PENUMBRA AND OUTPUT FACTORS MEASUREMENTS FOR SMALL AND NON-SMALL FIELDS IN RADIOTHERAPY

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ABSTRACT

Background

The use of radiotherapy linear accelerators in special procedures require strict quality assurance procedures to ensure the level of confidence in the accuracy of dose delivered. The radiation beam needs to be precisely targeted to maximize the dose to the target volume cancer, and minimize the dose to the surrounding healthy tissue.

Objectives

The aim of this study was to measure the penumbra and output factors of different ionization chambers for small and non-small fields using two photon energies.

Methods

The penumbra and output factors were measured using PinPoint, Roos, Farmer and Semiflex chambers at a depth of 10 cm and photon beam energies of 6 MV and 10 MV for both small (1×1, 2×2, 3×3) cm^2 and non-small fields (4×4, 5×5, 10×10) cm^2 defined by conventional multi-leaf collimators. As the same detectors, field sizes, photon energies were used to measure the output factors. The Percentage dose depth of the beam measured for all field sizes and beam energies.

Results

Our results showed that the extension of the Roos chamber was less than the other chambers and the output factors corresponding to non-small field 5×5 cm^2 and above had identical values and exhibited similar Percentage dose depth (PDD) curves, while in those corresponding to small field 3×3 cm^2 and below exhibited different output factors and PDD curves.

Conclusion

We conclude that the size of the chamber has a significant effect on the output factor and penumbra and the PinPoint chamber is the most suitable choice of chambers for use as an output detector from those available in Zhianawa cancer center.

Keywords: *Small field, penumbra, Output factor, Ionizing chambers, Intensity modulated radiation therapy.*

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INTRODUCTION

The use of radiotherapy linear accelerators in special procedures such as intraoperative electron therapy (IORT), stereotactic radiosurgery (SRS), intensity modulated radiation therapy (IMRT), volumetric-modulated arc therapy (VMAT) and three-dimensional conformal radiation therapy (3D CRT) require strict quality assurance (QA) procedures to ensure a high level of confidence in the accuracy of the radiation doses delivered to patients. The planning and delivery phases of radiotherapy treatment are the responsibility of a number of specially trained staff including radiation oncologists, clinical medical physicists, and technicians (therapists), and an optimal radiotherapy treatment can only be performed when there is close cooperation between all of them. However, since radiation not only harms cancerous tissue, but also causes damage to healthy tissues, radiation beams therefore needs to be precisely targeted to maximize the dose delivered to the cancerous target volume, and to minimize the dose delivered to surrounding healthy tissue [1-4].

Furthermore, the radiation dose delivered to both a tumor and the surrounding healthy tissue needs to be measured accurately since any mistake in the measurement would result in the patient receiving a radiation dose different to that prescribed. If the cancerous cells receive fewer doses than that prescribed, then tumor control could be compromised and the treatment may not be effective in removing the cancerous tissue. On the other hand, if nearby healthy tissues (or vital organs) receive a larger dose than that prescribed, the radiation may induce further complications. Thus, the accurate measurement of dose delivery is a vital part of radiotherapy treatments [3].

Typically, small fields are defined as fields that are 3×3 cm^2 or below in size or even less in the case of megavoltage photon dosimetry [5-7]. However, there are a number of dosimetrical problems associated with these small field sizes. First, the lateral charged particle equilibrium is lost, second, the finite size of the X-ray source becomes relatively large compared to the field size, which causes a large percentage of the field to be made up by penumbra, and negatively affects the detector´s capacity; and third, the finite size of the detector results in perturbations of the radiation field caused by the detector to becomes more significant as the field size decreases [8-10] . Moreover, small field dosimetry is made more difficult due to the steep dose inclination and the lack of lateral electronic equilibrium conditions, which complicates the interpretation of dose measurements [11] . In fact, Timothy (2010) reported that a number of corrections are required to maintain the dosimetric accuracy previously achieved in standard radiation dosimetry [12] .

The aim of this study was to measure the penumbra and output factors of different ionization chambers for small and non-small fields using two photon energies in radiotherapy at Zhianawa cancer center in order to be a reference and guide for the center.

