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# Determination of output factor for 6 MV small photon beam: comparison between Monte Carlo simulation technique and microDiamond detector

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**Abstract**. In order to improve the life's quality for a cancer patient, the radiation techniques are constantly evolving. Especially, the two modern techniques which are intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) are quite promising. They comprise of many small beam sizes (beamlets) with various intensities to achieve the intended radiation dose to the tumor and minimal dose to the nearby normal tissue. The study investigates whether the microDiamond detector (PTW manufacturer), a synthetic single crystal diamond detector, is suitable for small field output factor measurement. The results were compared with those measured by the stereotactic field detector (SFD) and the Monte Carlo simulation (EGSnrc/BEAMnrc/DOSXYZ). The calibration of Monte Carlo simulation was done using the percentage depth dose and dose profile measured by the photon field detector (PFD) of the 10×10 $cm^2$ field size with 100 cm SSD. Comparison of the values obtained from the calculations and measurements are consistent, no more than 1% difference. The output factors obtained from the microDiamond detector have been compared with those of SFD and Monte Carlo simulation, the results demonstrate the percentage difference of less than 2%.

## 1. Introduction

Radiotherapy for treatment with cancer involve numerous radiation techniques including the conventional technique (2D), 3DCRT, the development of a computerized radiation technique: "Multileaf Collimator: MLC" that enables radiation to be sheltered and shielded through a computerized program, introducing new techniques like the Intensity Modulated Radiation Therapy (IMRT) and the Volumetric Modulated Arc Therapy (VMAT), following the increasing demands to treat patients [1, 2]. Aimed towards the projection of high radiation upon the tumor and the tissues surrounding the tumor least affected, the projection of high radiation towards the tumor is limited by the Tolerance Dose or the amount of radiation the surrounding tissues received and are affected [3]. However, with radiotherapies like those of the IMRT and the VMAT, treatment extends the range from the ability to control radiation intensity according to the tumor, conformal radiation technique, enabling the affected tissues in the surrounding area to be controlled whilst the radiation upon the tumor can be increased. Therefore, these two techniques are widely accepted as treatments for patients.

Through the continuous movement of the MLC, radiation intensity can be controlled in both IMRT and VMAT. As radiation is performed dynamically to fully cover the tumor cell according to its figure, "beamlets" are produced where its sizes depend upon the sizes of MLC's leaf and its movement [4, 5]. Therefore, it is observed that IMRT and VMAT have smaller fields compared to that of the traditional radiotherapy. Treatment involves accuracy, that is, the amount of radiation the tumor receives must be as stated in the treatment plan. Thus, the study aims to reduce errors resulting from radiation in which involves an experiment to determine the specific beam characteristic and is a first step to controlling the errors of radiation and beam data collection. As beams are used as a standard in the calculation, accurate percentage depth dose (PDD), beam profile, and output factor will determine patient's treatment plans.

To accurately measure a small field area, it is crucial to understand the characteristics of the field and the measuring process. The measurement of radiation within a small field may result in errors in measurement due to the lack of charged particle equilibrium (Non-CPE) and the errors in the measurement of field width that overlaps with the edges, or the penumbra, and perturbation that results in volume averaging measurement [6, 7]. Thenceforth, the measurement of radiation in a small field requires a suitable detector which is dose rate independent, energy independent, angular independent, high in resolution and sensitivity, active in linearity, small and less in perturbation, and lastly, tissue equivalent [8].

Radiation detectors used in small fields are those of ionization chambers (IC) and semiconductors. Although the development of smaller ionization chambers is in progress, the detectors are not small enough to reduce perturbation [9], which then leads to volume averaging that results in underestimation. As the detectors become smaller in size, it also leads to lower sensitivity. In contrast to the latter, semiconductors like diode have higher sensitivity than IC. It is smaller in size, and higher in measurement resolution. However, the disadvantage of this radiation detector is its sensitivity that depends upon the dose rate (dose rate dependent), is angular dependent, and is non-water equivalent, which leads to the possibility of an increase in a secondary electron that then results in overestimation [10]. As a result, there is yet a suitable detector to measure the amount of radiation projected over a small field without any disadvantages. However, Ramathibodi hospital uses the stereotactic field detector (Scanditronix IBA SFD) with a diameter of 0.6 mm and sensitive volume of 0.017 $mm^3$ in the radiotherapy process to measure small fields. Currently, detectors are still in development to suit small fields, shifting from PTW's diamond detector to microDiamond detector (PTW-60019) with a diameter of 2.2 mm and a sensitive volume of 0.004 $mm^3$, which is 4 times smaller than that of SFD's. Moreover, the sensitivity of energy dependence and dose rate dependence are lowered along with the characteristics of being tissue equivalent, marking it a beneficial detector towards small field, but it is a costly tool. Furthermore, as the measurement of small fields may result in errors and lacks the standard conditions in measurement compared to large field, the evaluation of c measurement correct processes and controls are as well difficult. Monte Carlo simulation can be used to track the interactions between particle and media in random or stochastic process. With random numbers, probability distribution, the fundamentals of physics, and the absorbing of center photon radiation as interaction forecasting factors, the study of complex problems can be simpler and will further lead to standard acceptance [11].

