# STUDY THE EFFICIENCY OF PINPOINT AND SEMIFLEX CHAMBERS FOR MEASURING THE SMALLEST FIELD SIZE REQUIRED FOR INTENSITY-MODULATED RADIOTHERAPY (IMRT) TECHNIQUE

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## ABSTRACT

***Background:*** *IMRT is the logical continuation of conformal radiotherapy in the sense that, over the high-dose volume, the dose distribution itself rather than its geometry is actively controlled in three dimensions. Volume averaging and lack of electronic equilibrium complicate accurate dosimetry of small photon fields.*
***Objective:*** *To evaluate the performance of the PinPoint ion chamber for characterizing small fields used in intensity-modulated radiotherapy (IMRT) technique.*
***Method:*** *A 6 MV photon beam (Siemens Primus Linac) has been employed. We used the PTW dosimetry system and MP3 water tank to compare beam character of PinPoint and Semiflex chambers.*
***Results:*** *The build up region in pinpoint is 1.6 cm but in Semiflex is 1.7 cm. The penumbra regions in pinpoint is smaller than PinPoint.*
***Conclusion:*** *The pinpoint chamber has a high resolution. The smallest field size 2x2 cm or less should be measured using PinPoint chamber rather than semiflex chamber.*
***Keywords:*** *Radiation Equipment and Supplies - Radiotherapy, Intensity-Modulated - Radiotherapy Dosage - Radiotherapy, High-Energy – Biophysics - Quality Assurance, Health Care - Small field size - pinpoint chamber - Africa, Northern, Egypt.*

**Abbreviations:**

- **IMRT:** intensity modulated radiotherapy
- **MLC**: multileaf collimator
- **OAR**: organs at risk
- **MV**: megavolt
- **3D**: three-dimensional

## INTRODUCTION

The important step which revolutionized radiotherapy is the development of computerized MLCs in the middle of the 1980s.(1) With the advent of MLCs, the time-consuming fabrication of irregularly shaped beams with cerrobend blocks could be abandoned. Conformal treatments became less expensive and considerably faster, and were applied with increasing frequency. The combination of 3D treatment planning and 3D conformal beam delivery resulted in safe and efficient treatment techniques, which allowed therapists to escalate tumour doses while at the same time lowering the dose in OAR and normal tissues. By the mid 1990s, 3D conformal radiotherapy was supplemented by a new treatment technique, which is currently becoming a standard tool in modern clinics: IMRT using MLC-beam delivery or tomotherapy, in combination with inverse treatment planning. In IMRT the combination of hardware and software techniques solves the problem of irradiating complex target volumes with concave parts in the close vicinity of critical structures, a problem with which radio-oncologists have had to struggle from the very beginning of radiotherapy. In many modern clinics around the world, IMRT is successfully applied, e.g. in the head, neck and in prostate cancer. It has the potential to improve results in many other cancer treatments as well.(2,3)

The IMRT with photon beams can achieve a level of conformity of the dose distribution within the target volume which cannot be physically improved further. However, the absolute dose which can be delivered to the target volume is still limited by the unavoidable irradiation exposure of the surrounding normal tissue.

In IMRT the main variables to be optimized are obviously the intensity maps for each beam. Each beam is typically subdivided into beam elements (bixels) of 5×5 to 10×10 mm. The intensity (fluence) for each of the bixels is optimized. The total number of bixels for all beams is typically of the order of 1000–10,000. Because there is no way to deliver IMRT directly with a linear accelerator (Linac), the intensity maps are then converted to a series of MLC shapes (segments) in an independent step, which is called leaf sequencing. Of course, there has to be some link between optimization and sequencing. For example, the optimizer must know the leaf width of the MLC and should use that as the bixel size in one dimension.

Since IMRT uses small fields, there is a tendency to employ small chambers with active volumes of ~ 0.1 $cm^3$ or less for IMRT verification.(4-6) Recently it was experimentally verified that pinpoint ion chamber with an active volume equal to 0.009 $cm^3$

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may be used for absolute dose verification, provided the area of uniform target dose has dimensions >1 $cm^2$ and leakage corrections are taken into account.(7) Some studies have been conducted on the dosimetry of small photon beams, often in connection with dosimetry in radiosurgery.(8,9) However, the use of ion chambers for narrow beam absolute dosimetry remains questionable due to the lack of electron equilibrium in most of the field area.

