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Assessment of ion recombination and polarization correction factors for small and large field size of photon beams

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ABSTRACT

Purpose: To investigate ion recombination (K_s) and polarity correction factor (Kpol) for small and large field sizes using small volume ionization chamber for Flattening Filter (FF) and flattening Filter Free (FFF) beams of Varian TrueBeam STx linear accelerator.

Materials and Methods: All the readings were measured on PTW BEAMSCAN® water phantom at 100cm source to surface distance (SSD) at dmax and 10cm depth for 6, 10, 15, 6FFF and 10FFF mega voltage photon beams with maximum dose rate for square fields from 0.5×0.5cm2 to 30×30cm2. Two ion chambers such as PTW Semiflex 3D 31021 and Farmer chamber 30013 of volumes 0.07cc and 0.6cc respectively were hired. The correction factors were computed from the readings according to the protocol no 398 of International Atomic Energy Agency's Technical Report Series (IAEA TRS 398). The Ion recombination values obtained from "Two-Voltage Method" (TVM) were verified with 1/V versus 1/Q curves (Jaffé-plots) for all the beam energies.

Results: From the result, the Ion recombination correction factors (K_s) never exceeded 1.032, additionally the Jaffé-plot's results agree very well with TVM values (varies up to 0.3%), except for square fields 0.5×0.5cm^2 and 1×1cm^2 (up to 8%). The Ks values are completely independent of field sizes for all beam energies. The Kpol values varies independently with field sizes up to a square field 2×2cm^2, between square fields 2×2cm^2 to 10×10cm^2 the plot shows almost a straight line for all radiation condition. For all the square fields (except 0.5×0.5cm^2 and 1×1cm^2), K_s and Kpol values of FFF beams only varies by a maximum of 0.6% and 0.1% from the values of FF beams respectively.

Conclusion: The saturation voltage of the small field dosimeters is greater than the dosimeter working voltage. The Ks and Kpol values of small fields are different from standard field (reference field). The ion recombination can be adequately accounted for high dose rate FFF beams using Ks determined with the standard "Two-Voltage Method". The result obtained from FFF beams doesn't deviate significantly from flattened beams. The inappropriate readings of square fields ~~0~~.5×0.5cm^2 and 1.0×1.0cm^2 may be, also due to the lack of dosimeter response as a result of lack of lateral charged particle equilibrium and volume averaging effect of the chamber.

Keywords: polarity correction, Ion recombination, flattening filter free

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INTRODUCTION

Due to the increasing use in radiation therapy techniques such as Intensity Modulated Radiation Therapy (IMRT), Stereotactic Body Radiation Therapy (SBRT), Stereotactic Radiosurgery (SRS) and Stereotactic Radiation Therapy (SRT) with the access to the new instruments (Cyberknife and Tomotherapy), commonly used for stereotactic and conformal therapies where the heterogeneity is naturally occurring, the dosimetry of small fields become exceptionally important [1-3]. Consequently, increasing usage of small fields also decreased the need for Flattening Filter (FF) beams and increased the need for Flattening Filter Free (FFF) beams. In addition, the FFF photons provide dosimetric advantages, such as lower head scatter and lower out-of-field radiation. For very high photon energies, it has been proposed that fewer neutrons are produced with the FFF beams and thus unwanted exposure is reduced. Without the flattening filter in the X-ray beam path, the radiation output near the central axis and the dose rate at the treatment target has increased significantly, which is especially beneficial to facilitate motion management during stereotactic radiosurgery and stereotactic body radiation therapy.

