Physica Medica xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Physica Medica

journal homepage: http://www.physicamedica.com

Original paper

Dosimetric characterization of small fields using a plastic scintillator detector: A large multicenter study

Pietro Mancosu [a], Massimo Pasquino [b], Giacomo Reggiori [a], Laura Masi [c], Serenella Russo [d,*], Michele Stasi [b]

[a] Medical Physics Unit of Radiation Oncology Dept., Humanitas Research Hospital, Milano, Italy
[b] A.O. Ordine Mauriziano di Torino, Torino, Italy
[c] Department of Medical Physics and Radiation Oncology, IFCA, I-50139 Firenze, Italy
[d] Medical Physics Unit, Azienda USL Toscana Centro, Firenze, I-50012 Firenze, Italy

ARTICLE INFO

Article history:
Received 17 January 2017
Received in Revised form 23 March 2017
Accepted 28 March 2017
Available online xxxx

Keywords:
Small field output factor
Plastic scintillator detector
Multicenter intercomparison

ABSTRACT

Purpose: In modern radiation therapy accurate small fields dosimetry is a challenge and its standardization is fundamental to harmonize delivered dose in different institutions. This study presents a multicenter characterization of MLC-defined small field for Elekta and Varian linear accelerators. Measurements were performed using the Exradin W1 plastic scintillator detector.

Materials and methods: The project enrolled 24 Italian centers. Each center performed Tissue Phantom Ratio (TPR), in-plane and cross-plane dose profiles of $0.8 \times 0.8\ \text{cm}^2$ field, and Output Factor (OF) measurements for square field sizes ranging from 0.8 to 10 cm. Set-up conditions were 10 cm depth in water phantom at SSD 90 cm. Measurements were performed using two twin Exradin W1 plastic scintillator detectors (PSD) correcting for the Cerenkov effect as proposed by the manufacturer.

Results: Data analysis from 12 Varian and 12 Elekta centers was performed. Measurements of 7 centers were not included due to cable problems. TPR measurements showed standard deviations (SD) < 1%; SD < 0.4 mm for the profile penumbra was obtained, while FWHM measurements showed SD < 0.5 mm. OF measurements showed SD < 1.5% for field size greater than $2 \times 2\ \text{cm}^2$. Median OFs values were in agreement with the recent bibliography.

Conclusions: High degree of consistency was registered for all the considered parameters. This work confirmed the importance of multicenter dosimetric intercomparison. W1 PSD could be considered as a good candidate for small field measurements.

1. Introduction

The introduction of image guidance and advanced delivery technology in radiation therapy have improved the capability of treating small and/or complex lesions [1,2]. In this context, the use of small fields is essential to achieve the requested highly conformed dose distributions.

There are several dosimetric challenges in the use of small radiation beams, arising from loss of lateral electronic equilibrium, partial source occlusion and changes in the energy spectrum as a function of field size. These characteristics make the small field output factor measurements often irreconcilable [3]. As pointed out recently, obstacles are both related to the detector employed and to the methodology used to obtain these results [4]. In 2013, the Italian Association of Medical Physics (AIFM) started a working group dedicated to the physics and practical aspects of SBRT. The aim was to support the standardization of the involved procedures as well as to help the medical physicists to reach a high level of confidence in the accuracy of the entire treatment delivery process [5–14]. In particular, a sub-project was started aiming at the standardization of small beams dosimetry performing multi-institutional studies with different small field detectors [5,11–13].

Plastic scintillation detectors (PSDs) meet some of the requirements of an "ideal" small field detector such as a good spatial resolution and water-equivalence of the materials. Several authors have studied PSDs in recent years and their behavior in terms of linear response to absorbed dose, dose-rate and energy independence are well known [11,15–19]. Consequently, PSDs have just found large application in small field dosimetry [20–21]. However, at present the only commercially available PSD is Standard

---

* Corresponding author at: Medical Physics Unit, Azienda USL Toscana Centro, Firenze, Via dell'Antella 58, 50012, Bagno A Ripoli, Firenze, Italy.
E-mail address: serenella.russo@aslcentro.toscana.it (S. Russo).

http://dx.doi.org/10.1016/j.ejmp.2017.03.024

Please cite this article in press as: Mancosu P et al. Dosimetric characterization of small fields using a plastic scintillator detector: A large multicenter study. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.03.024

Imaging's Exradin W1, probably due to the difficulty of handling all the technical issues related to these detectors. The main drawback of PSDs is represented by the generation of Čerenkov light in the PMMA optical fiber guide when the scintillator is exposed to a radiation field. The Čerenkov effect is not accounted for in Monte Carlo simulations and it can therefore introduce experimental uncertainties difficult to be predicted. Two approaches have been suggested to subtract the Čerenkov light component: the method proposed by Beddar et al. [15], that uses a background optical fiber not coupled with a scintillating fiber, and the two fiber or spectral method, by Guillot et al. [23], which takes advantage of the spectral difference between the scintillation and the Cerenkov light in order to discriminate and subtract the background. Since the intensity of Cerenkov light depends on the length of the irradiated fiber, a correct calibration method is crucial in order to have consistent measurements. Considering that the Beddar's approach depends on fiber, coupling and photodetector equivalence, the Guillot method seems to be more appropriate, reducing the Čerenkov effect within 0.7%, which represents an acceptable uncertainty for the aims of the radiation therapy dosimetry. As reported in literature [22], W1 PSD showed an energy-independent response for megavoltage photon and electron beams, a short-term repeatability within 0.25%, a dose-response linearity within 0.5%, an almost isotropic response around its symmetric axis and a linear temperature dependence. Moreover, Monte Carlo simulations [18,19] have demonstrated that W1 PSD accurately reproduces PDDs, TMRs and OARs in water and can be considered essentially correction-free for OFs determination. The choice of the W1 scintillator for the present study has therefore the twofold objective of evaluating the detector's dosimetric characteristic in small fields as well as the reproducibility of the results in a multi-institutional context where the objective was to support the standardization of small beams dosimetry.

