Radiation Measurements 85 (2016) 99–110

Contents lists available at ScienceDirect

Radiation Measurements

journal homepage: www.elsevier.com/locate/radmeas

Small field output factors: Comparison of measurements with various detectors and effects of detector orientation with primary jaw setting

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HIGHLIGHTS

- Output factors vary significantly with various detectors for the smallest field of all collimating systems.
- Small field output factors depend on the configuration of secondary as well as tertiary collimating systems.
- The detector orientation and the position of jaws influence the output factors considerably in small fields.

ARTICLE INFO

Article history:
Received 20 May 2015
Received in revised form
27 November 2015
Accepted 28 December 2015
Available online 31 December 2015

Keywords:
Detector orientation
Output factor
Small field

ABSTRACT

Accurate dosimetry in small photon fields used in modern radiotherapy is a challenging task due to electronic disequilibrium, steep dose gradients, source occlusion and size of the sensitive volume of the detector. These challenging effects and the lack of metrological dosimetric reference instigated an investigation on the acquisition of output factor with various detectors in parallel and perpendicular orientations. Small field output factor measurements of tertiary collimators such as BrainLab circular cones, BrainLab mMLC and Millennium MLC were carried out in this study. The data acquired show the differences between output factor results with different detectors for all collimating systems. Good agreement in output values was observed in field sizes greater than ~2×2 cm^2 for all detectors and all tertiary collimators. For smaller fields when compared to electron field diode (EFD), 0.125 cm^3 ion chamber underestimates the output by up to −11.1% and −20.4% and pinpoint ion chamber underestimates the output by up to −1.5% and −6.1% in their parallel and perpendicular orientation, respectively. In contrast, PTW SRS diode and photon field diode (PFD) overestimate the output factor by up to 2.5% and 6.9% respectively in its parallel orientation. The investigated data for the effect of jaw position (0.25×0.25 cm^2, 0.5×0.5 cm^2 and 1×1 cm^2) away from the field edge generated by different tertiary collimating systems inferred that the opening of X−Y jaw highly influences the small field output factors. The orientation of the detectors and the position of the jaws could influence the output factors considerably in small fields.

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1. Introduction

Modern state-of-the art techniques such as intensity modulated radiation therapy (IMRT) and stereotactic radiosurgery (SRS) have substantially increased the use of uniform or non-uniform small fields in radiation therapy (Alfonso et al., 2008). The evolution of recent technology has improved the conformity of the beam aperture to treat small and irregular lesions with the use of computer controlled multi-leaf and micro-multileaf collimators (Ding et al., 2006). The accurate dosimetry of small fields that are in sub-centimeter range used in stereotactic treatments makes the interpretation of measurement difficult due to the lack of charge particle equilibrium, steep dose gradient, the finite size of the detector as well as the partial occlusion of the viewable part of radiation source (Das et al., 2008; Seuntjens and Verhaegen, 2003;

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http://dx.doi.org/10.1016/j.radmeas.2015.12.038
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Scott et al., 2008).

Systematic errors occur due to volume averaging, non-tissue equivalence of detectors, lack of lateral charged particle equilibrium and positional uncertainty affects the accurate measurement of output factors (Fan et al., 2009). These sources of errors are known to be severe, even for detectors with very small active regions. Generally, different detectors such as ionization chambers, micro-ionization chambers, solid state detectors, and diamond detectors are being used in the accurate dosimetry of high-energy narrow photon beams. Ionization chambers are considered to be the gold-standard in radiotherapy dosimetry, but they are not suitable in situations where the high dose gradient and non uniform beam distribution are encountered (Heydarian et al., 1996). If air filled micro ion chambers are used, the detector oriented parallel to the central axis of the beam should be preferred than perpendicular orientation (Francescon et al., 2014). Solid state and liquid filled detectors show better dosimetric performance in terms of spatial resolution and accurate output factor measurements (McKerracher and Thwaites, 2006; Martens et al., 2001). However, a large directional and energy dependence have been observed while using silicon diode detectors (Rikner and Grusell, 1987; Song et al., 2006; Saini and Zhu, 2007). A number of studies have been reported on the output factor measurements of different detectors with a deviation of about 35% for 1×1 cm^2 field size (Haryanto et al., 2002).

Generally, tertiary collimators such as mMLC or cone are attached as add-ons to the conventional linear accelerator to shape the beam required for stereotactic irradiation. In IMRT irradiation, MLCs are used to generate irregular beam segment for the dose delivery. The experimental determination of relative output factors presents the greatest challenge, especially for small fields with different detectors yielding measurements that exhibit a high degree of uncertainty and deviate significantly (Westermark et al., 2000). The position and configuration of jaws above tertiary collimators could change dosimetric characteristics in both SRS and IMRT. The X–Y jaw setting can significantly change the fluence of the incident beam, distribution of dose and output of small fields. The dose characteristics such as beam profile, PDD and output along the central and off axis of the beam would also be changed due to the configuration and position of the jaws (Chow et al., 2005).