International Atomic Energy Agency (IAEA) TRS-483 protocol presented the comprehensive definition among the various descriptions of small fields [4-7]. According to the previous definition, to describe a small field, an external photon beam must be established by at least one of the following three physical conditions: Lack of Lateral Charged Particle Equilibrium (LCPE) on the beam axis; Partial blockage of the primary photon irradiation source via a limiting tool in the beam axis; and the ratio of the size of the detector to the dimensions of the beam (radiation field) should be a unit or more. In the same field size, the first and the second characteristics are related to the beam and the third one is related to the detector. All of the characteristics lead to an overlap between the field penumbra and the detector volume [8]. Utilization of small fields creates dosimetric challenges which do not exist in standard field. The small field dosimetry will be challenged by the lack of LCPE along with the effects of the volume and composition of the detector, the partial blockage of a limited-size radiation source, and the proper dosimeter selection [1, 9], although the most important challenge is the lack of lateral electronic equilibrium. This challenge happens in the photon beam fields when half of the radius or width of the field is smaller than the maximum range of secondary electrons involved in absorbed dose measurement (8). Consequently, according to the Bragg–Gray cavity theory, the electron disequilibrium of small fields leads to a deviation from the reference dosimetry [10].

In recent years, there is a growing body of literature that recogniz-es the importance of dosimetric challenges in small fields. In 2017, the IAEA TRS-483 in cooperation with IAEA and American Association of Physicists in Medicine (AAPM) published a new protocol for small field dosimetry (the same as the IAEA TRS- 398 for the reference fields) [8, 11], but according to the further studies, there is no comprehensive investigation of ion recombina-tion and polarization correction factors for small fields [12-24]. In the present study, it was attempted to analyse K_s and K_{pol} values for small and large fields of flattened and unflattened beams. We aim to compare the ion recombination and polarization correction factors of small fields with reference fields as well as FFF beams with FF beams based on TRS-398 protocol. The validity of the measurements of K_s by TVM was confirmed with 1/Q versus 1/V plot (Jaffé plots). This action provides the accuracy of the dose administered to the patient during the radiation therapy.

MATERIAL AND METHODS

PTW BEAMSCAN® water phantom was used to measure the megavoltage photon beams generated by a Varian TrueBeam® STx linear accelerator (Figure 1). All measurements were taken at dmax and 10 cm depth, 100 cm Source-to-Surface Distance (SSD), 6, 10, 15, 6FFF and 10FFF mega voltage photon beams with maximum dose rate, and the MU value were 100 for all the square fields from 0.5 $cm^2 \times 0.5$ cm^2 to 30 $cm^2 \times 30$ cm^2. After electrometer readout, the computations of polarization and ion recombination correction factors have been done based on IAEA TRS-398 protocol. K_{pol} values were obtained from voltages +400 V and -400 V, whereas measurements of K_s were made using +400 V and +100 V on the basis "Two-Voltage Method" (TVM). Some studies argued that the "Two-Voltage Method" is not a proper method for determining the amount of collected ions in different voltages, as this method only examines the ion recombination but not the charge multiplication. Therefore, to validate the “Two-Voltage Method”, the K_s values obtained from TVM were compared with the Jaffé-plots based recombination values for all field sizes and beam energies .

The collected charge from 100 MU was measured as a function of chamber voltage, which was varied between 100 V and 400 V (100, 200, 250, 300, 350 and 400 volts). The measured signal was extrapolated to 1/V=0 (i.e., infinite voltage) to estimate the recombination effect at 400 V. Finally, the K_s and K_{pol} values of small and reference fields were compared along with the comparison between flattened (FF) and unflattened (FFF) beams. In this study, two ionization chambers were used, including PTW Semiflex 3D 31021 and Farmer chamber 30013 with nominal sensitive volumes of 0.07 cc and 0.6 cc respectively. PTW Farmer chamber 30013 (0.6 cc) is only used to measure K_s for field sizes 5 $cm^2 \times 5$ cm^2 to 30 $cm^2 \times 30$ cm^2 in order to support the results of K_s obtained from PTW Semiflex 3D 31021 ion chamber. The wall and central electrode material of both the chambers are Polymethyl Methacrylate (PMMA) and Aluminium respectively. According to the manufacturer's instruction, the working voltage of both of the dosimeters was 400 V.

