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The effect of an air gap on a 2D monolithic silicon detector for relative dosimetry

Kananan Utitsarn

University of Wollongong, Lopburi Cancer Hospital, ku566@uowmail.edu.au

Z A. Alrowaili

Jouf University, zaa931@uowmail.edu.au

Nauljun Stansook

University of Wollongong, Mahidol University, ns938@uowmail.edu.au

Giordano Biasi

University of Wollongong, gbiasi@uow.edu.au

Martin G. Carolan

Wollongong Hospital, mcarolan@uow.edu.au

See next page for additional authors

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Abstract

Purpose: To evaluate the impact of an air gap on the Magic Plate (MP512) response and optimize this gap for relative dosimetry in photon and electron beams. **Materials and methods:** MP512 is a 2D monolithic silicon detector manufactured on a p-Type substrate. The array consists of 512 pixels with 0.5 x 0.5 mm² size and 2 mm pitch with an overall dimension of 52 x 52 mm². The signal ratio (SR) as a function of beam size and the percentage were measured with MP512 in 6 MV and 10 MV photon beams. The enhanced dynamic wedge (EDW) beam profile measurements were performed for 6 MV photon beams. In this work the signal ratio is defined as the ratio of central axis MP512 reading for field sizes ranging from 0.5 x 0.5 cm² to 10 x 10 cm² and for the reference square field of side 10 cm at a depth of 10 cm in solid water phantom. The measurements were performed with an air gap immediately above the detector array of 0.5, 1.0, 1.2, 2.0 and 2.6 mm, respectively. The PDD was measured for field sizes 2x 2 cm², 5x 5 cm² and 10x 10 cm² by scanning the MP512 from the depth of 0.5 cm to 10 cm. The beam profiles were measured for Varian linac enhanced dynamic wedge (EDW) angles of 15, 45 and 60 for field size 5x 5 cm². The PDD for 6, 12 and 20 MeV electron beams were performed for a standard applicator providing 10x 10 cm² field size. **Results:** The signal ratio measured with MP512 reduces with increasing air gap above the detector. The strongest effect of the air gap size was observed for small fields of 0.5x 0.5 cm² and 1x 1 cm² while the effect was negligible within $\pm 2\%$ (1 standard deviation) for field sizes larger than 4x 4 cm². The signal ratio measured with MP512 with air gaps of 0.5 mm and 1.2 mm showed a good agreement with signal ratio measured with the EBT3 film (within $\pm 2\%$) and MOSkinTM for 6 MV and 10 MV, respectively. Similar results were observed for the PDD measurement for field size 5x 5 cm² and 10x 10 cm². The PDD measured with M512 was in good agreement with Markus Ionization chamber (IC) within $\pm 1.6\%$ (1 standard deviation) for 6 MV and $\pm 1.5\%$ (1 standard deviation) for 10 MV. The PDD discrepancy for 2x 2 cm² was within $\pm 3\%$ of the EBT3 for both photon energies. The EDW dose profile matched well with the EBT3 for the air gap of 0.5 mm within $\pm 2\%$ (1 standard deviation) for all wedge angles. The PDD measured by electron beams demonstrated no significant effect of the air gap size above MP512 for all energies. The results showed similar variations (within $\pm 3\%$) compared to Markus IC for both 0.5 mm and 2.6 mm gap. **Conclusion:** The MP512 diode array was demonstrated to be suitable as an in-phantom dosimeter for QA in small radiation treatment fields. The study shows that air gap size has a significant effect on small field photon beam dosimetry due to a loss of electronic equilibrium. The small air gaps of 0.5 mm and 1.2 mm were the best air gaps for 6 MV and 10 MV, respectively. The effect of the air gap in electron beam fields is not significant due to the fact that an electronic equilibrium is fully established.