MATERIALS AND METHODS

In order to study the effects of different types of ion chamber, the percentage dose depth (PDD) of the beam was measured for small fields (1×1, 2×2, 3×3) cm^2 and non-small fields (4×4, 5×5, 10×10) cm^2 at two different photon energies (6 MV, 10 MV).

A large number of small field measurements were performed using four different detectors in their optimal field ranges. Our first measurements were performed with a Farmer-type ionization chamber (PTW 30013, Freiburg, Germany); the second set of measurements was performed using a 0.125 cm^3 Semiflex thimble-type (PTW31010); the third set of measurements was performed with a Roos-type chamber (PTW 34001); and the final small field measurements were performed with a 0.015 cm3 PinPoint thimble ionization chamber (PTW 31006) in an automatic MP3-M water phantom analyzer (PTW). In each case, the output factors were measured with a Unidos dosimeter (PTW, Freiburg). A 200V bias was applied to the Roos ion chamber detector, while a 400 V bias was applied to the PinPoint, Farmer, and Semiflex chambers. The linear accelerator (linac) was then set to deliver a dose rate of 400 monitor units (MU) min−1, corresponding to 1Gy min−1at a reference depth of 10 cm for a photon beam energy of 6 MV and 10 MV, a 10×10 cm^2 field and a source–detector distance (SDD) of 100 cm. The MU readout of the linac´s monitor chamber was then used to correct the variations in output rate. We note that the precision of the positioning within the phantom was 0.1 mm, all measurements were performed with a source-to-surface distance (SSD) of 100cm, and that the linac was calibrated to 1 cGy/MU for a10×10 cm^2 field at a depth 10 cm and SSD of 100 cm.

RESULTS

Penumbra measurement

The penumbra arising from the PinPoint, Roos, Farmer and Semiflex chambers was measured at a depth of 10 cm depth, using 6 MV and 10 MV photon beams for both small and non-small fields, which were defined using a conventional multi-leaf collimators (MLC). As listed in Table 1, for the non-small 4×4 cm^2field, the penumbra was determined to be 5.7 mm for both the Farmer and Semifiex chambers, 5.0 mm for the PinPoint chamber, and 9.9 mm in the case of Roos chamber. At 5×5 cm^2 field size, the penumbras corresponding to the Farmer, Semiflex, PinPoint, and Roos chambers were 5.6, 6.3, 4.8 and 11.3 mm, respectively, and at the field size 10×10 cm^2, the penumbras were determined to be 6.3, 6.0, 4.9 and 11.9 mm respectively.

Table 2 represents the data recorded for small fields. In the case of the smallest field size (1×1 cm^2), the penumbras corresponding to the Farmer, Semiflex, Pinpoint and Roos chambers were given by 5.6, 5.0, 3.5 and 6.3 mm, respectively; while for the 2×2 cm^2 field, the corresponding values were determined to be 5.6, 4.9, 3.0 and 9.1mm; and 6.3, 4.9, 3.5 and 9.8 mm for the 3×3cm^2 field size, respectively.

Table 3 represents the penumbra broadening measured with the different chambers for 1×1 cm^2 and 10×10 cm^2 field sizes. We can distinguish a difference of 20-80% between the penumbra widths. As in the case of our earlier results, the measurements were recorded at a depth of 10 cm. For the non-small field (10×10 cm^2), the penumbras arising from the PinPoint, Semiflex,Farmer and Roos chambers were broadened by 0.0, 1.5, 2.1 and 2.8 mm, respectively, while for the small field size 1×1 cm^2 the corresponding penumbras were broadened by 0.0, 1.1, 1.4 and 7.0 mm.

Table 1. Penumbra depths for non-small fields at a beam energy of 6 MV.

Chamber Types	In-plane Penumbra at $D_{100\ mm}$ (mm)		
	Field size (4×4 cm^2)	Field size (5×5 cm^2)	Field size (10×10 cm^2)
Farmer	5.7	5.6	6.3
Semiflex	5.7	6.3	6.0
Pinpoint	5.0	4.8	4.9
Roos	9.9	11.3	11.9

Table 2. Penumbra depths for small fields at a beam energy of 6 MV.