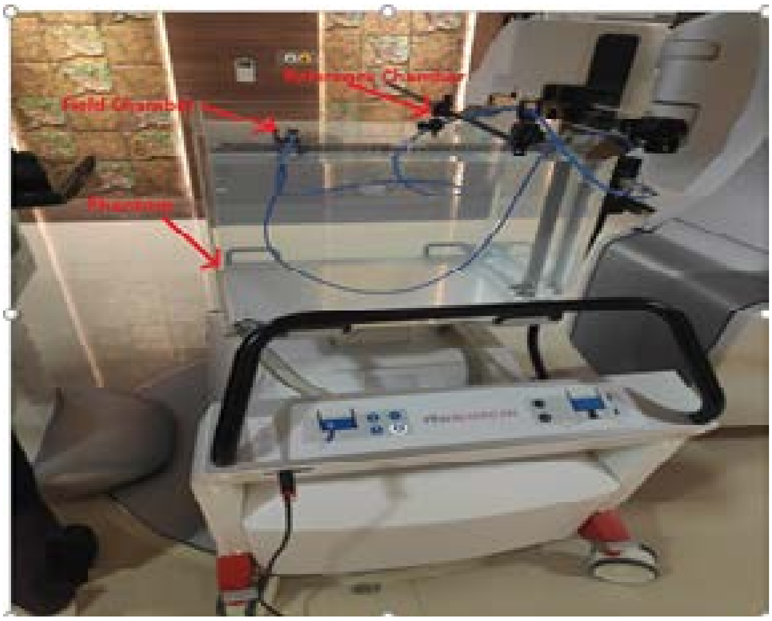

Fig. 1. Measurement setup: PTW– Beam Scan

PTW UNIDOS® E-electrometer

PTW UNIDOS® E is a high quality dosemeter for universal use in radiotherapy and diagnostic radiology (Figure 2). It complies with International Eelectrotechnical Commission (IEC) 60731 as field class and reference class dosimeter and IEC 61674 as a diagnostic dosimeter. It has high accuracy and excellent resolution of 1 fA and covers wide dynamic measuring ranges. The HV power supply can be varied between +400 V and -400 V insteps of 50 V. It can measure integrated dose (or charge) and dose rate (or current) simultaneously. This light weight and compact dosimeter is used for daily routine dosimetry in radiation therapy. Both ion cham-bers and the solid-state detectors can be connected. Air density corrections, Calibration factors etc can be keyed into the unit to get the measured dose directly in radiological mode.

Fig. 2. PTW UNIDOS® E-electrometer

RESULTS

Polarization correction factor (K_{pol})

By increasing the field size from 0.5 cm^2×0.5 cm^2 to 2 cm^2×2 cm^2, the polarization correction factor shows different trends for different beam energies. In this condition, the changes of the polarization correction factor based on the field size showed a flat-chart in all radiation conditions and field sizes greater than 2 cm^2×2 cm^2 as depicted in Figure 3. The maximum and minimum value ranges of K_{pol} are given in Table 1. Except for square fields of sizes 0.5 cm and 1 cm of 6 mV (up to 4%) the variation of K_{pol} values between flattened and unflattened beams are within 0.1%.

Tab. 1. Maximum and minimum values of K_{pol} for different photon beam energies

Polarity correction factor (K_{pol})	Photon Energies (MV)				
	Flattened beams (FF)			Flattened beams (FFF)	
	6	10	15	6	10
Minimum	1.001	1.001	1.002	1.002	1.003
Maximum	1.032	1.002	1.003	1.005	1.007