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Authors

Kananan Utitsarn, Z A. Alrowaili, Nauljun Stansook, Giordano Biasi, Martin G. Carolan, Michael L. F Lerch, and Anatoly B. Rosenfeld

The effect of an air gap on a 2D monolithic silicon detector for relative dosimetry

Kananan Utitsarn^{1,3}, Ziyad A Alrowaili⁴, Nauljan Stansook^{1,5}, Giordano Biasi¹, Martin Carolan² Michael Lerch¹, Anatoly Rosenfeld¹

¹ Centre for Medical Radiation Physics, University of Wollongong, Australia

² Illawarra Cancer Care Centre, Wollongong Hospital, Australia

³ Lopburi Cancer Hospital, Medical Service Department, Lopburi, Thailand

⁴ Physics Department, College of Science, Jouf University, Saudi Arabia

⁵ Faculty of Medical, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand

Corresponding author: ku566@uowmail.edu.au

Abstract

Purpose: To evaluate the impact of an air gap on the Magic Plate (MP512) response and optimize this gap for relative dosimetry in photon and electron beams.

Materials and Methods: MP512 is a 2D monolithic silicon detector manufactured on a p-type substrate. The array consists of 512 pixels with 0.5 x 0.5 mm² size and 2 mm pitch with an overall dimension of 52 x 52 mm². The signal ratio (SR) as a function of beam size and the percentage were measured with MP512 in 6MV and 10MV photon beams. The enhanced dynamic wedge (EDW) beam profile measurements were performed for 6MV photon beams. In this work the signal ratio is defined as the ratio of central axis MP512 reading for field sizes ranging from 0.5 x 0.5 cm² to 10 x 10 cm² and for the reference square field of side 10 cm at a depth of 10 cm in solid water phantom. The measurements were performed with an air gap immediately above the detector array of 0.5, 1.0, 1.2, 2.0 and 2.6 mm, respectively. The PDD was measured for field sizes 2x2cm², 5x5 cm² and 10x10cm² by scanning the MP512 from the depth of 0.5 cm to 10 cm. The beam

profiles were measured for Varian linac enhanced dynamic wedge (EDW) angles of 15°, 45° and 60° for field size 5x5 cm². The PDD for 6, 12 and 20 MeV electron beams were performed for a standard applicator providing 10x10 cm² field size.

Results: The signal ratio measured with MP512 reduces with increasing air gap above the detector. The strongest effect of the air gap size was observed for small fields of 0.5x0.5 cm² and 1x1 cm² while the effect was negligible within ±2% (1 standard deviation) for field sizes larger than 4x4 cm². The signal ratio measured with MP512 with air gaps of 0.5 mm and 1.2 mm showed a good agreement with signal ratio measured with the EBT3 film (within ±2%) and MOSkinTM for 6 MV and 10 MV, respectively. Similar results were observed for the PDD measurement for field size 5x5cm² and 10x10cm². The PDD measured with M512 was in good agreement with Markus Ionization chamber (IC) within ±1.6% (1 standard deviation) for 6 MV and ±1.5% (1 standard deviation) for 10 MV. The PDD discrepancy for 2x2 cm² was within ±3% of the EBT3 for both photon energies. The EDW dose profile matched well with the EBT3 for the air gap of 0.5 mm within ±2% (1 standard deviation) for all wedge angles. The PDD measured by electron beams demonstrated no significant effect of the air gap size above MP512 for all energies. The results showed similar variations (within ±3%) compared to Markus IC for both 0.5 mm and 2.6 mm gap.

Conclusion: The MP512 diode array was demonstrated to be suitable as an in-phantom dosimeter for QA in small radiation treatment fields. The study shows that air gap size has a significant effect on small field photon beam dosimetry due to a loss of electronic equilibrium. The small air gaps of 0.5 mm and 1.2mm were the best air gaps for 6 MV and 10 MV, respectively. The effect of the air gap in electron beam fields is not significant due to the fact that an electronic equilibrium is fully established.

Keyword: silicon diode detector, air gap, photon beams

1. Introduction

Stereotactic radiosurgery (SRS) and stereotactic body radiation therapy (SBRT) have been proven useful for cancer treatment in the case of small tumor size. SRS and SBRT use a hypofractionation technique where a large radiation dose per fraction is delivered allowing a short overall treatment time [1], [2]. While SRS and SBRT have many advantages, errors in delivery can lead to serious consequences such as poor tumor coverage or normal tissue toxicity. Thus, patient treatment plan needs to be verified thoroughly before delivery of the radiation dose to the patient can occur [3]. Dosimetry in small radiation fields is challenging and complicated because of the loss of charged-particle equilibrium (CPE), occlusion of the radiation source, dose volume averaging and beam perturbations effects in detectors [4]. The requirements of detectors for use in small radiation field dosimetry, including small size, high spatial resolution, minimal density effect of the sensitive volume of the detector and extra cameral volume, are addressed in Kline et al. [5].