This study aims to compare the relative output factor obtained from the measurement of the stereotactic field detector (Scanditronix IBA SFD), which is considered as a standard detector for small fields at Ramathibodi hospital, and microDiamond detector (PTW Freiburg, Germany, PTW-60019), with the outcome from Monte Carlo simulation.

## 2. Materials and method

### *2.1. Monte Carlo simulation*

Monte Carlo Simulation models a linear accelerator (LINAC) Clinac iX through EGSnrc which is divided into the physical part model in linear accelerator coded: BEAMnrc, using data and information obtained from (Monte Carlo Data Package: High Energy Accelerator DWG NO. 100040466-02) and calculation of radiation done in virtual mediums coded with DOSXYZnrc.

The simulation of radiation projectors includes several unknown parameters as a model. Here, the energy of initial electrons beam and its radial intensity distribution width are in our consideration. To find these parameters percentage depth dose and the dose profiles at 5 cm and 10 cm depth, for the field size of 10 × 10 cm$^2$ in water obtained from the simulation are used for the comparison with the measured data. The comparison of these factors involves systematic changes in the values of both parameters. The set of parameters yielding the lowest Chi-square value and the difference in comparison between measurement and simulation of less than ± 1% is selected for the model of the linac. Then, the radiation-in-water for the field sizes of 1 × 1, 5×5 and 10 × 10 cm$^2$ at 5 cm and 10 cm depths are simulated with the DOSXYZnrc code. The relative outputs are then evaluated and compared with the measured values obtained from SFD and microDiamond detector (PTW Freiburg, Germany, PTW-60019).

### *2.2. Measurement*

Radiation measurement (dosimetry) is divided into two sectors: (i) common beam data for simulation examination and (ii) relative output factor for the comparison with the simulation.

Common beam data requires the SFD in the measurement of depth dose, dose profiles with SSD 100 cm, F.S 10 × 10 cm$^2$, and depths of 5 and 10 cm of dose profile with IBA Blue Phantom2 through a step-by-step scan with a resolution of 1 mm. They are the database to find the energy of initial electron beam and radial intensity distribution width used in beam simulation. The microDiamond detector (PTW Freiburg, Germany, PTW-60019) is a synthetic single crystal diamond detector with a small sensitive volume of 0.004 mm$^3$ (smaller than that of SFD's which is: 0.017 mm$^3$) and is tissue equivalent. It has been used to measure the absorbed dose across each field size at 5 and 10 cm depth five times. The average dose value at the beam center is required to compute the relative output factor which is later compared with those obtained from the Monte Carlo simulation.

## 3. Results

For our MC simulation, the best energy of initial electron beam and the full width at half-maximum (FWHM) of the radial intensity is 6.2 MeV and 0.6 mm, respectively. These parameters give the difference between measurement and simulation of less than 1%. Consequently, the percentage depth dose and dose profile, at depth 5 and 10 cm, for the square field sizes between 1 × 1 and 5 × 5 cm$^2$ have been measured and compared with the values obtained from Monte Carlo simulation. The results from the measurement match those of simulation well where the difference does not exceed over 2%.

**Table 1.** Comparison of between the relative output factors obtained from the measurement using SFD and microDiamond detector and from the calculation using Monte Carlo simulation (MC). The percentage difference from the MC value is given in parenthesis.

| Type | Relative Output Factor (%diff) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Depth 5 cm | | | | Depth 10 cm | | | |
| | 1×1 cm$^2$ | 2×2 cm$^2$ | 3×3 cm$^2$ | 5×5 cm$^2$ | 1×1 cm$^2$ | 2×2 cm$^2$ | 3×3 cm$^2$ | 5×5 cm$^2$ |
| SFD | 0.7574 (1.6) | 0.8786 (1.3) | 0.9140 (1.4) | 0.9373 (1.2) | 0.6995 (1.5) | 0.8243 (1.8) | 0.8669 (1.6) | 0.9052 (1.3) |
| microDiamond | 0.7586 (1.7) | 0.8799 (1.4) | 0.9115 (1.1) | 0.9381 (1.2) | 0.7028 (1.9) | 0.8113 (1.7) | 0.8645 (1.3) | 0.8920 (1.3) |
| Calculation (MC) | 0.7457 | 0.8673 | 0.9018 | 0.9266 | 0.6893 | 0.8099 | 0.8533 | 0.9037 |

In the case of the relative output factor, the measurement results from both the SFD and microDiamond detector have been compared with the simulated results where the differences are found to be less than 2% as illustrated in table 1.

## 4. Conclusion

This study has found that microDiamond detector (PTW Freiburg, Germany, PTW-60019 owns appropriate characteristics in the measurement of the output factor in small fields although it's high price. The results of this study have revealed that the measurement of output factor in small fields results in same values obtained from SFD, with a difference not exceeding 2%. At any rate, this study aims to compare the values of the output factor obtained from the measurement of both detectors with the calculation. Moreover, this study does not involve the study of specific characteristics of the micrDiamond detector, therefore, the information obtained from this study may not be enough to point the advantages and disadvantages, the necessity upon purchases, replacement, or encourage promotional agencies the detectors in use.

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