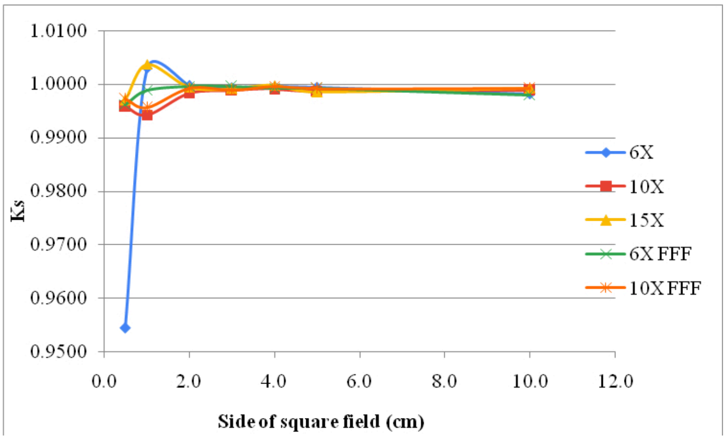

Fig. 3. Chamber's polarization correction factor in different field sizes

Ion recombination correction factor (K_s)

In all the radiation conditions and chamber types, there was no correlation between the variations of ion recombination correction factor and the field sizes as shown in Figure 4. The maximum and minimum values range of K_s are given in Table-2. Ks values of flattened (FF) and unflattened beams (FFF) doesn't differ a lot, the overall variation is within 0.6%, except for field size 0.5 cm^2×0.5 cm^2 of 6 mV beam (3%).

Tab. 2. Maximum and minimum values of Ks of all photon beam energies

Ion recombination correction factor (Ks)	Photon Energies (MV)				
	Flattened beams (FF)			Flattened beams (FFF)	
	6	10	15	6	10
Minimum	0.954	0.994	0.997	0.996	0.995
Maximum	1.003	0.999	1.003	0.999	0.999

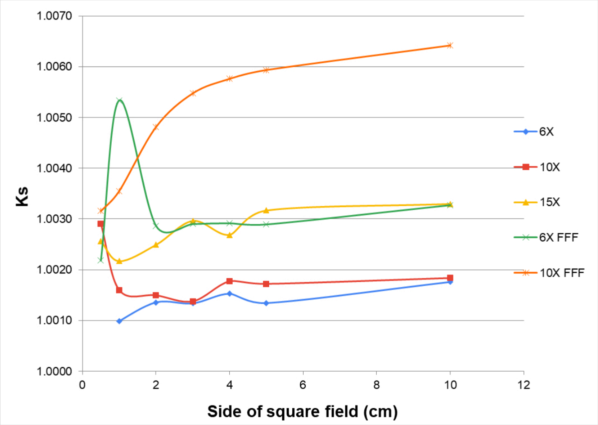

Fig. 4. Chamber's ion recombination correction factor in different field sizes

The Jaffé-plots values for all beam energies agrees very well with TVM values, for all field sizes other than 0.5×0.5cm^2 and 1×1cm^2 the variation between TVM values and Jaffé-plots values are always within 0.3% (Figure 5).

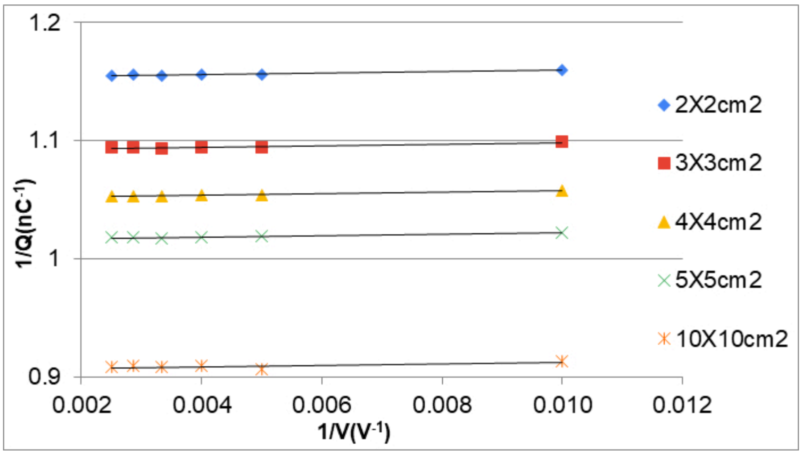

Fig. 5. The inverse of the collected charge (1/Q) versus the inverse of the applied voltage (1/V) for the 6 mV beam. A linear best-fit line through the data is included for each series