Two-Dimensional (2D) silicon diode arrays implemented in radiation therapy quality assurance (QA) applications have a lot of advantages such as real time operation, small size of a single diode and a large dynamic range. However, currently most diode arrays have a detector pitch that is not suitable for routine use in small field applications [6]–[9]. The Centre for Medical Radiation Physics (CMRP) introduced a monolithic high spatial resolution silicon detector called Magic Plate (MP512) with an individual detector element size of 0.5mmx0.5mm and a pitch of 2 mm. A silicon monolithic detector MP512 with a high spatial resolution has a large overall size and requires packaging that can be associated with non-water equivalent materials and air gaps that can affect small field dosimetry measurements.

The air gap has significant impact on small field dosimetry since a loss in charge particle equilibrium depends on the size of the low density cavity [10], [11]. Several studies have shown that the reduction in dose is affected by increasing the air gap size. Charles et al [12] reported on the effect of very small air gaps, less than 1 mm, on small field dosimetry used for stereotactic

treatments. They simulated with Monte Carlo the response of an optically stimulated luminescent dosimeter (OSLD) in a 6mm x 6 mm 6 MV photon field. A dose reduction of about 5% for an air gap of 0.5mm upstream of OSLD relative to the simulation with no air gap was observed. A 0.2 mm air gap caused a dose reduction of more than 2%. The authors also noted that the thin air gap can cause a significant reduction in the measured dose. The air gap can be useful for correcting the response of non-water equivalent detectors in small field dosimetry. Charles et al [13] demonstrated that silicon diode overresponse relative to water in small fields can be neutralised by a small upstream air gap which depends on diode design and its packaging. That approach led to the “air diode” concept for stereotactic dosimetry [14].

The main aim of this study was to investigate the effect of the upstream air gap on the response of MP512. Further to this was the optimization of the air gap to match the response of the MP512 to water in small field dose measurements for both photon and electron beams. The signal ratio and the wedge beam profile of the MP512 with different sized air gaps upstream of the MP512 detector for 6 and 10 MV photon beams were measured in comparison with EBT3 films, the MOSkin™, and an Ionization Chamber (IC). Extensive PDD measurements as a function of the air gap upstream of the MP512 in photon and electron beams were also carried out.

2. Materials and Methods

2.1 Magic Plate (MP512) detector array

MP512 is a monolithic silicon detector array manufactured on a bulk *p*-type substrate. The MP512 array consists of 512 pixels with a detector array-element size of 0.5 x 0.5 mm² and pitch 2 mm with an overall dimension of 52 x 52 mm² as shown in Figure 1.

Figure 1. MP512 2D active area wire-bonded to a PCB.

The MP512 monolithic detector is mounted and wire-bonded to a printed circuit board (PCB) 0.5 cm thick and covered by a thin layer of epoxy resin to preserve the silicon detector from moisture and chemical contamination and to protect the wire bonds [15].

Figure 2. Simplified schematic of the MP512 packaging.

Figure 2 shows a schematic diagram of the MP512 packaged between two PMMA slabs.

The air gap thickness between the PMMA slab and the PCB used in this study was adjusted between 0.5 mm, 1.0 mm, 1.2 mm, 2.0 mm and 2.6 mm from the PCB surface. Taking into account the thickness of the silicon substrate is 470 μm , the actual air gap sizes above the MP512 for the

studies described here were therefore 0.03 mm, 0.53 mm, 0.73 mm, 1.83 mm and 2.13 mm. The data acquisition system is described in Fuduli *et al* [16], [17].