Chamber Types	In-plane Penumbra at D_{100mm} (mm)		
	Field size (1×1 cm^2)	Field size (2×2 cm^2)	Field size (3×3cm^2)
Farmer	5.6	5.6	6.3
Semiflex	5.0	4.9	4.9
PinPoint	3.5	3.0	3.5
Roos	6.3	9.1	9.8

Table 3. Penumbra broadening for different ionization chambers and field sizes.

Chamber Types	Penumbra broadening (mm)	
	Small field (1×1 cm²)	Non-Small field (10×10 cm²)
PinPoint	0.0	0.0
Semiflex	1.1	1.5
Farmer	1.4	2.1
Roos	7.0	2.8

Output Factors measurements

The output factors corresponding to the four detectors and different field sizes were obtained for two different photon beam energies (6 and 10 MV), as shown in Figs. (1 and 2) respectively. For the non-small fields (*i.e*, 5×5 cm^2 and above), one observes that the output factors are almost the same, but for the smaller fields (*i.e*, 3×3$cm^2$and below), they have different values.

Percentage Depth Dose (PDD)

The PDD curves corresponding to the four ion chambers and beam energy of 10MV are shown in Figs. (3–5) for three different field sizes (10×10, 5×5, 1×1) cm^2, respectively. We observed that the curves are very similar for the non-small field sizes while differences in PDD curves are evident for the 1×1 cm^2 small field cases (Fig.5).

For different field sizes, the PDD curves corresponding to Farmer chamber and beam energy of 6MV are shown in Fig. (6). In this case, the curves do not have the same shapes. The curves become shallower as the field size is reduced from larger field sizes to smaller sizes. The shapes of PDD curves corresponding to a PinPoint chamber as shown in Fig.(7) were also different but these curves were different to those obtained for the Farmer ion chamber.

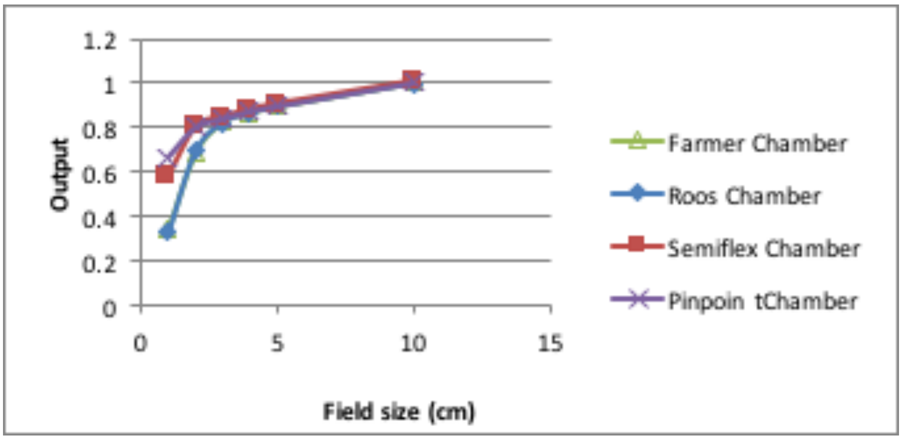

Figure 1. Output factors corresponding to different ion chambers and different field sizes at a beam energy of 6 MV.

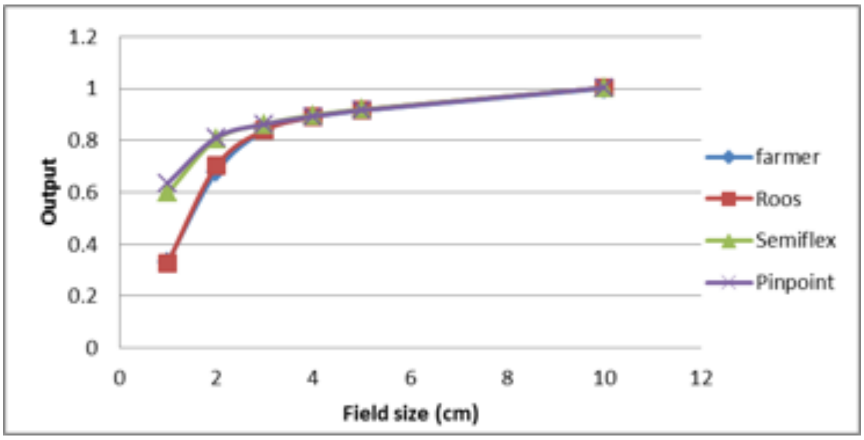

Figure 2. Output factor corresponding to different ion chambers and different field sizes at a beam energy of 10 MV.

