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Today's monolithic silicon array detector for small field dosimetry: The Octa

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Abstract

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Today’s monolithic silicon array detector for small field dosimetry: the Octa

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Abstract. The dosimetry of small photon beams is challenging due to detector position uncertainties, dose averaging and lack of electronic equilibrium. Currently only few, single detectors are suitable for measurements in this context, and none is ideal. This study reports on the dosimetric characterization of small fields collimated by fixed cones, performed by a novel 2D monolithic silicon array detector, the Octa.

1. Introduction

The challenges associated with the relative dosimetry of small photon beams, i.e. detector position uncertainties, dose averaging and lack of charged particle equilibrium, have been widely discussed in the recent literature [1,2]. For a detector dedicated to small field dosimetry, characteristics such as a sensitive volume (SV) sufficiently small with respect to the radiation field and the ability to offer high spatial resolution measurements are considered paramount. Ideally, it would also be water equivalent and have a response which is linear with the absorbed dose, as well as be energy and dose rate independent [3,4]]. However, no ideal detector dedicated to small field dosimetry exists, and it is advised to use different dosimeters and cross-check the consistency of results [1,2].

In particular, solid-state detectors are recommended by the IAEA-AAPM protocol dedicated to small field dosimetry [2], but only single 1D solid-state detectors used with various scanning techniques have been shown to offer the necessary sub-mm spatial resolution [1]. Furthermore, their readings need correction factors to account for beam perturbations that are detector design, linear accelerator (linac) treatment head design, beam quality, field size and measurement conditions dependent [5]. As a consequence, these are inconvenient to use in practice because of the multidimensional factor dependencies (field size, depth and distance) [6].

A ‘correction-free’ detector, i.e. one maintaining a correction factor close to unity, would be a preferable solution. This has been shown to be possible with the addition of low density media to the high density SVs components [7]. However, it would still be necessary to verify that these modifications are correctly compensating for a specific measurement condition [8].

Recently, the Centre for Medical Radiation Physics (CMRP) has developed the Octa, a 2nd generation silicon array detector dedicated to small field dosimetry which has been shown to be accurate for relative dosimetry with both flattened and flattening filter free photon beams [9] and to possess unique potentials for quality assurance for an Accuray CyberKnife system [10]. This study reports on its dosimetric characterization of small fields collimated by fixed cones attached to an Elekta Axesse linac.

2. Material and Methods

The Octa, pictured in Figure 1, is a 2D monolithic silicon array detector based on 512 diode-SVs arranged on 4 arrays. The device offers sub-mm spatial resolution, with diodes having a 0.3 mm pitch along the vertical and horizontal arrays and a 0.43 mm pitch along the 2 diagonals. It is operated in passive mode, connected to a multichannel data acquisition system based on a commercially available analogue front end (AFE0064, Texas Instruments). Conceived for measurements in solid water, the device is sandwiched between two Perspex plates each 5 mm thick and has a small air gap on top of its SVs to minimize the corrections that are required to relate its readings to dose [9].

Experimental measurements described in this study were carried out at the Prince of Wales Hospital, Randwick (NSW), using 6 MV flattened photon beam from an Elekta Axesse linac with a retrofitted Agility head. Fixed conical collimators (Elekta) with nominal diameter, defined as the projection of their openings at the isocentre, between 5 mm and 50 mm were employed. Parameters commonly used by commercial treatment planning systems, such as dose profiles (DPs), percentage depth dose (PDD) and output factors (OFs) were measured with at least 2 different detectors. For the Octa, measurements were performed in solid water (*Gammex RMI 457, Middleton, USA*). Measurements by GafChromic EBT3 films (ASHLAND) performed in solid water (*Gammex RMI 457, Middleton, USA*) and by a SFD diode (IBA Dosimetry) performed in water tank (*Bluephantom, IBA*) were added to the study to cross-check the consistency of results. EBT3 GafChromic films were scanned 24 hours post irradiation with an EPSON 10000XL using a 48-bit RGB with a resolution of 72 dpi following a procedure detailed in [11]. A test to verify the gantry sag was performed by rotating the gantry at 0° and 180° and measuring the shift in the most responsive SV on the Octa.

Prior to all measurements, the Octa was aligned with respect to the machine central axis (CAX) by maximizing the response of its central pixel using the smallest available field size. OFs and DPs were measured at 90 cm source to surface distance (SSD), 10 cm depth. The accuracy of DPs was assessed by comparing FWHM and penumbra widths, defined as the distance between the 20% and 80% of the CAX dose. CAX PDD were measured with 10 cm solid water for backscattering purposes and by adding the required amount of solid water slabs on top of the detector. For a quantitative estimation of the results, the detector readings were analysed using MATLAB (Mathworks) with a shape preserving interpolant function.