This study is focused on the effects of detector orientation in the determination of small field output factors using different detectors and also to investigate the variation in output factors due to the relative positions of jaw above the tertiary collimator.

2. Materials and methods

2.1. Treatment unit

Dosimetric measurements were performed on two different linear accelerators (Varian Clinac 2100CD and Siemens Primus). The Clinac 2100CD linear accelerator incorporates a millennium MLC that consists of 60 pairs of tungsten leaves as a tertiary collimating system. The central leaves of 40 pairs and outer leaves of 10 pairs on either side of the isocenter have projected leaf widths of 5 mm and 10 mm respectively at isocenter. The Primus linear accelerator has been used for stereotactic irradiation with micro multileaf collimator (mMLC) or BrainLab circular cones as an add-on tertiary collimating system. The add-on mMLC has 26 pairs of tungsten leaves with variable width over a field size of 9.8×9.8 cm^2. The design includes central leaves of 14 pairs with 3 mm projected width, adjacent leaves of 3 pairs with 4.5 mm projected width and adjoining leaves of 3 pairs with 5.5 mm projected width at the isocenter. BrainLab circular cones are made up of lead embedded in a brass shell of 11.5 cm length and an outer diameter of 10.8 cm. The inner diameter of circular cones varies from 10 mm to 40 mm in steps of 5 mm.

2.2. Detectors

The detectors used in this study were Scanditronix photon field diode (PFD), Scanditronix electron field diode (EFD), PTW SRS diode, PTW 31014 pinpoint ion chamber, PTW 31010 scanning chamber and PTW LA48 linear detector array (LDA). The readings were obtained using a PTW UnidosE electrometer with diodes operated at 0 V, ion chambers at +400 V and LDA at +900 V. The recommended orientation of the diode and ion chamber is to position its axis parallel and perpendicular to the central axis of the beam, respectively. The characteristics of detectors used in this study are tabulated in Table 1. PTW MP3 radiation field analyzer (RFA) of ±0.1 mm positional accuracy was used in the acquisition of data. Relative dose profiles at 10 cm depth were used to confirm the accurate positioning of the detector at the center of the radiation field.

2.3. Output factor measurement

Small field output factor measurements were performed with three different tertiary collimators namely BrainLab circular cones, BrainLab mMLC and Varian millennium MLC with 6 MV photon beams. The SRS output factors were measured on Siemens Primus with BrainLab mMLC and circular cones forming field sizes ranging from 1.2×1.2 cm^2 to 9.8×9.8 cm^2 and circular fields of diameter ranging from 1.0 cm to 4.0 cm with an increment of 0.5 cm respectively. Millennium MLCs were opened for the square fields varying from 1×1 cm^2 to 5×5 cm^2 in steps of 0.5 cm and fields up to 10×10 cm^2 in steps of 1.0 cm. Output factors were measured with a source-to-detector distance of 100 cm at a depth of 10 cm for all measurements. The jaws were positioned at the edges of the fields defined by tertiary collimators for all measurements. All detectors were positioned with their axis in parallel and perpendicular orientation to the central axis (CAX) of the beam except PTW LA48 that was oriented perpendicular to the beam axis. Pre-irradiation was carried out by delivering 1000 MU to the detectors with their respective bias voltage described earlier. Each measurement was repeated four times by delivering 100 MU for all field sizes and the average value was used in the study. The data obtained are normalized to each of the detectors in 4 cm diameter, 9.8×9.8 cm^2 and 10×10 cm^2 reference fields for Brain Lab circular cones, BrainLab mMLC and millennium MLC respectively.

Several authors have suggested that the unshielded diodes are a good choice for the measurement of small field output factor (Scott et al., 2008; Azangwe et al., 2014; Belec et al., 2005; McKerracher and Thwaites, 1999). Wang and Beddar (2011) estimated the field size dependence by modeling Monte Carlo simulation with an air core fiber optic scintillation dosimeter (FOD) and found that the detector response was within 0.5% from 1 cm to 10 cm field. The FOD was used by Ralston et al. (2012) as a reference to determine correction factors for various diodes and found that the unshielded diode (EFD) requires less correction. The correction required for EFD is less than other diodes in small fields because of its lower signal due to volume averaging effect gets compensated with its higher response due to the presence of silicon chip (Ralston et al., 2012). As the results obtained with EFD are closer to FOD and the theoretically evaluated values, it is presumably the most accurate dosimeter in this study though it is not a perfect detector. The diodes oriented with their stem parallel to the central axis of the beam have the sensitive volume (silicon chip) facing the beam (Lechner et al., 2013). EFD oriented parallel to the CAX of the beam

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