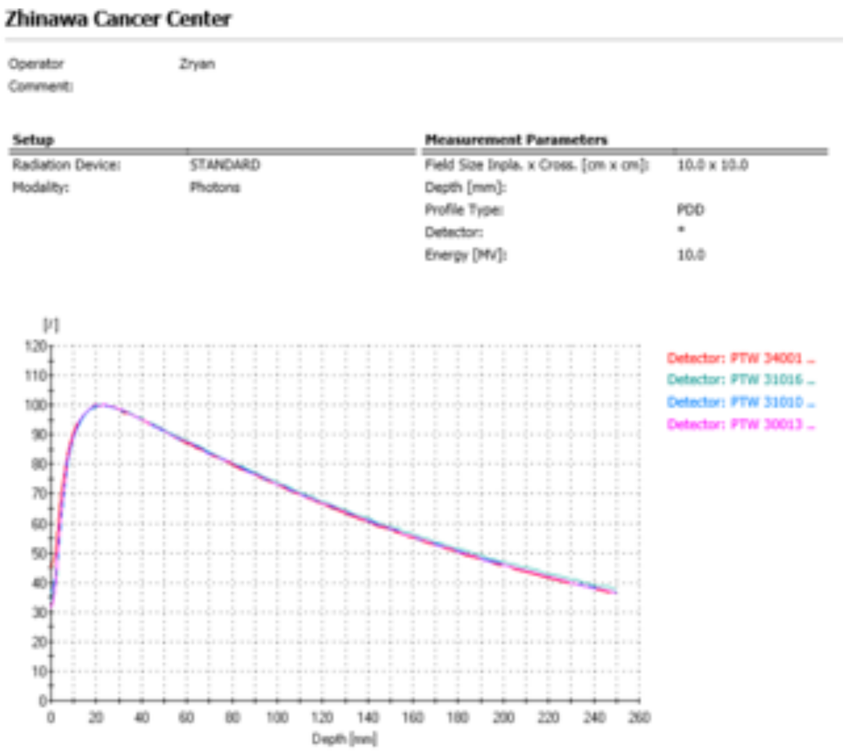

Figure 3. PDD curves for different ion chambers and a 10×10 cm² field at abeam energy of 10 MV..