3. Results

The central pixels of the Octa were small enough to identify the CAX position accurately without any volume-averaging effect. Figure 2 shows OFs measured by the Octa and EBT3 films for all fixed cones investigated, normalized to the biggest available field size of 50 mm diameter. Figure 3 shows DPs measured by the Octa and EBT3 films for a 5 mm diameter fixed cone. In the figure, profiles are normalized to the response at CAX and aligned such that the origin lies at the coordinate corresponding to the 50% CAX dose. Figure 4 shows PDD measured by the Octa and a SFD diode for a 5 and a 10 mm diameter fixed cone. Nominal depths were converted to water equivalent depths to account for the density of the Perspex plates of the Octa.

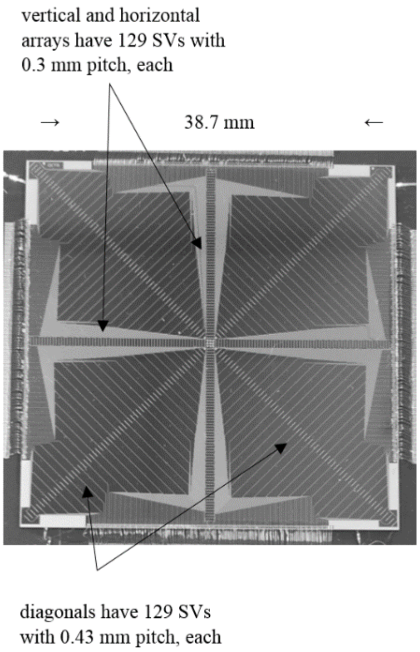

Figure 1. The Octa is a 2D monolithic silicon array detector consisting of 512 diode-SVs arranged along 4 intersecting orthogonal linear arrays.

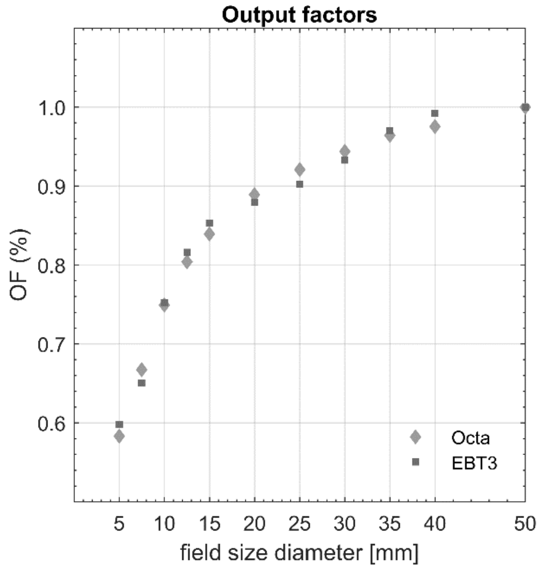

Figure 2. OFs measured by the Octa and EBT3 films for circular fields from 5 mm to 50 mm diameter, collimated by fixed conical cones. OFs are shown normalized to the 50 mm diameter response.

