Assessment of polarization and ion recombination correction factors and leakage of small megavoltage photon beams

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ABSTRACT

Background: Small field dosimetric challenges lead to a deviation from the reference dosimetry. The aim of this study is to investigate the changes of polarization (k_{pol}) and ion recombination (k_s) correction factors and determination of leakage dose in small fields. ***Materials and Methods:*** All values were measured on a RW3 slab phantom, at 100 cm Source-to-Surface Distance, 10 cm depth and 6, 10 and 18 MV photon beams for square fields (0.5 to 10 cm). Three ionization chambers (PTW Pinpoint 31014 and 31015, Semiflex 31010) were hired. After the electrometer readout, the correction factors were computed according to the protocol No. 398 of International Atomic Energy Agency's Technical Report (IAEA TRS-398). ***Results:*** The $k_{pol\,(min)}$ and the $k_{pol\,(max)}$ value occurred in 0.5×0.5 cm^2 and 10×10 cm^2 field size, respectively. Dosimeters with a larger sensitive volume showed greater k_{pol} values. In all three dosimeters, an increasing trend detected in normalized dosimeter reading after working voltage. The level of leakage in all of the values and radiation conditions was at the level of a few Nano colons. ***Conclusion:*** The values of k_{pol} and k_s in the small fields were different from the reference field. The saturation voltage of the small field dosimeters was greater than the dosimeter working voltage. The leakage values of the dosimeter-electrometer combination in the present study were negligible for all radiation conditions. The correction factors should be considered due to the differences between small fields and reference dosimetric conditions.

Keywords: *Ion recombination, leakage, polarization, radiotherapy, small field dosimetry.*

INTRODUCTION

The dosimetry of small fields is considered as a turning point due to the increasing use in radiation therapy techniques (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) [1-3]. Small fields are commonly used for stereotactic and conformal therapies where the heterogeneity is naturally occurring.

The recent and comprehensive definition among the various descriptions of small fields has been presented by the IAEA TRS-483 protocol [4-7]. According to the previous definition, to describe a small field for an external photon beam must be established by at least one of the following three physical conditions: 1) Lack of Lateral Charged Particle Equilibrium (LCPE) on the beam axis; 2) Partial blockage of the primary photon irradiation source via a limiting tool in the beam axis; 3) 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 and dosimetry create challenges which do not exist in standard (or reference) fields. 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)]. The most important challenge is the lack of lateral electron 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 recognizes the importance of dosimetric challenges in small fields. In late 2017, the TRS-483 in cooperation with IAEA and American Association of Physicists in Medicine (AAPM) published as a new protocol for small fields 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 the polarization and ion recombination correction factors for small fields [(12-24)].

In the present study, it was attempted to enhance the accuracy of the dose calculated by dosimeters. This task is applied by the evaluation of parameters affecting the small fields dosimetry in megavoltage photon beams. This action provides the accuracy of the dose administered to the patient during the radiation therapy. We aim to compare the polarization, ion recombination correction factors, and dose leakage in small and reference fields based on TRS-398 protocol.

MATERIALS AND METHODS

The megavoltage photon beams emitted by an Elekta Synergy linear accelerator (Elekta, Stockholm, Sweden). RW3 slab phantom (SP34, IBA, and Germany) was used according to the established facilities and the properties of water equivalent dosimetry. Common features of all measurements were in 10 cm depth, 100 cm Source-to-Surface Distance (SSD), 6, 10 and 18 MV photon beams, and the MU value equal to 100 for the square fields (with 0.5, 1, 2, 3, 4, 5 and 10 cm sides). After electrometer readout, the computations of polarization and ion recombination correction factors have been done based on the instructions of IAEA-AAPM TRS-483 and IAEA TRS-398 protocols.