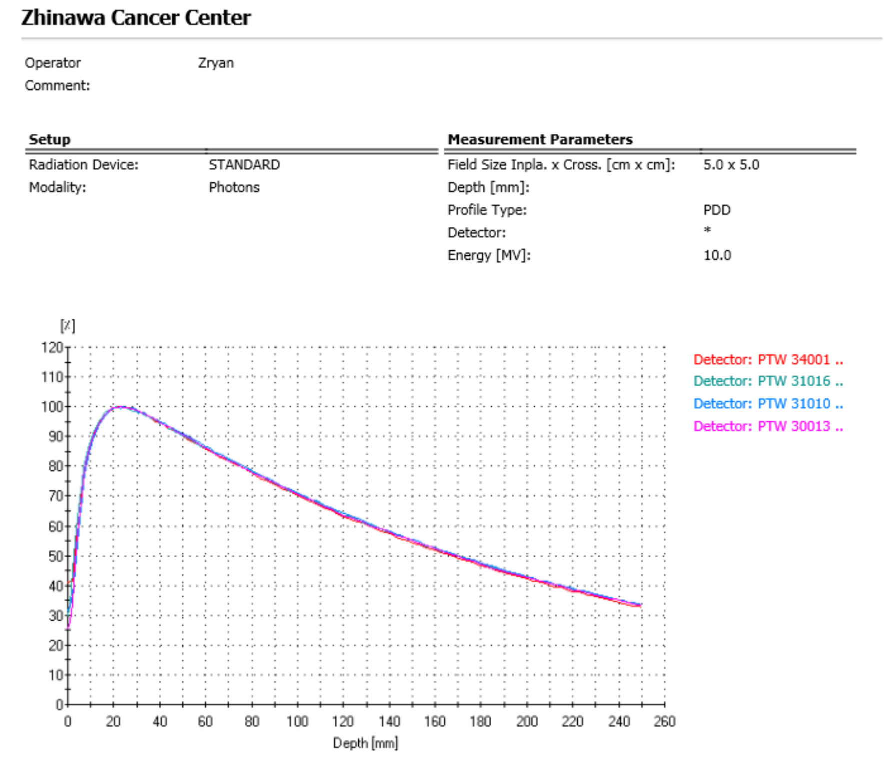

Figure 4. PDD curves for different ion chambers and a 5×5 cm² field at a beam energy of 10 MV.

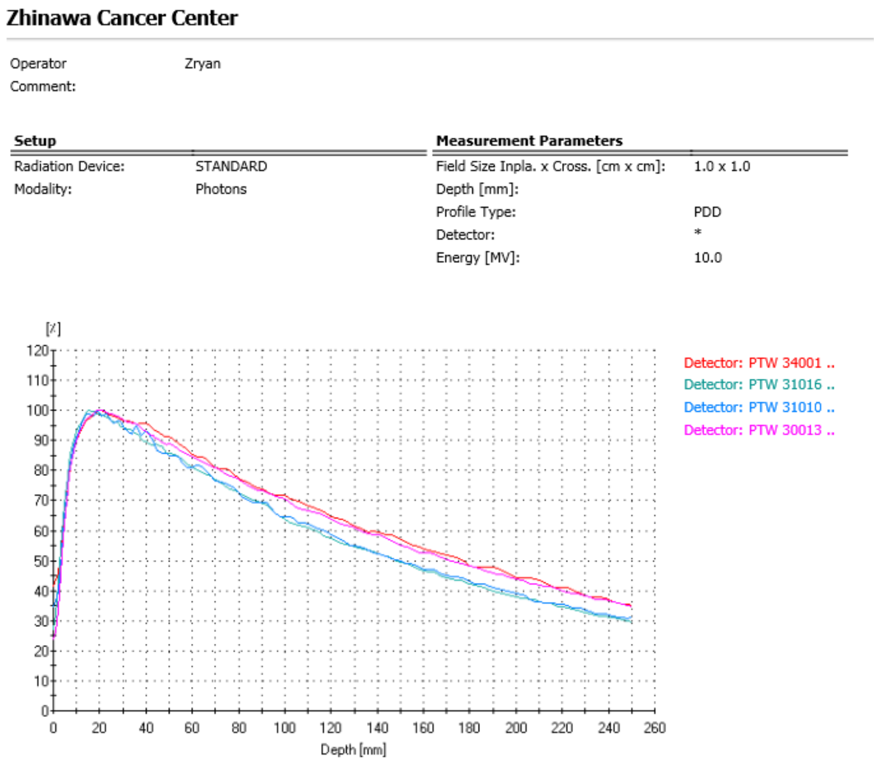

Figure 5. PDD curves for different ion chambers field of 1×1 cm² at a beam energy of 10 MV.