2.2 Signal ratio for 6 MV and 10 MV photon beams

2.2A Signal ratio measurement by MP512

The signal ratio (SR) according to [18] formalism is defined as the ratio of central axis MP512 readings for field size ranging from $0.5 \times 0.5 \text{ cm}^2$ to $10 \times 10 \text{ cm}^2$ and for the reference square field of side 10 cm [19]. The MP512 was placed on a solid water phantom at the depth of 10 cm with an additional 10 cm of solid water to act as back scatter and was aligned at the center of the beam as show in Figure 3.

Figure 3. The signal ratio measurement setup of Magic Plate 512 with various detector air gaps.

The size of the air gap was set at 0.5, 1.0, 1.2, 2.0 and 2.6 mm. The signal ratio was measured for square fields ranging from 0.5×0.5 to $10 \times 10 \text{ cm}^2$ and deduced based on the response of the central pixel which is located at row 11 and column 12. The measurements were performed in 6 and 10 MV photon beams with a 600 cGy/min dose rate. 100 cGy was delivered with open field multi-leaf collimator (MLC). Each measurement was the average of at least three repetitions

of the same measure and error bars were calculated as one standard deviation. Measurements were compared with EBT3 films and MOSkinTM response under the same conditions.

2.2B Signal ratio measurement by EBT3 film

The Gafchromic EBT3 film (ASHLAND, Wayne, NJ) sheet was cut into 3 x 3 cm² for the dose calibration and 5 x 5 cm² for signal ratio measurement. To characterise the response of the film, dose calibration measurements were performed. The full back scatter condition was set with 10 cm thick of solid water. The film was positioned at 1.5 cm depth ($d_{\max}$) in a solid water phantom and aligned at the beam centre. Each film was calibrated by exposing 6 MV photon beam with the field size of 10 x10 cm², the dose ranging from 0 – 40 Gy. The EBT3 calibration curve was generated by fitting an optical density vs dose with the secondary order polynomial function as presented in equation below [20], [21].

$$Dose = A + Bx + Cx^2$$

The standard deviations were determined from the repetition of the fitting process across the film scan image sets associated with fitting constants A, B and C with error σ_A , σ_B and σ_C , respectively.

To measure the signal ratio for the 6 MV and 10 MV photon beams, each film was placed at depth of 10 cm in solid water phantom. The SSD was set at 90 cm. The signal ratio measurements were performed for the same field sizes as for MP512 and 400 cGy was delivered for all field sizes. After irradiation, the film was left for at least 48 hrs for full development at the unexposed UV area to avoid any possible darkening of the film [22]. An Epson Expression 10000XL was used for the film read out. In order to warm up the scanner and for better film analysis consistency, each film was scanned six times and the last three scan were kept for analysis [21]. The film was positioned at the centre of the scanner (Microtex ScanMaker i800) and was scanned in 48bit RGB colour mode; only the red channel was used to dose conversion with 70 dpi scanning resolution. All films were placed in the same orientation to minimize any uncertainties. Film images were

analysed with two software tools including the Image J version 1.48v (National Institute of Health) and MATLAB (The Math Works Inc., Natick, MA). The optical density (OD) of the film per pixel value was converted to the dose in cGy related to the calibration curve by the following equation [23] where I is intensity and I₀ is background intensity. The values were measured from image pixel values of the film scan with associated statistic error σ_I and σ_{I0}.

$$OD = \log\left(\frac{I_0}{I}\right)$$

The final error in the calculated dose and the measure quantities of I, I₀ and the fitting constant of the second order polynomial was calculated from the equation below [15].

$$(\sigma_{Dose})^2 = \left[\left(\frac{B}{I_0 \times \ln 10} + \frac{2C \times \ln\left(\frac{I_0}{I}\right)}{I_0 \times \ln^2 10} \right) \sigma_{I_0} \right]^2 + \left[\left(\frac{-B}{I \times \ln 10} + \frac{-2C \times \ln\left(\frac{I_0}{I}\right)}{I \times \ln^2 10} \right) \sigma_I \right]^2 + [\sigma_A]^2 + \left[\left(\log_{10}\left(\frac{I_0}{I}\right) \right) \times \sigma_B \right]^2 + \left[\left(\log_{10}\left(\frac{I_0}{I}\right) \right)^2 \times \sigma_C \right]^2$$

The average uncertainty calculated across all measurements was approximately 1.98%

