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Small field dosimetry

Detector comparison for small field output factor measurements in flattening filter free photon beams

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ABSTRACT

Purpose: The applicability of various detectors for small field dosimetry and whether there are differences in the detector response when irradiated with FF- and FFF-beams was investigated.

Materials and methods: Output factors of 6 and 10 MV FF- and FFF-beams were measured with 14 different online detectors using field sizes between 10 × 10 and 0.6 × 0.6 cm^2 at a depth of 5 cm of water in isocentric conditions. Alanine pellets with a diameter of 5 and 2.5 mm were used as reference dosimeters for field sizes down to 1.2 × 1.2 and 0.6 × 0.6 cm^2, respectively. The ratio of the relative output measured with the online detectors to the relative output measured with alanine was evaluated (referred to as dose response ratio).

Results: The dose response ratios of two different shielded diodes measured with 10 MV FF-beams deviated substantially by 2–3% compared to FFF-beams at a field size of 0.6 × 0.6 cm^2. This difference was less pronounced for 6MV FF- and FFF-beams. For all other detectors the dose response ratios of FF- and FFF-beams showed no significant difference.

Conclusion: The dose response ratios of the majority of the detectors agreed within the measurement uncertainty when irradiated with FF- and FFF-beams. Of all investigated detectors, the microDiamond and the unshielded diodes would require only small corrections which make them suitable candidates for small field dosimetry in FF- and FFF-beams.

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During the last years unflattened or flattening filter free (FFF) photon beams have stimulated medical physics research in radiotherapy. It is generally agreed that the prime clinical applications of FFF beams may focus on stereotactic radiotherapy in the cranial and extra-cranial region as well as intensity modulated radiotherapy with a static or rotating gantry [1–3]. Common features of these treatment techniques are that either small fields or small segments are utilized to deliver radiation to patients. In this context, dosimetry in non-reference conditions with non-standard beams and especially small field dosimetry has become an important topic.

One of the physical phenomena that contribute to small field conditions is the lack of lateral charged particle equilibrium [4–8] and it has been demonstrated that it is very difficult to predict perturbation correction factors [6], i.e., deviations from ideal Bragg–Gray cavity behavior, for finite detectors in the absence of charged particle equilibrium. Nevertheless, recent papers have shed some light on the theoretical aspects of small field perturbation factors by separating volume averaging effects and the indication that the main other source of fluence perturbation is the density difference between the detector (both of the sensitive medium and the surrounding components) and water [9–11]. For the application of a recent formalism [12] in future dosimetry codes of practice for small fields, this suggests a practical approach in which field specific volume averaging corrections are determined by the user and material related fluence perturbations by other means (theoretical, Monte Carlo simulations or tabulated data). A number of authors have used the Monte Carlo method to evaluate overall perturbation factors for diodes, diamond and ionization chambers in small fields [11,13–17] while numerous experimental studies of the relative response of those detectors have been reported as well [4,5,11,18,19]. Very few of those studies pertain to FFF beams and the ones that do, are mostly related to the CyberKnife [13,18,20].

Aim of this study was therefore to investigate a comprehensive set of online detectors for their applicability in small fields and to determine whether differences in correction factors can be observed between FF- and FFF-beams.

Materials and methods

An Elekta Precise linear accelerator (Elekta, Crawley, UK) providing both 6 and 10 MV flattened (FF) and flattening filter free

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(FFF) photon beams was equipped with a M3 μMLC (BrainLAB AG, Heimstetten, Germany) to produce field sizes between 10 × 10 and 0.6 × 0.6 cm². Dosimetric properties of this linac have been described earlier [21–24]. Beam quality indices $TPR_{20/10}$ were 0.684, 0.686, 0.714 and 0.735 for the 6 MVFFF, 6 MVFF, 10 MVFFF and 10 MVFF beam, respectively. This linac was calibrated to deliver 1 cGy/MU at10 cm depth of water, a field size of 10 × 10 cm² and a source to surface distance of 90 cm.

