, 7]. Field chambers are usually cross calibrated against the calibrated reference chamber at user beam qualities.

As the reference chamber, especially in a large department, should be kept in a safe condition. It has been recommended that one or more chambers should be cross-calibrated using the reference chamber. In addition, for electron beam it has been highly recommended that a plane parallel chamber should be calibrated with the highest available electron beam at the department [7]. The ^{60}Co calibration factors for some plane-parallel chambers seem to be very sensitive to the small features of the chamber construction, and the overall uncertainty for a chamber calibration either at a PSDL or SSDL using a ^{60}Co is reported to be 2.1%. Therefore a cross calibration for a plane parallel ionization chambers at home has been recommended by the protocols to avoid problems associated with the chamber's reading perturbation factor especially P_{wall} correction factor at ^{60}Co beam and the reduction of the combined uncertainty [7, 12]. In order to achieve the goal, the reference and all field chambers should be placed in a water phantom with effective point at Z_{ref} according to reference condition recommended by international standard dosimetry protocols [4, 7, 8].

The calibration factor in terms of absorbed dose to water for the cross calibrated ionization chambers is given by

$$N^{cross}_{D,W,Qcross} = \frac{M^{ref}_{corr,Qcross}}{M^{cross}_{corr,Qcross}} N^{ref}_{D,W} k^{ref}_{Qcross,Q_0}$$

Where M^{ref}_{corr} and M^{cross}_{corr} are the reference and field chambers readings respectively, corrected for temperature and pressure, electrometer calibration, polarization and ion recombination effects. The $N^{ref}_{D,W}$ is the calibration factor for reference chamber obtained at ^{60}Co beam provided by SSDL and $k^{ref}_{Q_{cross},Q_0}$ is the beam quality correction factor for reference chamber.

As the highest available electron beam energy is not identical for all radiotherapy departments, for each type of chamber a two dimensional table for $k_{Q,Qcross}$ factors would be required. However, it is recommended to use an arbitrary electron beam quality Q_{int} as an intermediate between the cross calibration energy and the beam quality Q. This allows presenting a single table for $k_{Q,Qcross}$ values for all available electron beam energies at the department. The $k_{Q,Qcross}$ values is given by

$$k_{Q,Qcross} = \frac{k_{Q,Q_{int}}}{k_{Qcross,Q_{int}}}$$

where the values of $k_{Q,Qint}$ and $k_{Q,Qcross,Qint}$ have been reported in standard protocols for various chamber types calibrated in electron beams [7].

In this study, all available cylindrical ion chambers used for photon absolute dosimetry and a plane parallel ion chamber applied for electron beam calibration have been cross calibrated against a reference chamber calibrated at ^{60}Co beam at SSDL. A one dimensional table has been made for the beam quality correction factors $k_{Q,Qcross}$ for all available electron energy at department.

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MATERIALA AND METHODS

The measurements have been performed using a Siemens Primus Plus linear accelerator (Siemens Health Care) which is able to generate photon beams with nominal energy of 6 and 18 MV as well as electron energies of 6, 8, 10, 12, 15 and 18 MeV. The machine has been calibrated for photon to deliver 100 cGy per 100 MU for a 10×10 field size at reference depth of D_{max} at water phantom with source to surface distance (SSD) of 100 cm. For electron beam, the machine has also been calibrated for a 10×10 applicator at Z_{ref} depth and SSD of 100cm.

In current study, PTW (PTW Freiburg- Germany) cylindrical chambers of type of 30013 Farmer, 31010 Semiflex and 31006 Pin point and a PTW 34001 Roos Plane Parallel have been cross calibrated against a PTW30013 Farmer chamber calibrated at ^{60}Co beam at SSDL. The PTW 30013-005306 Farmer 0.6 cm^3 is used as a field detector for monthly routine calibration of photon beams. The PTW 31010 Semiflex 0.125 cm^3 and PTW pin point 31006 ionization chambers are often used for absolute dosimetry for small field dosimetry of the photon beam and the PTW 34001 Roos plane parallel chamber is usually employed for absolute dosimetry of electron beams.

At the first step, all of chambers have been checked by PTW ^{90}Sr check source for linearity and constancy before measurements. The charge measurements have been taken using PTW 3D water phantom and by PTW UNIDOSE electrometer. The chambers and water phantom were allowed to equilibrate with room air temperature. All measurements were also repeated in a PTW RW3 slab phantom to have more reproducible condition and also as a double check for measurement accuracy.

The cylindrical ion chambers cross-calibration at photon beams

The central point of the reference and field ion chambers placed at 10 cm depth for photon beam measurements one by one. The pre- and post-irradiation leakage current generated by the complete measuring system were checked to be less than 0.1% of the measurement current [13,14]. Readings were taken for 100 MU and the measurements were repeated three times for each polarity. The voltages +400, -400 and +100 Volts were considered to correct ion recombination effect. The readings were then corrected for environmental condition of pressure and temperature. Humidity correction was not considered.