2.3C Signal ratio measurement by MOSkin™

The MOSkin™ is a Metal-Oxide-semiconductor Field-Effect Transistor (MOSFET) designed for skin dosimetry. The detector has a water equivalent depth of 0.07mm [22]. It is packaged in tissue equivalent material to avoid any beam perturbation effects from high Z materials. The MOSkin™ measurements of the signal ratio were performed in both 6 MV and 10 MV photon beams using the same Varian 21EX medical linear accelerator (Linac) used for MP512 and EBT3 film measurements. The MOSkin™ detector was placed at the centre of the beam at a depth of 10 cm in solid water phantom with an addition 10 cm of solid water back scatter. The SSD was set at 90 cm, and 50 cGy was delivered. The radiation field size was varied from 0.5 x 0.5 cm² to 10 x 10 cm². The difference between two threshold voltage values, ΔV_{th}, was calculated

to find the measured absolute dose using the following equation after initial calibration in a 10 x 10 cm² field at 1.5 cm depth [23].

$$Sensitivity = \frac{\Delta V_{th} (mV)}{Dose (cGy)}$$

Each measurement was the average of at least three repetitions of the same measure and error bars were calculated as one standard deviation. The signal ratio responses were normalized to 10 x 10 cm² field size.

2.2 Percentage Depth Dose (PDD) for 6 MV and 10 MV photon beam.

The PDD profiles were acquired using different air gap sizes upstream of MP512 detector. The air gaps used for the 6 MV photon beam was 0.5 mm and 2.6 mm and for the 10 MV photon beam they were 1.2 mm and 2.6 mm. The MP512 was placed perpendicular to the direction to the central axis (CAX) of the beam at an SSD of 100 cm for field size of 2 x 2 cm², 5 x 5 cm² and 10 x 10 cm². The PDDs were obtained by scanning the MP512 from a depth of 0.5 cm to 20 cm. The PDDs were normalized to the MP response at the depth of d_{max} for all photon energies investigated. For all irradiation geometries, 100 cGy was delivered with a 600 cGy/min dose rate. The PDD measured by the MP512 with different air gaps were directly compared with the PDD response measured by a Markus IC for field sizes of 10 x 10 cm² and 5 x 5 cm² while for the field size of 2 x 2 cm² the results were compared to the EBT3 films.

2.3 Wedge beam profile for 6 MV photon beam

Wedge beam profile measurements were done using a 5x5 cm² radiation field size which was the smallest field the Linac can generate for wedge field. The MP512 was placed at a depth of 10 cm in solid water phantom and aligned on the central axis of the beam. The EDW of 15°, 45° and 60° were generated by Varian Linac (model 2100IX). 100 cGy was delivered at 100 cm SSD for each wedge angle for a 6 MV photon beam. The air gap sizes of 0.5 mm and 2.6 mm were

used as part of this particular study. To convert the MP512 response to the dose, the response of the MP512 in a field size of $10 \times 10 \text{ cm}^2$ was measured at d_{max} to deduce a calibration factor. The dose measured by the MP512 was directly compared with the independently calibrated EBT3 film response measurements made under the same conditions.

2.4 Percentage Depth Dose (PDD) for 6 MeV, 12 MeV and 20 MeV electron beams

The PDD measurements in electron beam fields were performed in the same solid water phantom. The SSD was set to 100 cm. A $10 \times 10 \text{ cm}^2$ applicator and a standard cerrobend cutout of $10 \times 10 \text{ cm}^2$ were used to define the electron field dimensions. The MP512 was placed in the solid water phantom and aligned at the center of the beam. The measurements were performed at the depth of 0.5 cm to 10 cm in a solid water phantom. The results were investigated for 6 MeV, 12 MeV and 20 MeV electron beams with air gap sizes of 0.5 mm and 2.6 mm.

3. Results

3.1 Signal ratio for 6 MV and 10 MV photon beams

Figure 4 and Figure 5 show the signal ratio measured by MP512 at a depth 10 cm in solid water phantom for different air gaps above detector compared to the EBT3 film and MOSkinTM (with no air gap above them) normalized to the response measured in a $10 \times 10 \text{ cm}^2$ field size, for 6 MV and 10 MV, respectively. For 6 MV, the MP512 with the air gap of 0.5 mm shows good agreement to the signal ratio measured with the EBT3 film and MOSkin within $\pm 2\%$ (1 SD). The MP512 response with air gap size of 1.2 mm best matched the signal ratio measured with the EBT3 and MOSkinTM within $\pm 2\%$ (1 SD) for 10 MV photon beam fields.