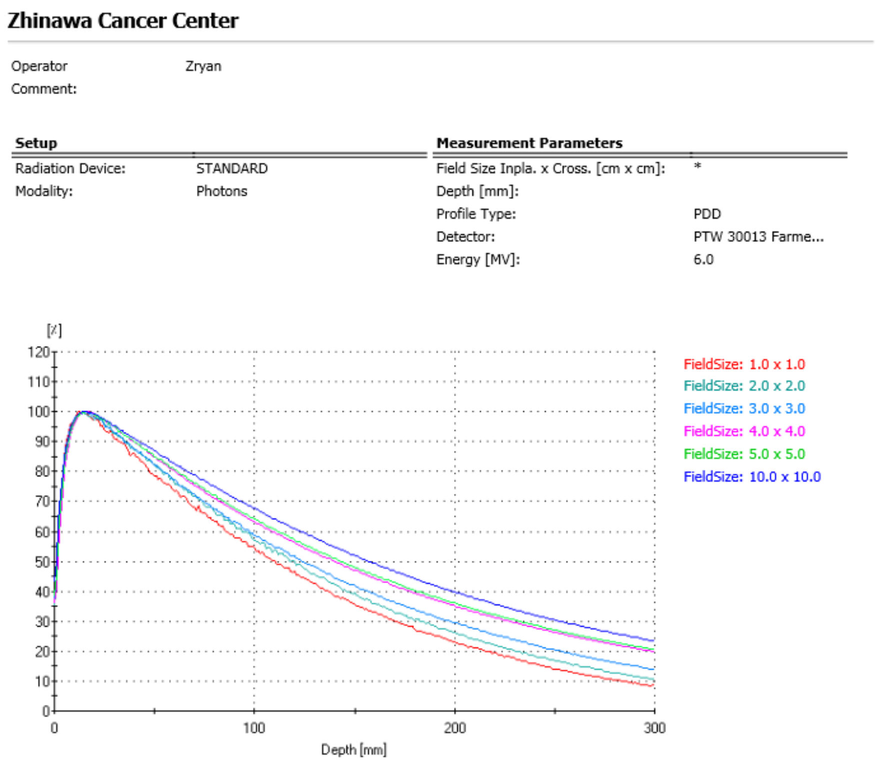

Figure 6. PDD curves for Farmer ion chamber and different field sizes at a beam energy of 6 MV..

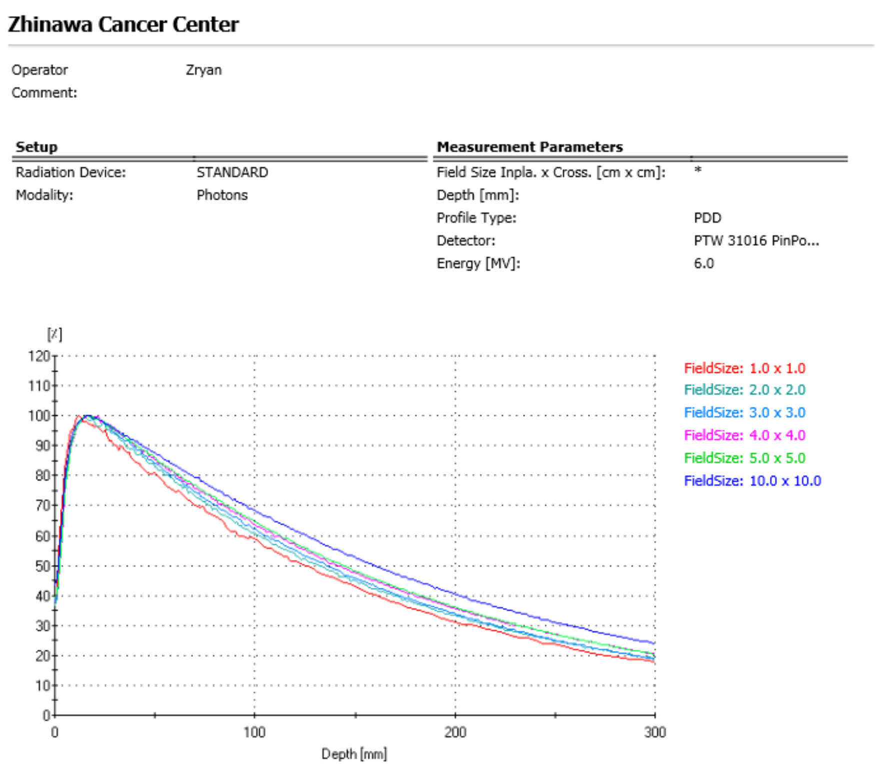

Figure 7. PDD curves for PinPoint ion chamber with different field sizes at a beam energy of 6 MV.

DISCUSSION

We observed that the penumbra widths corresponding to different chambers are different. We can account for this difference by noting that the extension of the Roos chamber was less than the other chambers, and that the PinPoint chamber was slightly broadened due to volume averaging and the non-water equivalence of the air ion chamber. The larger range of electrons in air compared to electrons in water results in a broadening of the measured penumbra.