For square fields of sides 0.5 cm and 1 cm this variation goes up to 8%. The values of K_s were higher for the FFF beams than the values for the flattened beams of equivalent nominal energy and depth. At 6 MV, Ks were higher for the FFF beam by 0.03%, whereas it was 0.04% higher for the 10 MV FFF beam at standard field size (10 cm^2×10 cm^2). The Ks values were higher at d_{max} than at a depth of 10 cm because of the increased dose per pulse at that location. All the parameters obtained from 0.5 cm^2×0.5 cm^2 and 1 cm^2×1 cm^2 are completely inappropriate.

DISCUSSION

In the present study, the important parameters of small fields were investigated including the magnitude of variations, the dependence of polarization, ion recombination correction factors, megavoltage photon beam energy and operating voltage of the ion chamber. The field sizes and the photon beams used in this study were 0.5 cm^2×0.5 cm^2 to 30 cm^2×30 cm^2 and 6, 10, 15, 6FFF and 10FFF respectively. It seems that in the range of small fields, the variation of field sizes presented significant changes in readings and polarization correction factor due to the changes in amount of primary radiation. On the other hand, the changes in the greater field size will be more effective on scattered photons and the polarization correction factors will be closer to each other. Despite of a significant increase in the K_{pol} value with the characteristic of 0.5 cm^2×0.5 cm^2 to 2 cm^2×2 cm^2, the field sizes seems obvious but a part of this significant increment is related to the range of immeasurable dosimeters response in field sizes smaller than 2.5 cm^2×2.5 cm^2.

According to the study of Keivan et al. the volume averaging effect is predominant in the field sizes smaller than 2 cm^2×2 cm^2, for and Semiflex chamber, this phenomenon is due to the large size of the air cavity which results in the underestimation and measurement error of the output ratio [20]. Shimono et al. and Looe et al. also obtained the same results by assessment of the changes in the polarization correction factors which showed an incremental and exponential trend [21, 24]. The results of Looe`s survey is related to the creation of a balance between the amount of produced ionization in the collecting electrode and the cable used in large field sizes. Because the size of the dosimeters in greater fields is small enough to provide the LCPE and the Bragg -Gray cavity condition, the polarization correction factor is more perceptible. The independence of K_s to the field size can be explained in two ways. First, each dosimeter in every radiation condition collects the samples from the radiation field proportional to its sensitive volume dimension. Second, according to the "Two-Voltage Method" (TRS-398 recommendation) the dosimeter calculation of ion recombination occurs in two different voltages (not in two different field sizes).

Due to the several studies, the K_s value does not depend on the field size and energy strictly but depends on the dose per pulse (15-17). Although in these studies, the dependence of K_s on doses per pulse of treatment machine was investigated but according to our limited access to only one machine, it was impossible to compare this parameter. In the small fields, the non-flat curve around 400 V indicates the higher dependence of small fields on the operating voltage, compared to the reference field (10 cm^2×10 cm^2). However, due to the restrictions of electrometer to supply higher than 400 V, it was not possible to investigate the changes of higher voltages. Thus, it can be mentioned that the chambers saturation voltage in small fields is different and greater than the large field sizes. This phenomenon is probably related to this fact that the dimensions of the dosimeter in small fields are closer to the field dimensions and the chamber samples more percent of the field and require higher voltages for reading saturation.

CONCLUSION

The polarization and ion recombination correction factors in small fields are different compared to the large fields. By increasing the size of small field, the variation of the polarization correction factor is more severe than the reference fields. Saturation voltage of small field dosimeters is higher than their working voltage. The ion recombination factor is not related to the field size and the megavoltage beam energy and changes only by changing the voltage and dose per pulse. K_s and K_{pol} values of FFF beams doesn't differ significantly from FF beams. Considering the values of correction factors in small field dosimetry is crucial, because of their difference from the values of the reference dosimetric conditions.

CONFLICT OF INTEREST

Nil

FINANCIAL SUPPORT

Nil

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