Some studies argued that the "two-voltage" is not a proper method for determining the amount of collected ions in different voltages. This method only examines the ion recombination but not the charge multiplication. Consequently, the examination of the amount of collected ions in different voltages (and not just in two specific voltages) has been proposed [(12, 18)]. To apply the assessment of ion collection (also ion recombination) based on different voltages, collected ions at 6 MV photon beam were measured by different voltages and field sizes. The used voltages were 10, 30, 60, 80, 100, 200, 300, 400 and 500 V. For a more accurate evaluation, the readings were normalized to reading at 400 V for each voltage (operating voltage of the dosimeters).

None of the dosimetric protocols propose a solution or equitation to measure the dosimeter leakage accurately. An empirical equitation is our suggestion to compute this parameter in equitation 1.

$$M_{Leak} = M_{total} - (M_{after\ finish\ MU} - M_{background}) \qquad (1)$$

The M_{total} value is a complete reading of dosimeter at the end of 60 seconds measurement time (more than MU time). After the time has elpased, the electrometer reduces

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the background from overall reading and displays measurement. Thus the M_{total} includes the main reading along with the leakage radiation. In this study, the $M_{background}$ is a background reading as a dosimeter reading in non-radiation conditions for 60 seconds. In all radiation conditions, the difference between readings with or without leakage was calculated which multiplied to the correction coefficients. Due to the results, the difference in the amount of absorbed dose is related to leakage.

In this study, three small-volume ionization chambers were used, including PTW Pinpoint 31014, 31015 and Semiflex 31010 with 0.015, 0.03 and 0.125 cc nominal sensitive volumes. The wall and central electrode material of all three chambers are PMMA and Aluminum, respectively. According to the manufacturer's instruction, the working voltage of all three dosimeters was 400 V. The DOSE-1 electrometer (IBA, Co, Germany) was used to read and apply the bias voltage.

The Kruskal-Wallis test was used for statistical analyses. All computations were performed using the SPSS software v.16 (SPSS Inc., Chicago, IL, USA). A p-value < 0.05 was considered as significant.

RESULTS

Polarization correction factor

The values ranges of k_{pol} for PinPoint 0.015, 0.03 and Semiflex 0.125 cc were 0.9673-0.9839, 0.9788-0.9922 and 0.9806-0.9927, respectively. All minimum and maximum k_{pol} values were in 0.5×0.5 and 10×10 cm^2 field sizes, respectively. By increasing the field size, the polarization correction factor of all the chambers and the photon energies showed an incremental and exponential trend. 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 5×5 cm^2 (figure 1). The values ranges of k_{pol} for PinPoint 0.015, 0.03 and Semiflex 0.125 cc at 6 MV photon beam were 0.9673-0.9832, 0.9821-0.9915 and 0.9888-0.9924, respectively. These ranges at 10 MV photon beam were 0.9676-0.9839, 0.9788-0.9922 and 0.9806-0.9927, respectively. At 18 MV photon beam, the value ranges were 0.9679-0.9831, 0.9852-0.9915 and 0.9873-0.9924, respectively. In the same field size and beam energy, the polarization correction factor was increased with the size of the chamber sensitive volume figure 2.

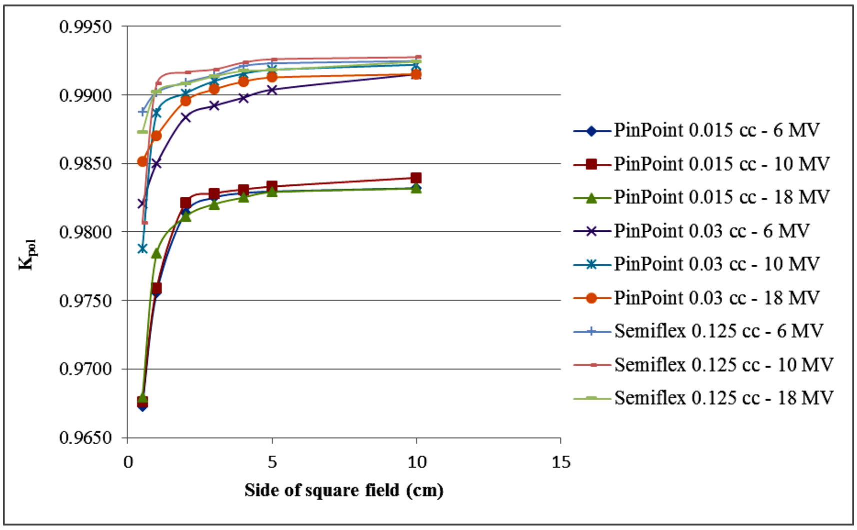

Figure 1. Chambers polarization correction factors in different field sizes.