In fact, considerable uncertainty exists regarding the validity of using existing dosimetry data (based on broad field measurements) with such small chambers. Therefore, the field of absolute dosimetry of IMRT in beamlets remains open.(10)

The present work aims to study the efficiency of two types of detectors used in the radiation therapy field. These detectors are the micro chamber (PinPoint chamber) and the semiflex chamber (0.125 $cm^3$ chamber). Ionization chamber type dosimeters are of finite size to give the required sensitivity. The new type of pinpoint microchambers partially overcomes this problem.

## METHODS

### A. Accelerator and collimator

A 6 MV photon beam produced by a Siemens Primus Linac has been employed in this study. This linac is a dual photon linac equipped with a MLC used for IMRT treatments. The MLC has 29 opposed leaf pairs, the outer leaves of each bank project a shadow width of 6.5 cm at the isocenter plane, while the inner 27 leaf pairs project a width of 1 cm. Both leaf end and leaf side match the beam divergence, making the configuration double-focused.

### B. Ionization chambers

The ion chambers introduced in water could cause significant chamber-dependent fluence perturbations and volume-averaging effects, especially when used for the dosimetry of the narrow photon beams. It is therefore important to include a model as complete as possible of the radiation therapy measurements to fully reproduce the experimental set-up. The waterproof PinPoint chambers (Fig. 1) have been specially designed for relative beam profile measurements in a motorized water phantom for characterization of linac radiation fields where superior spatial resolution is desired. The PinPoint chambers are ideally suited for this purpose with their inner diameters of only 2 mm (model 31014). When calibrated against a PTW Farmer chamber, the PinPoint chambers can be used for depth dose and absolute dose measurements. The sensitive volume is vented. The wall material is graphite with a protective acrylic cover. The chambers are fully guarded up to the measuring volume. The nominal energy range is $^{60}Co$ up to 50 MV photons. These previous chambers models were used for the evaluation of stereotactic and IMRT photon beams.

The second chamber used in this study is the PTW semiflex ionization chamber (Fig. 2) with an active volume equal to 0.125 $cm^3$, designed for therapy dosimetry, mainly for dose distribution measurements in motorized water phantoms. The 0.125 $cm^3$ chamber is ideal for three dimensional (3D) dosimetry in a water phantom since the measuring volume is approximately spherical resulting in a flat angular response over an angle of ±160º because practical we cant reach to 180º and a uniform spatial resolution along all three axes of a water phantom.

### C. Dosimetry System

The MP3-S water tank with its horizontal detector moving range of 500 mm x 400 mm and its vertical range of 400 mm is suitable for dose distribution measurements of standard field sizes in radiation therapy up to 40 x 40 cm.

### Beam characteristics

Percentage depth dose (PDD) measurements were performed for smallest field size 2x2 cm. This PDD curve was measured using two detectors; PinPoint and semiflex chambers. From the literature, especially in stereotatic radiosurgery (SRS) field, many studies have compared between the different detectors for SRS measurements. From their results, they found that for 6-MV X-ray the smallest field to achieve lateral electronic equilibrium is 3x3 cm. With IMRT technique, the smallest field size used is 2x2 cm. From the field size 3x3 cm and upward, the literature proved that there is no significan difference between the two detectors. But the problem for the field sizes smaller than 3x3 cm is that these fields lie in the lateral disequilibrium region.

So, in the present work, it was focused on field 2x2 cm. PDD data measured at source to surface distance (SSD) equal 100 cm. A water tank with a motor-driven depth dose apparatus was used. The depth control precision is 0.1 mm. The two chambers were used with the computerized water phantom factor.

Also for beam profile for the field size 2x2 cm, the data measured at the reference conditions where the SSD is 100 cm and the profile measured at different depths; $D_{max}$ ,1.6, 3, 5, 10, 20, and 30-cm.