The plane parallel ion chamber cross-calibration at electron beams

The cross calibration of plane parallel ion chambers are usually performed at the highest available energy for electron beams at clinics [7]. The central axis of cylindrical chamber were placed 1.5 mm below the reference depth and for plane parallel chamber, the reference depth of measurement was set to 1.2 mm below the front window of the Roos chamber. The reference depth for 18 MeV electron beam which was the highest available electron energy with R_{50} = 7.46 cm measured by a 20×20 Applicator was 4.3 cm. The pre- and post-irradiation leakage current generated by the complete measuring system was found to be less than 0.1% of the measurement current. Readings were taken for 100 MU and the measurements were repeated three times for each polarity. The voltages +200, -200 and +50 Volts were considered to correct ion recombination effect and the readings were then corrected for environmental condition of pressure and temperature. Both +400 and +200 Volts were checked for Roos chamber readings and the difference was less than 0.3%. The +400 Volt was considered for cross calibration calculation. Humidity correction was not taken into account.

RESULTS AND DISCUSSION

^{90}Sr check

The short-term reproducibility and linearity of all chambers are performed using ^{90}Sr check sources. Results are shown in figure 1. The maximum standard deviation for all chambers for consistency checks was found to be 0.223% (1SD). More information is tabulated in table 1.

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This shows that all chambers are reliable for absolute dosimetric tasks based on AAPM TG 40 recommendation [14].

Consistency and linearity checks are known as the main important checks to rely a chamber for absolute dosimetry tasks. Although a short term reproducibility assessment has been considered in this study, the long term reproducibility should also be taken into account [15]. The tolerance of consistency and linearity checks has been reported to be within 2% and current results show that all chambers used in this study can be used for absolute dosimetry. Although, due to the small cavity volume and consequently small signal to noise ratio, for some chambers such as Pin Point and Semiflex, they are not recommended for routine dosimetry, because of the application of small fields for some techniques such as Intensity Modulated Radiotherapy (IMRT) and Stereotactic Radio-surgery (SRS) the calibration of these chambers for dosimetric tasks should be taken into account.

Cross calibration of the ionization chambers

Measurements were performed in 6 MV photon beam for all cylindrical chambers mentioned above and at 18 MeV electron beam for reference farmer chamber and Roos plan parallel chamber. The measurements were repeated three times and the average values were calculated. The maximum difference between any three measurements for a given chamber was ± 0.01nC.The results of measured values for $N_{D,W}$ and the values reported by the PTW and SSDL certificates have been shown at table 2.

As table 2 shows, the $N_{D,W}$ values field farmer chamber was found in agreement with certificate within 1%. In contrast for small active volume chambers, the maximum deviation from the PTW and SSDL measurements increases up to 2.3%. And in a more high extent, the difference between PTW, SSDL and Home measurements are found to be about 11.8%. The results of the measurements in water confirmed by the measurements in RW3 Slab phantom and the calculated $N_{D,W}$ values for both were the same.

The uncertainty associated with the cross calibration procedure for photon and electron beams at the department were about 1.6% and 1.8% respectively. This value is related to charge reading, monitor chamber, pressure, temperature, relative humidity, polarity and saturation [16].

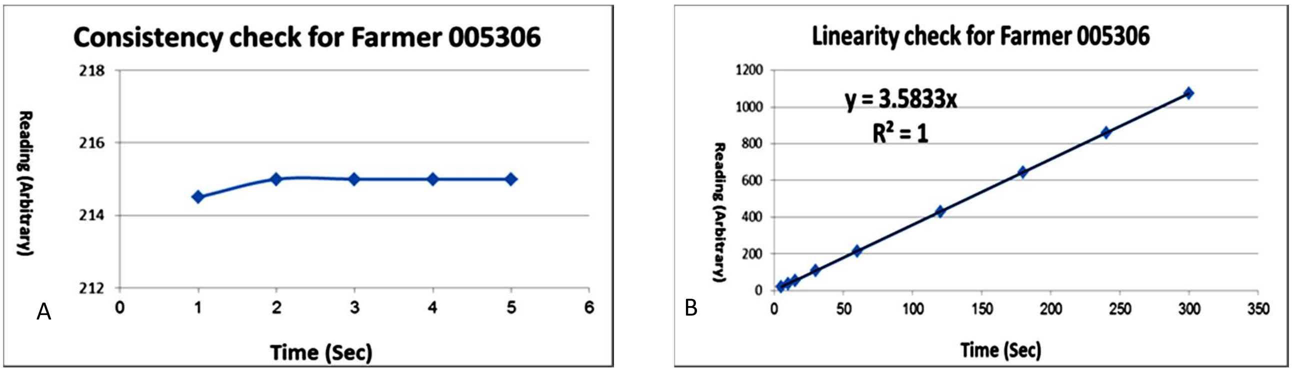

Figure 1. (a) Consistency check, (b) linearity check for a typical field Farmer chamber.