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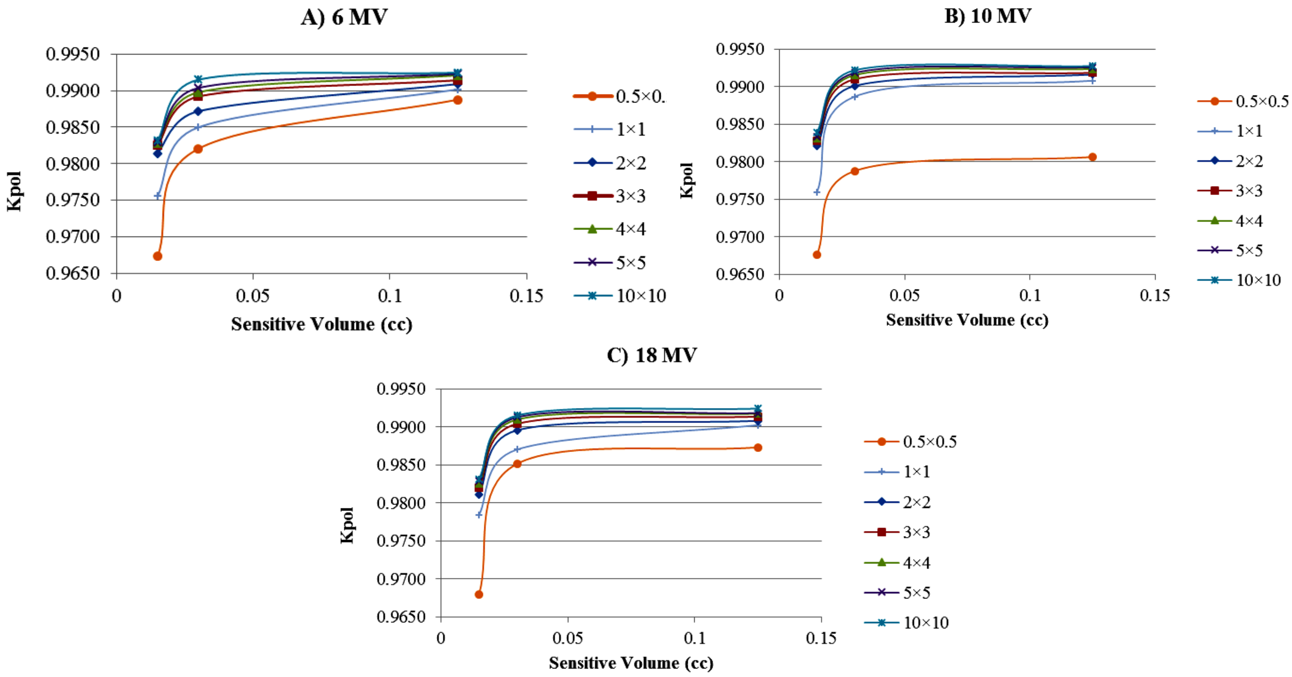

Figure 2. Polarization correction factors in **A)** 6 MV, **B)** 10 MV and **C)** 18 MV photon beams.

Ion recombination correction factor

The values ranges of k_s for PinPoint 0.015, 0.03 and Semiflex 0.125 cc were 0.9975-1.0080, 0.9985-1.0024 and 0.9969-1.0052, respectively. In all the radiation conditions, there was no correlation between the variations of ion recombination correction factor and the field size (figure 3). According to the results (figure 4), by increasing the voltage, the reading ratio of the dosimeter to its reading at 400V was increased. To examine how changes in the shape of the curve occur, it can be divided into three distinct sections. In the voltage range of 0-150 V, the collected ions ratio is increased irregularly and in the 150-400 V, the reading ratio increases almost in a linear pattern. In the voltages of higher than 400 V, the reading ratio almost increases linearly for small fields but remains flat in greater field sizes. The biggest difference in the reading ratio (especially in voltages greater than 400 V) was observed in the 2×2 cm^2 which is the lowest measurable field by the chambers.