## RESULTS

Figure 3 shows the comparison of PDD measured directly from linac using two detectors; pinpoint chamber and semiflex chamber for smallest field size 2x2 cm. The results give some difference between the two measurements. In figure 4, the percentage difference between the two measurements is shown. From the figure it can be notice that the difference is large in the buildup region where there is no electronic equilibrium. These differences are clear in table 1 which contains some parameters tabulated as a result of the analysis of the PDD curves. The results indicate that the PinPoint is more accurate than semiflex in the IMRT measurements. The build-up region is 1.6 cm in case pinpoint chamber but 1.7 cm in semiflex chamber.

Figure 5 shows the comparison between the beam profiles measured using pinpoint chamber and the corresponding measured using semiflex. From the results, there is a difference between the two measurements. From the figure, the pinpoint chamber gives us the width of the beam narrower than in case of semiflex chamber. Table II contains the analytical parameters for these two curves. In the table, the pinpoint chamber measurements give sharper penumbra regions than in case semiflex chamber. Also the field size defined at source-isocenter distance (SID) by pinpoint chamber is more accurate than the defined by semiflex chamber.

Figures 6 and 7 show the beam profiles measured for the field size 2x2 cm at different depths; 1.6, 3, 5, 10, 20, and 30-cm measured using pinpoint chamber and semiflex chambers respectively. The comparison between the analytical parameters for these measurements is illustrated in table III.

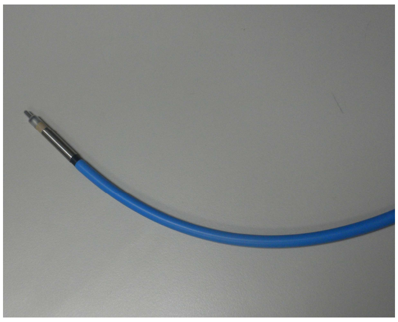

**Fig 1:** PTW-Waterproof PinPoint chamber used for depth dose and absolute dose measurements.

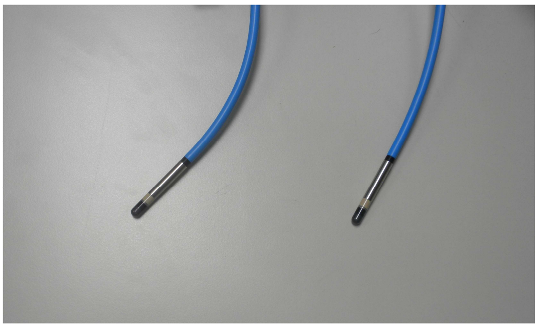

**Fig 2:** PTW-Waterproof Semiflex chamber used mainly for dose distribution measurements in motorized water phantoms.

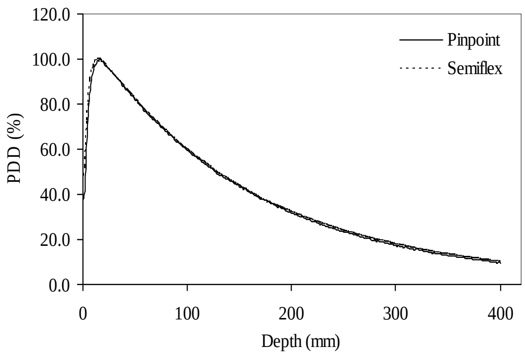


**Fig 3:** The comparison between the PDD measured using PinPoint chamber and the corresponding PDD measured using semiflex chamber for smallest field size 2x2 cm.

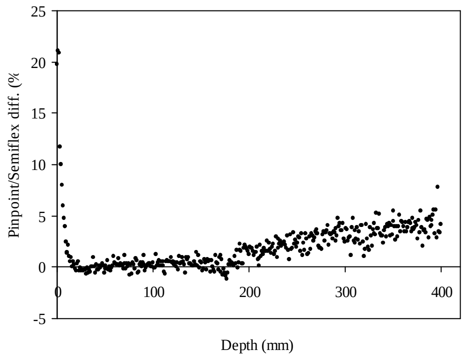


**Fig 4:** The percentage difference between the PDD measured using PinPoint chamber and the corresponding PDD measured using semiflex chamber for smallest field size 2x2 cm.