The measured penumbra broadening increases with decreasing field sizes due to volume averaging and the non-water equivalence of an air ion chamber. In fact, choosing a suitable detector for measuring small fields is not an easy task, although Yarahmadi et al.(2013) have shown that a Gafchromic EBT2 film is a suitable detector for small field dosimetry, especially for penumbra and output factor measurements (13). Thus, while air ionization chambers can be used for large fields, different types of detectors need to be used for small fields. For instance, solid detectors such as silicon diodes are often used in small field dosimetry (14), and diamond detectors are very suitable for small field measurements (15). Jamil et al. (2012) have also reported that air core dosimeters can provide accurate measurements in fields as small as 1 ×1 cm^2 (16). However, we note that as the possibilities provided by our center were limited, we were only able to use PinPoint, Semiflex, Farmer and Roos chambers in this work.

For the non-small fields (*i.e*, 5×5 $cm^2$and above), the output factors are almost the same, but for the smaller fields (*i.e*, 3×3 $cm^2$and below), they have different values. This variation increased with decreasing field sizes due to the volume effects of the PinPoint chamber, while in large volume chambers, part of the penumbra is integrated into the measured dose. We observed that down to a field size of 2×2 cm^2 the Semiflex and PinPoint chambers yield the same values, while the Farmer and Roos chambers start to deviate below a field size of 4×4 cm^2. Clinically a Semiflex chamber can be used to in the linac until a field size 2 2 cm^2.

For smaller field sizes, such as 1×1 cm^2, one actually needs to use a micro- chamber or films. In fact, operation of a linac with a Semiflex chamber and field size of 1×1 cm^2 would over-estimate the MU by 1.14% compared to a PinPoint chamber. Similarly, operation of a linac with a Farmer chamber and 1×1 cm^2 field would imply that the dose rate at D_{max} would be 3.92 mGy/100 MU and require 669.6 MU to deliver 1Gy at a depth of 14 cm along the central axis. With a Pinpoint chamber, the dose rate would be 6.88 mGy/100 MU and required just 316.75 MU to deliver 1Gy. This means that if we calibrate the treatment with1×1 cm^2 field and a Farmer-type chamber, the radiation dose is in error by a factor 2.11. In this study, we observed between the four chambers the PinPoint chamber was the most suited for measuring the output factors in small fields. These results agree with those found by Martens et al.(2000), where they also concluded that the PinPoint chamber is an excellent choice for output measurement in IMRT (17). However, in a recent study performed by Marsolat et al. (2013), they demonstrated that a water-equivalent single crystal chemical vapor deposition (CVD) diamond dosimeter performed better than a PinPoint ionization chamber in measuring output factors with a small beam (18).

The PDD curves corresponding to the four ion chambers and beam energy of 10 MV are very similar for the non-small field sizes (10×10, 5×5) cm^2 while differences in PDD curves are evident for the 1×1 cm^2 small field size. The PDD curves corresponding to Farmer chamber and beam energy of 6MV do not have the same shapes. The curves become shallower as the field size is reduced from larger field sizes to smaller sizes because in large fields, charged particle equilibrium (CPE) is possible that causes all the chambers to read the same values. In contrast, a CPE is not able to be realized in small fields. Moreover, part of the chamber stays outside of the field range in the small field case, especially in front of the water surface and at low depths. Thus the chamber reads a lower value than expected, and this effect decreases with depth because of the divergence of the field size. We note because the PinPoint chamber resulted in a greater dose being measured.

Conclusions

On the basis of our results, we concluded that: the size of the chamber has a significant effect on the output factor and penumbra of the beams. The larger the size of the chamber, the larger is the adverse effect on smaller beams. In particular, the error can reach double that of the original value, which would eventually lead to doubling the dose administered to the patient, the PinPoint chamber is the most suitable chamber available to us in our research center, and is an excellent choice of output measurement detector in IMRT, irrespective of the photon energy. Moreover, in terms of beam penumbra analysis, its performance is superior to that of the other chambers, and combining measurements performed using more than one dosimetric technique can significantly help to reduce or eliminate the uncertainty. In this manner, the clinical outcomes of modern radiotherapy treatments can be made more accurate and reliable.

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