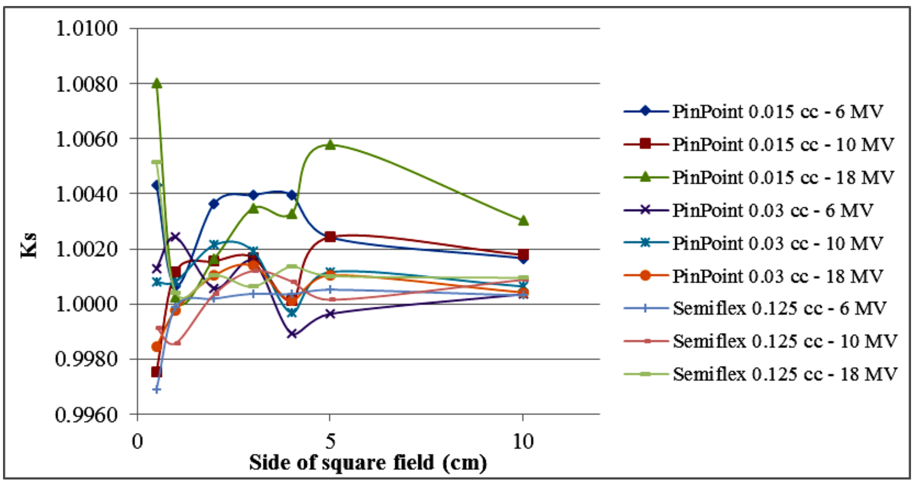

Figure 3. Chambers ion recombination correction factors in different field sizes.

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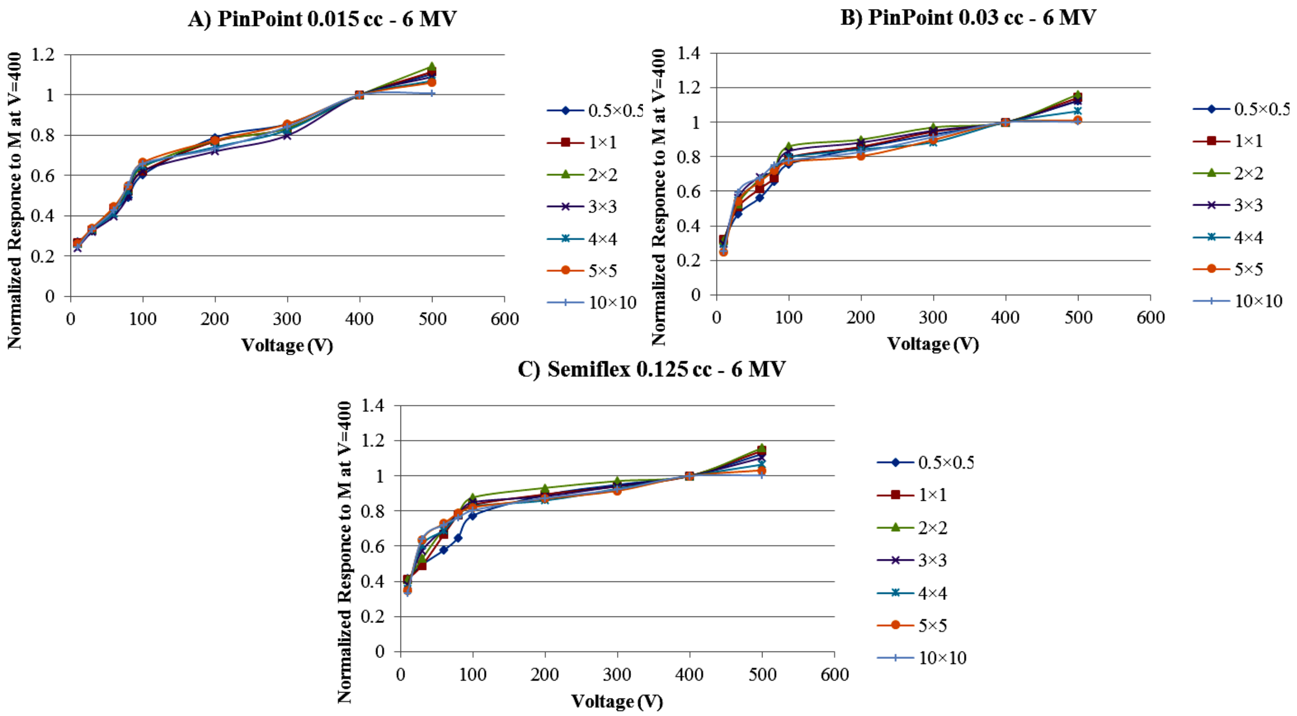