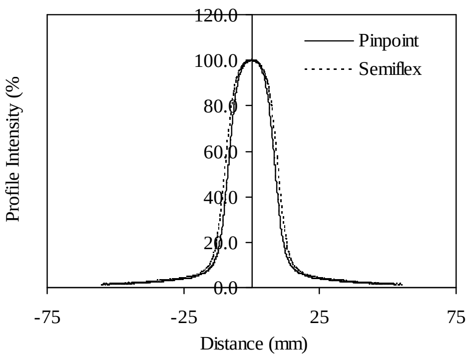


**Fig 5:** The comparison between the beam profile measured using PinPoint chamber and the corresponding beam profile measured using semiflex chamber for smallest field size 2x2 cm.

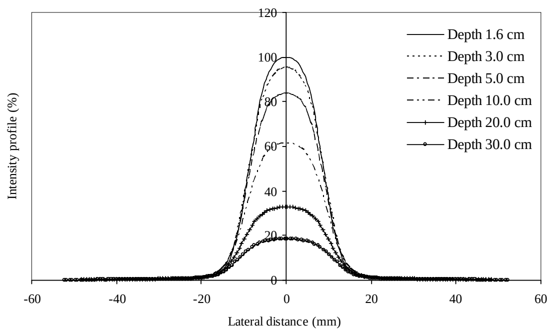


**Fig 6:** The beam profiles measured using PinPoint chamber for smallest field size 2x2 cm at different depths; 1.6, 3, 5, 10, 20, and 30-cm.

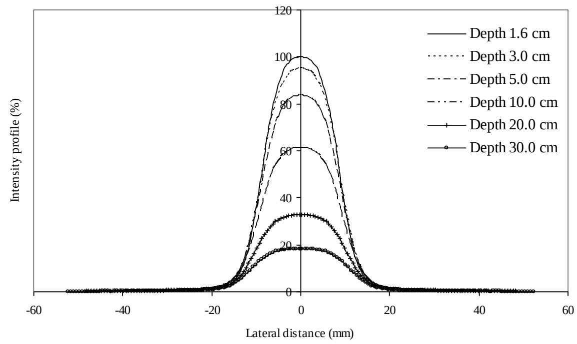


**Fig 7:** The beam profiles measured using semiflex chamber for smallest field size 2x2 cm at different depths; 1.6, 3, 5, 10, 20, and 30-cm.

**Table I:** The parameters obtained as a result of the analysis of the PDD curves measured using two detectors.

| | R100 (Dmax) [mm] | R80 [mm] | R50 [mm] | Ds [%] | D100 [%] | D200 [%] | Qi |
|---|---|---|---|---|---|---|---|
| Pinpoint | 16 | 54.04 | 126.96 | 37.3 | 59.47 | 31.76 | 0.6133 |
| Semiflex | 17 | 53.8 | 128.01 | 46.86 | 59.7 | 32.15 | 0.6191 |

* **R100**: depth of the maximum dose; **R80**: depth of the 80% dose; **R50**: depth of the 50% dose; **Ds**: percentage dose at the surface; **D100**: percentage dose at a depth of 100 mm; **D200**: percentage dose at a depth of 200 mm; **QI**: quality index

**Table II:** The parameters obtained as a result of the analysis of the beam profile curves measured using two detectors.

| Parameters | Pinpoint chamber | Semiflex chamber |
|---|---|---|
| CAX Dev. [mm] | 0 | 0 |
| Pen. Left [mm] | 5.27 | 5.48 |
| Pen. Right [mm] | 5.27 | 5.48 |
| Field Size at SID [cm] | 1.767 | 1.752 |

* **CAX Dev.:** (Central Axis Deviation), deviation of the center of the field from the central axis, calculated from the field size; **Pen. left/right**: (penumbra) distance between the positions of the 80% and 20% dose values; Field **Size at SID:** Field size at isocenter