Table 1. Reproducibility check for a range of available ionization Chambers.

Reading	Farmer 07	Farmer 06	Semiflex 4377	Semiflex 4222	Plane Parallel	Pin Point
1	188.5	214.5	34	34	368.5	3.5
2	188.5	215	34	34	368.5	3.5
3	188.5	215	34	34	368.5	3.5
4	188.5	215	34	34	368.5	3.5
5	188.5	215	34	34	368.5	3.5
Standard Deviation	0	0.223	0	0	0	0

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Table 2. $N_{D,W}$ values for a range of available chambers.

Chamber Model	$N_{D,W}$ (Gy/C) Measured	$N_{D,W}$ (Gy/C) PTW Certificate	$N_{D,W}$ (Gy/C) SSDL Certificate	Deviation%
PTW 30013-005307 (0.6 cc) Farmer	Reference	5.34 E+07 (2011-04-11)	5.36 E+07 (2013-07-18)	———
PTW 30013-005306 (0.6 cc) Farmer	5.29 E+07 (2014-04-25)	5.33 E+07 (2011-04-11)	5.35 E+07 (2013-07-18)	0.52%
PTW 31010-004222 (0.125 cc) Semiflex	2.91 E+08 (2014-04-25)	2.98 E+08 (2011-04-11)	3.02 E+08 (2013-07-18)	1.9%
PTW 31010-004377 (0.125 cc) Semiflex	2.98E+08 (2014-04-25)	2.97 E+08 (2011-04-11)	3.02 E+08 (2013-07-18)	2.19%
PTW 31006-000437 (0.015 cc) Pin Point	2.45E+09 (2014-04-25)	2.48 E+09 (2012-08-27)	———	1.10%
PTW 34001-001919 Roos	7.48 E+07 (2014-04-25)	8.43 E+07 (2011-04-12)	8.31 E+07 (2011-07-18)	11.80%

The beam quality correction factors $k_{Q,Qcross}$ for all available electron energy at department have been presented at table 3. As the Q_{cross} (R_{50} = 7.46 cm) is too close to Q_{int} (R_{50} = 7.5 cm), the $k_{Q,Qcross}$ values are also close to the reported values for $k_{Q,Qint}$ by the IAEA absolute dosimetry protocol [7].

Table 3. $k_{Q,Qcross}$ values for a range of available electron beam at the department.

Beam Energy	6 MeV	8 MeV	10 MeV	12 MeV	15 MeV
R_{50} (cm)	2.5	3.3	4.3	4.8	6
$k_{Q,Qcross}$	1.048	1.038	1.027	1.022	1.011

In Iran, it is used to send the whole chambers, applied for absolute dosimetry, to SSDL for calibration. However, based on the current study, apart from reference chambers, other field chambers can easily be cross calibrated in home department. This not only can be a rational action from socio-economical point of view, but it also reduces uncertainty as the chambers are cross-calibrated using a department beams. In addition, it has been known that the apparatus transport may affect the results of calibration. Moreover, the calibration of plane parallel chambers, used for electron beam calibration, has not been recommended by a Cobalt beam. This can be easily done in a department. However, due to lack of expert human resources at small departments this is not recommended.

The difference between field and reference farmer chambers, which is less than 1%, can be expected. Although most of physical properties for both reference and field Farmer chambers are the same, the minor deviation probably depends on the difference in manufacturer. In addition, the uncertainty of two different approach to achieve $N_{D,W}$ values should also be considered. In contrast, for small volume chambers, the difference can be increased as the reference and field chambers are structurally different and charge collection can be affected by the effective volume of each chamber. In comparison, as the results for both Semiflex chambers are identical, it can be said that the uncertainty strongly depends on the chamber type as well as different approach for $N_{D,W}$ obtaining.

The most significant difference was found for a plane parallel chamber which is structurally different from reference chamber. This has also been observed at a different study even the same source of calibration is applied [17]. Nearly the same result for $N_{D,W}$ of a PTW Roos chamber has been reported against PTW farmer chamber at 18 MeV electron beam. As the charge collection procedure is different for a well-guarded plan parallel chamber compared to a typical farmer chamber this can be well understood.

CONCLUSION

The calibration of ionizing chambers plays a significant role in radiotherapy dosimetry. The

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calibration of all reference chambers used for absolute dosimetry through a PSDL or SSDL is recommended. However, for field chambers, this can be done at home department. This study tries to extend the cross calibration as a part of local medical physicists tasks.

Conflicts of interest: *none to declare.*

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