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(a)

(b)

(c)

(d)

(e)

Figure 4. Signal ratios of MP512, EBT3 film and MOSkinTM for a 6 MV photon beam, normalized to the response measured in a 10 x 10 cm² field size at a depth 10 cm in a solid water phantom for different air gaps of (a) 0.5 mm, (b) 1.0 mm, (c) 1.2 mm, (d) 2.0 mm and (e) 2.6 mm. Error bars were calculated as 1 standard deviation over the repetitions of each measure.

(a)

(b)

(C)

(d)

(e)

Figure 5. Signal ratios of MP512, EBT3 film and MOSkinTM for a 10 MV photon beam normalized to the response at 10 x 10 cm² field size at a 10 cm depth in a solid water phantom and air gap of (a) 0.5 mm, (b) 1.0 mm, (c) 1.2 mm, (d) 2.0 mm and (e) 2.6 mm. Error bars were calculated as 1 standard deviation over the repetitions of each measure.

3.2 Percentage Depth Dose (PDD) for 6 MV and 10 MV photon beams

Figure 6 and Figure 7 show the PDD measured with the MP512 in a solid water phantom for 0.5 mm, 1.2 mm and 2.6 mm air gap upstream of the detector for different field sizes in comparison with a Markus IC for 6 MV and 10 MV photon beams, respectively. All reading from the Markus IC were corrected for over response by using the corrected factor given by Chen et al [24]. Similar results were observed for field size of 5x5 cm² and 10x10 cm² where the response reduces with increasing air gap above the detector. The PDD for the 2x2 cm² field was within $\pm 3\%$ (1 SD) of the EBT3 for both photon energies. The PDD measured with the MP512 was within $\pm 1.6\%$ (1 SD) and $\pm 1.5\%$ (1 SD) of that measured using a Markus ionization chamber (IC) for 6 and 10 MV beams respectively.

(a)

(b)

(c)

Figure 6. 6 MV beam: PDD measured with 0.5 mm and 2.6 mm air gap above MP512 of in comparison with an ionization chamber and EBT3 film for field sizes of (a) 10x10 cm², (b) 5x5 cm² and (c) 2x2 cm². Error bars do not exceed symbol size.

(a)

(b)

(c)

Figure 7. 10 MV beam: PDD measured with 1.2 mm and 2.6 mm air gap above the MP512 in comparison with an ionization chamber and EBT3 film for field sizes of (a) 10x10 cm², (b) 5x5 cm² and (c) 2x2 cm². Error bars do not exceed symbol size.

3.3 Wedge beam profile for photon beams

Figure 8 shows the beam profile measured in the wedge direction at a depth of 10 cm for the MP512 with a 0.5mm and 2.6 mm air gap above the detector in comparison with EBT3 film. The EDW dose profile matches well with the EBT3 for the air gap of 0.5 mm, within $\pm 1\%$ (1 SD), except at the toe and heel region where the difference is within $\pm 3\%$ (1 SD) for all wedge angles. The difference increases with increase the air gap size. For the 2.6 mm air gap, the difference on the heel side was observed to be about $\pm 10\%$ (1 SD).

(a)

(b)

(c)

Figure 8. Wedge beam profiles measured with the MP512 with different air gaps in comparison with those measured using EBT3 film at the depth of 10 cm for 6 MV photon beam with a field size of 5x5 cm² (a) 15° Wedges, (b) 45° Wedges and (c) 60° Wedges. Error bars do not exceed symbol size.

3.4 Percentage depth dose (PDD) for electron beams

The PDD measured by the MP512 in electron beams demonstrated no significant effect with increasing air gap above the MP512 for all energies. The correction for use of the plastic phantom for electron depth dose distributions follows the TRS398 instruction [25]. The results for both 0.5 mm and 2.6 mm air gap are within $\pm 3\%$ (1 SD) of similar measurements made using the Markus IC and are shown in Figure 9.