For this study, various solid state detectors and ionization chambers were investigated and classified according to the size of their active volumes in mm³. All investigated detectors are listed in Table 1. In accordance with the TG-106 report [25], the detectors were classified as "micro" if the active volume was smaller than 10 mm³ and as "mini" if it was between 10 and 40 mm³. Detectors with an active volume larger than 40 mm³ were classified "standard" detectors. The micro-detector category almost exclusively contained solid state detectors with the exception of a liquid filled ionization chamber. The microDiamond detector (PTW, Freiburg, Germany) is a prototype of a synthetic diamond detector. Characteristics of an earlier version of this detector can be found elsewhere [26–28]. The micro detectors were oriented with their stems parallel to the beam axis so that their circular shaped sensitive volumes were perpendicular to the beam axis. In contrast to that, the air filled ionization chambers' stems were oriented perpendicular to the beam axis with the long axis of the active volume parallel to the leaves of the MLC. Most detectors were operated with nominal voltage according to vendors' specifications. The CC01, Pinpoint14 and PinPoint16 were operated at 200 V. The detectors were pre-irradiated 1000 MU to the measurement series. Each field was consecutively irradiated five times with 100 MU and the readings of the detectors were averaged. The only exception to this experimental protocol was the microDiamond, which required 150 MU per measurement as recommended by the vendor. The beam profiles of the 1.2 × 1.2 cm² field were acquired in a step and shoot mode (scanning mode was not available for all the detectors) prior to each measurement series to verify the detector's position and to move it to the maximum of the beam profile if necessary.

The detectors were positioned in a water phantom (Blue Phantom, Wellhöfer, Schwarzenbruck, Germany) at a depth of 5 cm water and a source-to-surface distance of 95 cm. A Bragg Peak ionization chamber (PTW, Freiburg, Germany) was used as reference and was positioned with its entrance window aligned with the water surface. Two Unidos Webline (PTW, Freiburg, Germany) electrometers were used to collect charges from the investigated online detectors and the Bragg Peak chamber.

Alanine pellets with diameters of 5 and 2.5 mm, an average thickness of 2.3 mm, average density of 1.23 g/cm³ and a composition of 90.9% by weight L-α-alanine and 9.1% high melting point paraffin wax were employed as reference detectors. The National Physical Laboratory (NPL) reported the uncertainty associated with the calibration of the alanine pellets to be 0.9% in terms of absolute dose. The radiological properties and the density are nearly water equivalent, which only causes little fluence perturbations. Hence only volume averaging needs to be taken into account. In contrast to the investigated online detectors, the alanine pellets were irradiated in a solid water phantom (Gammex-RMI GmbH, Giessen-Allendorf, Germany) using the same geometry. Alanine pellets with a diameter of 5 mm were used in all fields down to 1.2 × 1.2 cm². In the two smallest fields, namely the 1.2 × 1.2 cm² and the 0.6 × 0.6 cm², alanine pellets with a diameter of 2.5 mm were used. Given the relatively low sensitivity of alanine, a substantially higher dose was needed compared to the investigated online detectors. The numbers of MUs were set sufficiently high to ensure that the 5 and 2.5 mm alanine pellets used for the smallest fields received a dose of at least 10 and 30 Gy, respectively. The

Table 1
Summary of investigated detectors.

Category	Label	Vendor	Type	Active volume (mm³)	Material	Z_{eff}	Sensitivity (nC/Gy)
Micro							
	microDiamond 60019	PTW	SYD	0.004	Diamond	6	0.7–1.2
	SFD	IBA	UD	0.017	Silicone	14	6
	DiodeP 60008	PTW	SD	0.03	Silicone	14	9
	EFD	IBA	UD	0.188	Silicone	14	25
	PFD	IBA	SH	0.188	Silicone	14	33
	microLion 31018	PTW	LIC	2	Wall: graphite Electrode: graphite Medium: isooctane		9.8
Mini							
	CC01	IBA	AIC	10	Wall: 0.5 mm C-552 Electrode: Ø 0.35 mm steel		0.33
	PinPoint14 310014	PTW	AIC	15	Wall: 0.57 mm PMMA 0.09 mm graphite Electrode: Ø 0.3 mm Al		0.4
	PinPoint16 310016	PTW	AIC	16	Wall: 0.57 mm PMMA 0.09 mm graphite Electrode: Ø 0.3 mm Al		0.4
	CC04	IBA	AIC	40	Wall: 0.4 mm C-552 Electrode: Ø 0.35 mm C-552		1.3
Standard							
	Semiflex 31010	PTW	AIC	125	Wall: 0.5 mm PMMA 0.15 mm graphite Electrode: Ø 1.1 mm Al		3.3
	IC10	Wellhöfer	AIC	140	Wall: 0.4 mm C-552 Electrode: Ø 1 mm C-552		4.4
	CC13	IBA	AIC	150	Wall: 0.4 mm C-552 Electrode: Ø 1 mm C-552		4.4
	NPL2611	NPL	AIC	325	Wall: graphite Electrode: Al		11

Abbr.: AIC, air filled ionization chamber; LIC, liquid filled ionization chamber; SD, shielded diode; UD, unshielded diode; SYD, synthetic diamond.