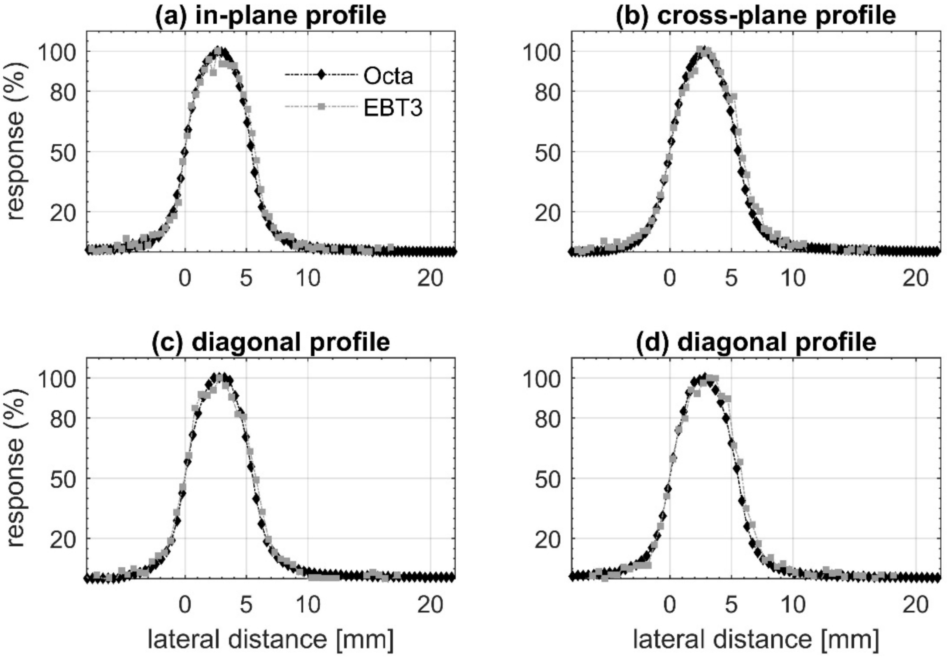

Figure 3. DPs measured by the Octa and EBT3 films for a 5 mm diameter circular field collimated by a fixed conical cone. Profiles are normalized to the CAX dose response and aligned to its 50% value.

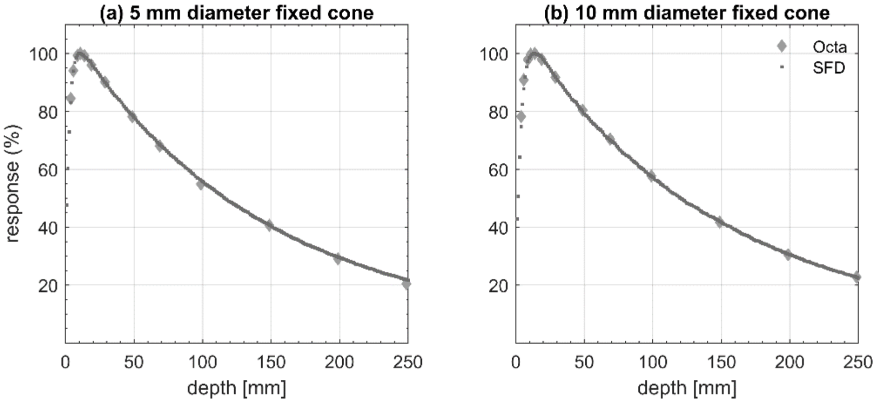

Figure 4. PDD measured by the Octa and a SFD diode for a (a) 5 mm and (b) 10 mm diameter field collimated by a fixed conical cone.

4. Discussion and Conclusion

An accurate measurement of OFs for small radiation fields is paramount. Their high sensitivity to small changes in cone size, due for instance to manufacture-related variations, was demonstrated, with a difference in OF of about 10% for 0.3 mm variation in a 5 mm cone aperture [12]. Silicon diodes are known to require corrections for OF measurements due to electron spectra perturbations with respect to water [13,14]. In this study, OFs measured by the Octa were accurate within 3% with respect to those measured by EBT3 films, a result which supports the current ‘correction-free’ design of the detector for these measurement conditions.

For fixed cones, DPs by the Octa were overall in good agreement with the EBT3 measurements in terms of FWHM, with discrepancies well within 3% for fields equal to or larger than 10 mm in diameter, and approximately 5% for the 5 mm and 7.5 mm field diameters. A maximum discrepancy of 6.9% or 0.4 mm was found for the in-line profile of the 5 mm cone. The elliptical shape of the electron source in Elekta linacs partially explains the expected small differences between in- and cross-plane penumbra widths [12]. The Octa measured a penumbra width of 1.8 mm for the in-plane profile and of 2.1 mm for the cross-plane profile. Overall, penumbra widths measured by the Octa were generally in close agreement with those measured by EBT3 films, with discrepancies within 0.3 mm.

For PDD measurements, for silicon detectors a decrease in sensitivity is expected with decreased dose per pulse [15]. This could be partially offset by an overestimation of the dose due to the increase of the relative number of low energy scattered photons with increasing depth [16,17]. In this study, while no correction was made to account for dose rate response variations, discrepancies in PDD measured by the Octa with respect to the benchmarks were within 3% at all depths, for all field sizes investigated. The gantry sag was determined to be minimal (within 0.3 mm) in the cross-plane direction and approximately 1.2 mm in the in-plane direction.

Overall, the Octa was demonstrated to be an accurate ‘correction-free’ detector for small field dosimetry with potential for the dosimetric characterization of stereotactic dedicated collimators such as fixed cones. Allowing for the simultaneous real-time read-out of OF and DPs along cross- and in-plane along with 2 diagonal directions, all acquired with sub-mm accuracy for any given field size, the Octa would greatly reduce the measurement time needed to comply with quality assurance protocols.

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