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Original paper

Small field output factors evaluation with a microDiamond detector over 30 Italian centers

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A B S T R A C T

Purpose: The aim of the study was a multicenter evaluation of MLC&jaws-defined small field output factors (OF) for different linear accelerator manufacturers and for different beam energies using the latest synthetic single crystal diamond detector commercially available. The feasibility of providing an experimental OF data set, useful for on-site measurements validation, was also evaluated.
Methods: This work was performed in the framework of the Italian Association of Medical Physics (AIFM) SBRT working group. The project was subdivided in two phases: in the first phase each center measured OFs using their own routine detector for nominal field sizes ranging from 10×10 cm^2 to 0.6×0.6 cm^2. In the second phase, the measurements were repeated in all centers using the PTW 60019 microDiamond detector.
Results: The project enrolled 30 Italian centers. Micro-ion chambers and silicon diodes were used for OF measurements in 24 and 6 centers respectively. Gafchromic films and TLDs were used for very small field OFs in 3 and 1 centers. Regarding the measurements performed with the user's detectors, OF standard deviations (SD) for field sizes down to 2×2 cm^2 were in all cases <2.7%. In the second phase, a reduction of around 50% of the SD was obtained using the microDiamond detector.
Conclusions: The measured values presented in this multicenter study provide a consistent dataset for OFs that could be a useful tool for improving dosimetric procedures in centers. The microDiamond data present a small variation among the centers confirming that this detector can contribute to improve overall accuracy in radiotherapy.

1. Introduction

Nowadays, the possibilities in providing highly conformal dose distributions and accurate dose delivery offered by integrated

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image-guided systems have contributed to the SBRT technique proliferation in many anatomical regions [1–6].

The impact of small field dosimetry on treatment quality is constantly growing due to delivery equipment and planning system issues posed by tiny beam segments used in dynamic beam-delivery modalities. In particular, dosimetry parameters, such as output factors (OF), are essential to provide accurate SBRT dose calculation. The experimental determination of small beam data is challenging given (i) the lack of lateral charged particle equilibrium, (ii) high dose gradients and peaked dose distributions, (iii) energetic spectrum changes as a function of field size. Therefore, the dosimetry of small beams cannot be performed neither using standard dosimeters nor with standard dosimetric protocols. Uncertainties are still very high with reported differences >20% in small beam (<3×3 cm^2) output ratios [7–10]. The resolution (i.e. detector dimension compared to the beam size) and the material composition (i.e. non tissue-equivalent dosimeter) are the two main issues occurring in small field dosimetry.

A proposal for a new international formalism has been developed by the International Atomic Energy Agency (IAEA) in conjunction with the American Association of Physicists in Medicine (AAPM) [11]. The dosimetric formalism introduced the necessity of applying correction factors to raw experimental data. These correction factors are supposed to be calculated using Monte Carlo simulations of the detector used for the measurement. In particular, the correction factors take into account the detector non-water equivalence and the volume averaging effect. Recent publications reported correction factors for a limited set of detectors, different field sizes and shapes (circular and square), different types of linear accelerators and add-on devices [12–18]. This heterogeneity makes data comparison often difficult. The treatment head design affects the OF measurement too; in particular the electron spot size, and incident electron energy, have been investigated, [12,19–21] showing a non-negligible influence of these parameters. Therefore, specific correction factors for the dosimeters used in each center could be difficult to determine. In addition, no consensus regarding the best detectors for small field OF determination has been reached yet [18].

Diamond has long been considered a suitable material for the construction of small volume high-resolution radiation detectors due to its radiation hardness, near tissue-equivalence, small size, high-sensitivity, independence from the energy of photons and low leakage current [22–25]. Particularly the new synthetic PTW 60019 microDiamond detector has been evaluated and considered suitable for the dosimetry of small beams [26–30]. Small microDiamond output correction factors are generally reported for field sizes down to 1×1 cm^2: Azangwe et al. [14] found an agreement better than 2% for field sizes greater than 1.2×1.2 cm^2 with alanine reference measurements on an Elekta Precise equipped by BrainLAB m3 micro-multileaf collimator. Underwood et al. [31] suggested that microDiamond might be utilized without corrections down to 1×1 cm^2 on 6 MV TrueBeam with a dosimetric tolerance of 2%. However, contradictory results are reported in different studies for field sizes below 1×1 cm^2: Morales et al. [29] and Chalkley et al. [32] reported the microDiamond to be correction free to within 1% for field sizes of 5 mm at 6 MV. On the other hand, Ralston et al.[16] and Azangwe et al.[14] found a continuous over-response down to small field sizes up to 4–6%, while O'Brien et al.,[18], Papaconstadopoulos et al. [33] and Lárraga-Gutiérrez et al.[30] indicated a sudden under-response at very small field sizes within 1.4%.

In 2012 the Italian Association of Medical Physics (AIFM) instituted a working group focused on "Dosimetry, physics, and radiobiology of image guided hypo-fractionated ablative radiotherapy". Specific literature reviews [6,34], multi-planning comparisons on many target regions [35–37], and two multicenter CyberKnife small field OF evaluations [38,39] have been addressed. A multi-institute study on small field dosimetry using the 10FFF beam of TrueBeam accelerators has been also performed [40].

In the present study, multicenter OF measurements for the major linac companies and for different beam energies were performed. In each center two sets of measurements were acquired. A first set was measured with the center-specific routinely used detector and a second set with a new generation dosimeter, the PTW 60019 microDiamond. The aim of this work was to evaluate the center-specific small field dosimetric parameters and the related measurement procedures in order to identify potential discrepancies among centers. In particular we wanted to highlight the importance of employing shared procedures within different centers across the whole country. Moreover, a broad range of measurements across many different linear accelerators available from a multicentre study could be used as reference for on-site measurements validation and could prove to be an invaluable tool [41].

2. Methods

A preliminary survey was performed in order to evaluate differences in terms of the used methodology. In particular, linac model, energy, collimation system and delivery technique (i.e. 3D conformal, IMRT, VMAT) adopted for standard SBRT treatments were considered. Minimum field size measured for TPS commissioning and detector type used for OF evaluation were requested too.

The project was divided in two phases: in the first one each center performed OF measurements with routinely used detectors for nominal field sizes ranging from 10×10 cm^2 to 0.6×0.6 cm^2, defined by both secondary jaws and MLC whenever possible. In the second phase the new PTW 60019 microDiamond detector was used to perform the same measurements.

In order to speed up the process, the measurements were performed using two microDiamonds. The National Institute of Ionizing Radiation Metrology ENEA-INMRI carried out a complete characterization of the two diamond dosimeters to ensure the dosimetric equivalence of the detectors.

2.1. Measurements with microDiamond

The microDiamond detector is a synthetic single crystal detectoroperating in photovoltaic regime, with no external bias voltage applied. The active volume embedded in the diamond crystal has a cylindrical shape of 1.1 mm radius and length of 1 µm. The reference point is on detector axis, 1 mm from the tip, marked by a ring. In all measurements, the two microDiamond dosimeters were oriented with their axis parallel to the beam direction with the detector facing up with the gantry at zero degrees, as recommended by literature and manufacturers [26–30].

2.2. Experimental set-up

OF measurements were performed in two different set-up conditions: 10 cm depth in water phantom at SSD 90 cm and 10 cm depth at SSD 100 cm. Each detector was centered performing in-line and cross-line profiles with 0.1 mm steps for two field sizes: the smallest available one and 1×1 cm^2. Central point measurements were acquired using 200 monitor units (MU). Data were averaged over 3 acquisitions. The uncertainties of the measurements were evaluated as one standard deviation on the repeated measurements.

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