**Table III:** The parameters obtained as a result of the analysis of the beam profile curves measured using two detectors at different depths; 1.6-cm, 3-cm, 5-cm, 10-cm, 20-cm, and 30-cm.

| Parameters | 1.6 cm | | 3.0 cm | | 5.0 cm | | 10.0 cm | | 20.0 cm | | 30.0 cm | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pin. | Semi. | Pin. | Semi. | Pin. | Semi. | Pin. | Semi. | Pin. | Semi. | Pin. | Semi. |
| Pen. Left [mm] | 5.27 | 5.48 | 5.23 | 5.65 | 5.46 | 5.79 | 5.76 | 5.96 | 5.96 | 6.31 | 6.32 | 6.63 |
| Pen. Right [mm] | 5.27 | 5.48 | 5.23 | 5.66 | 5.47 | 5.78 | 5.67 | 5.99 | 5.96 | 6.34 | 6.32 | 6.72 |
| Field Size at SID [cm] | 1.767 | 1.752 | 1.745 | 1.739 | 1.756 | 1.741 | 1.771 | 1.748 | 1.782 | 1.745 | 1.791 | 1.747 |

* **CAX Dev.:** (Central Axis Deviation), deviation of the center of the field from the central axis, calculated from the field size; **Pen. left / right**: (penumbra) distance between the positions of the 80% and 20% dose values; Field **Size at SID:** Field size at isocenter

## DISCUSSION

The definition of a small field in radiation dosimetry is currently very subjective. There is no clear consensus definition as to what constitutes a small field. Commonly, a field size of less than 3x3 $cm^2$ is considered outside the conventional treatment field size that needs special attention both in dose measurements and in dose calculations.(11) A more scientific approach is needed to set the criteria which define a small field condition based on the beam energy and the density of the medium. There are essentially three "equilibrium factors" that determine the scale if a radiation field is to be considered as small or not: (i) the size of the viewable parts of the beam source as projected from the detector location through the beam aperture; (ii) the size of the detector used in measurements; and (iii) the electron range in the irradiated medium.

By collimating a beam from a source of finite width, it is clear that below a certain field size, only a part of the source area can be viewed from a detector's point of view. The output will then be lower than compared to field sizes at which the entire source can be viewed from the detector's field of view.[12,13] If the entire source cannot be viewed from the center of the field, then the geometrical penumbra is extended all over the field cross section.[14]

The main problem associated with the dosimetry of small fields is the very presence of the detector itself that produces a perturbation hard to quantify in a reliable way.[15,16] This is because the detector is normally different from the medium in both composition and density. The major source of the effect comes from the perturbation of the charged particle fluence, which depends not only on the detector geometry but also on the medium in which the measurement is performed, as well as on the beam energy and field size. Therefore, it is difficult to use standard correction methods in the dosimetric measurement of the small field.

Advances in radiation detectors and specialized treatment techniques have fueled the need for better and suitable detectors. Many types of detectors have been used in small fields and cross compared with other detectors.[17,18] It is expected that calculation-aided dosimetry will be available where specific correction and perturbation factors are either precalculated for irradiation geometry or calculated online using state-of-the-art radiation transport codes, e.g., Monte Carlo. With improved manufacturing techniques with the emphasis on making reproducible detectors, it is likely that empirical corrections in hardware (e.g., energy compensated shielding on diodes) will be replaced by calculated correction factors. This type of calculation-aided detector could provide energy, dose, and dose rate independence suitable for small field dosimetry.

**Conclusions**

In the small field sizes, the selection of the appropriate detector is very important issue. Most investigators of small IMRT beamlets rely heavily on ion chamber measurements. The PTW PinPoint chamber (0.015 $cm^3$) has recently been reported to be overly sensitive to low energy scatter X-rays. By comparing between the PinPoint chambers for the smallest field size used in IMRT technique with the chamber used to measure the relative dosimetry in radiotherapy semiflex chamber, it is recommended that the small field sizes from 2x2 cm and less should be measured using the PinPointchamber.

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