(c)

Figure 9. PDD measured with MP512 and 0.5 mm and 2.6 mm air gap upstream of the detector on electron beams for a field size $10 \times 10 \text{ cm}^2$ in comparison with a Markus ionization chamber in a solid water phantom for electron beam energies of (a) 6MeV, (b) 12MeV and (c) 20 MeV.

Error bars do not exceed symbol size.

4. Discussion

The results obtained in this study showed that the air gap cause a measurable dose reduction for small radiation field sizes due to the loss in electron equilibrium. Based on these findings, we have tried to optimize the air gap size for a 2D monolithic diode array detector 'MP512' for both photon and electron fields.

Figure 4 illustrates that at small field sizes the signal ratio measured with the MP512 reduces with increasing of the detector air gap. A significant effect of the air gap size was observed for a 0.5×0.5 and $1 \times 1 \text{ cm}^2$ field size. The air gap had negligible effect for field size larger than $4 \times 4 \text{ cm}^2$ for the air gap of 0.5 mm, 1 mm and 1.2 mm above the detector. As expected, for small radiation

fields of $0.5 \times 0.5 \text{ cm}^2$ and $1 \times 1 \text{ cm}^2$ the signal ratio reduces with air gap increasing for the 10 MV photon beam as presented in Figure 5. Similar results were observed for the photon beam PDD measurements. As the size of the air gap above the detector increased, the PDD demonstrated a detectable decrease as shown in Figure 6 and Figure 7. The Wedge profiles show that if only the flattened area of the field is considered, the maximum difference between profile and the EBT3 film is within $\pm 1\%$ for small air gap size 0.5 mm for all wedge angles. There is an essential difference in the shape of the wedge profile when a 2.6 mm air gap size is used as illustrated in Figure 8. The depth dose characteristic of the electron beams, ranging from 6 to 20 MeV were not significantly affected by air gap size within the range of those studied as shown in Figure 9.

The air gaps of 0.5 mm and 1.2 mm were the best air gaps for small field dosimetry with the MP512 in 6 MV and 10 MV photon beams, respectively. The methodology we have used for optimizing that air gap of the MP512 was subsequently used for another 2D monolithic silicon detector, the Octa. The MP512 and the Octa differ in the thickness of the silicon substrate, in the topology of their 512 pixels and in the amount of epoxy resin over the active area.

Biasi et al. [26] used an Octa with an air gap optimized for small square fields jaw-defined produced by 6 MV and 10 MV flattened and flattening filter free photon beams and benchmarked its response with a PTW microDiamond and EBT3 films. Signal ratios measured with the dosimeters agreed to within 3% in the whole range of fields investigated (5 mm to 100 mm across).

Biasi et al. [27] used also an Octa with an air gap optimized for circular small fields produced by 6 MV flattening filter free photon beam delivered with a CyberKnife® system and benchmarked its response with a PTW SRS diode (readings corrected with correction factors published in the literature) and Monte Carlo simulations. Signal ratios calculated and measured with the dosimeters agreed to within 3% in the whole range of fields investigated (5 mm to 60 mm across).

Based on these results, and those in the present study, our conclusion is that it is possible to minimize the corrections required in small radiation fields to relate the readings of a 2D monolithic silicon detector by adapting the amount of air gap introduced on top of its active area. As previously suggested by other authors, it would be necessary to verify that the introduced air gap is appropriate under any beam energy and measurement condition [28]. Further study will be dedicated to improving the current understanding of the relationship existing between the required amount of air gap, detector design, beam energy and measurement condition.

5. Conclusion

The MP512 response with different air gaps upstream of the detector in a solid water phantom have been investigated in both photon and electron fields. The results confirmed that MP512 monolithic diode array is suitable for QA of small fields in a phantom. The study showed that the air gap size has a significant effect on small field photon dosimetry due to a loss of electronic equilibrium. The small air gap of 0.5 mm and 1.2 mm was the best air gap for small field dosimetry in 6 MV and 10 MV photon beams, respectively. The effect of air gap on electron beam was not significant due to an electronic equilibrium being fully established and maintained.

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