2. Materials and methods

2.1. LINACS and beams

The project initially enrolled 31 Italian centers. Seven centers were excluded from the analysis due to technical problems with the scintillator cable during the measurements. Of the remaining 24 centers, 12 were equipped with Elekta Linacs (Elekta, Crawley, UK) and 12 with Varian Linacs (Varian Medical System, Palo Alto, US) with photon beams used or commissioned for SBRT (6 MV, 6 MV FFF and 10 MV FFF). In detail, 20/24 used 6 MV beams, 3 used 6 MV FFF beams and 1 used 10 MV FFF beams. The dose rates ranged from 400 to 800 MU/min for the 6 MV beams while for FFF beams dose rates ranged from 1400 to 2400 MU/min. Each center performed the measurements at the maximum dose rate achievable with the own LINAC. The field sizes were MLC-defined both on Varian and Elekta linacs for fields >1 × 1 cm^2 with the secondary jaws following MLC apertures. For the smaller fields the size was defined by the jaws alone or by a combination of jaws and MLC. Field sizes were defined at a source detector distance of 100 cm and SSD (Skin source distance) of 90 cm. Different collimating systems were used with leaf width ranging from 1.6 to 10 mm; in particular 1 system had a leaf width of 1.6 mm, 2 systems of 2.5 mm, 4 of 4 mm, 15 of 5 mm and 3 of 10 mm. All leaf widths were defined at isocenter.

2.2. W1 plastic scintillator detector

The Exradin W1 PSD (Standard Imaging Inc., Middleton, WI) sensitive element is composed of a plastic scintillating fiber with dimensions of 0.1 cm in diameter and 0.3 cm in length (i.e. sensitive volume: 0.0024 cm^3). The scintillating fiber is based on polystyrene and is surrounded by an acrylonitrile butadiene styrene (ABS) plastic enclosure and a polymide stem. The density of the plastic scintillating fiber is 1.05 g/cm^3.

The scintillation light produced in the detector-sensitive element is transmitted to a photodiode by an optical fiber made of PMMA in order to reduce beam perturbation. This optical fiber produces its own visible light spectrum when irradiated, contaminating dose readings. Some techniques have been developed to subtract this unwanted signal, including the subtraction of Čerenkov light.

In this study the spectral method for W1 PSD Čerenkov effect compensation for small-field measurements was applied following the procedure described by Morin et al. [21]. Measurements were performed in water with the scintillator axis oriented parallel to the beam axis. For the minimum exposed fiber condition, the optical fiber was pulled out of the field so that only ~10 cm of fiber was within the beam without any significant optical bend; for the maximum exposed fiber condition, the optical fiber remained within the beam, extending it to the bottom of the tank so that 25–30 cm of the optical fiber was irradiated. For both conditions, the effective point of measurement was placed at a depth of 10 cm and the 10 × 10 cm^2 field size was used.

Exradin W1 Scintillator was connected to a two-channel SuperMAX electrometer (Standard Imaging Inc., Middleton, WI). The electrometer was set in triggered charge collection mode for channel 1 (green light, mainly scintillation light). Automatic start and stop trigger thresholds preconfigured as a default in the Supermax electrometer were used. Channel 2 collected the signal from blue light mainly produced by Čerenkov radiation. The electrometer software allows automatic correction of the Čerenkov effect if a preliminary calibration has been performed [22]. Two twin dosimetry systems (W1 detector, fiber, and electrometer) were adopted in the study to fast the measurements over the centers. In all centers, W1 was mounted on the own water tank routinely used and the detector was translated point-by-point using the proprietary tank controller of each center.

2.3. Experimental measurements and data analysis

The participants were requested to perform the Tissue Phantom Ratio (TPR_{10}^{20}) for assessing the energy quality, in-plane and cross-plane dose profiles for the 0.8 × 0.8 cm^2 beam size, and output factor (OF) measurements. Setup conditions were: 100 cm source to detector distance and 10 cm depth in water and the normalization field was the 10 × 10 cm^2 MLC field.

The measurements were performed with the W1 plastic scintillator detector used in parallel configuration (i.e. the detector axis parallel to the beam axis). W1 effective measurement point was set equal to 2.26 mm from the frontal surface according to Francescon et al. [19]. Different positioning systems were used in each center since W1 PSD has not yet been integrated with any scanning water-tank. For detector centering the W1 position was finely tuned to within 0.1 mm to achieve the maximum signal intensity.

Accordingly to IAEA TRS-398, the beam quality index TPR_{10}^{20} was evaluated as the ratio of the absorbed doses at depths of 20 and 10 cm in a water phantom, measured with a constant source-to-detector distance of 100 cm and a field size of 10 × 10 cm^2 at the plane of the detector.

Crossplane and inplane dose profiles were acquired at a depth of 10 cm in a water phantom for a 0.8 × 0.8 cm^2 field size with 0.2 mm step. FWHM of the dose profiles was defined as the distance from field edge to opposite edge at the 50% dose level, normalized to 100% on the central axis. Penumbra of the dose profiles was defined as the width of the 80% to 20% dose gradient.

Please cite this article in press as: Mancosu P et al. Dosimetric characterization of small fields using a plastic scintillator detector: A large multicenter study. Phys. Med. (2017), http://dx.doi.org/10.1016/j.ejmp.2017.03.024