Figure 4. Bias voltages collected ions (6 MV photon beam and normalized to reading at 400V) for **A)** PinPoint 0.015 cc, **B)** PinPoint 0.03 cc and **C)** Semiflex 0.125 cc chambers

Dosimeter leakage

The values ranges of leakage for PinPoint 0.015, 0.03 and Semiflex 0.0 cc were 0.0540-0.0725, 0.0465-0.0685 and 0.0410-0.0665 ($\times10^{-10}$ colons), respectively. The leakage level of small fields in the different radiation conditions and dosimeters did not show a specific relationship among the field size, beam energy, and type of dosimeter, meanwhile showed a few levels of leakage (at the level of few Nano colons) and the maximum leakage dose was observed in a low degree (2.25 cGy).

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, and the amount of dosimeters leakage to the field size, megavoltage photon beam energy and sensitive volume size of the ionization chambers. The field sizes and the photon beams used in this study were 0.5×0.5 to 10×10 cm² and 6, 10, 18 MV.

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 amount of primary radiation changes (p=0.01). 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 0.5×0.5 to 2×2 cm², 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 2×2 cm². According to the study of Keivan *et al*. the volume averaging effect is predominant in the field sizes smaller than 2×2 cm², for PinPoint and Semiflex chambers. 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.

The polarization correction factor increases by an increment of the chamber sensitive volume size in small fields' dimensions. Because the size of all used dosimeters in greater fields is small enough to provide the LCPE and the Bragg -Gray cavity condition, the polarization correction factor is more perceptible. Shimono *et al*. obtained similar results and the changes of k_{pol} value from the point of dosimeter dimensions view were almost in a linear pattern. These differences can be seen in the less number of examined dosimeters (3 chambers) compared to the study of Shimono *et al.* (7 chambers) [24].

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" (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 dependents 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.

According to the obtained results, the increasing reading ratio (almost in linear pattern) in 150-400 V which is attributed to the charge multiplication phenomenon is along with to the findings of Agostinelli *et al.*, and Hyun *et al.* [12, 19]. In the small fields, the non-flat curve after the use of 400 V indicates the more dependence on the voltage compared to the reference field (10×10 cm^2). However, due to the restrictions of electrometer to supply higher than 500 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 greater 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.

Due to the application of one electrometer, the results did not present a significant difference (p=0.1). Thus the leakage of the combination of dosimeter and electrometer was measured. In addition, since the method of the leakage calculation in this present study is novel, it is not possible to compare these obtained values with other studies.

CONCLUSION

The polarization and ion recombination correction factors in small fields are different compared to the large fields. By increasing the size of small fields and the chamber sensitive volume size, the incremental trend of the polarization correction factor is more severe than the reference fields. 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. Saturation voltage of small field dosimeters is higher than their working voltage. The leakage values of the dosimeter-electrometer combination were in a poor state of all radiation conditions. Considering the values of correction factors in small field dosimetry is crucial because of their difference from these values in the reference dosimetric conditions.

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Conflicts of interest: *Declared none.*

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