The angular dependence of a two dimensional monolithic detector array for dosimetry in small radiation fields

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Abstract. The purpose of this study is to investigate the directional dependence of a two dimensional monolithic detector array (M512) under 6 MV photon irradiation and to evaluate the effect of field size on angular dependence. Square fields of sizes: 3x3 cm^2 and 10x10 cm^2 were measured at the iso-centre of a cylindrical phantom. Beam angles with incidences from 0^0-180^0 in increments of 15^0 were used to investigate the central pixel angular response of M512, normalized to the pixel response for normal (0°) beam incidence. The angular response of the detector was compared to the response of EBT3 radiochromic film in the identical geometric orientation. The maximum angular dependence was observed at the angle 90°±15° to be -18.62% and -17.70% for the field sizes 3x3 cm^2 and 10x10 cm^2, respectively. The angular dependence of M512 showed no significant difference between field sizes of 3x3 cm^2 and 10x10 cm^2 ($p>0.05$). The maximum dose difference measured by the central pixel of M512 and EBT3 for all angles are -20% for 3x3 cm^2 field size and -18.58% for the 10x10 cm^2 field. The diode array's size and packaging effects the angular response of the detector. The angular correction factor is necessary to apply to increase accuracy in dosimetry for arc treatment delivery.

1. Introduction
Advanced external beam radiotherapy (EBRT) techniques such as stereotactic body radiotherapy (SBRT) and volumetric modulated arc therapy (VMAT) have been increasingly used in the treatment of cancer patients. Due to their delivery complexity, with small beamlets and high dose gradients modulated throughout the rotation of the gantry around the patient, the accuracy of patient verification before treatment becomes very important. Small field dosimetry introduces significant complications for simulations and measurement because of electronic disequilibrium and other factors [1]. The ideal dosimeter for the verification of a dose distribution requires a small sensitive volume, high spatial (submillimetre) resolution, energy independence, dose rate independence and tissue equivalence [2-5].

The diode is a widely used radiation detector for small field dosimetry due to their suitable characteristics such as high sensitivity compared with the ionization chamber, small active volume size, high spatial resolution and real time measurement. However, the limitations of the diode include: energy dependence, dose rate dependence, and angular dependence [6]. Paul et al [7] studied the directional response of the surface p-Si type diode, they found the sensitivity varies within ±12% for incident beam angles from 0°-180°. Due to the effects of detector configuration and materials, similar trends in the

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angular response of n-Si type diode arrays has been reported. The response of MapCHECK (SunNuclear, Melbourne, Florida-USA) showed significant difference of up to 20-30% at the incident beam angle of 90° for a 6 MV photon field when compared with a cylindrical ionization chamber [7, 8]. The Centre for Medical Radiation Physics (CMRP) has developed the two dimensional monolithic silicon detector array named MagicPlate-512 (M512) for dosimetry of small radiation fields with spatial resolution 2 mm, an improved spatial resolution relative to commercial diode arrays. Although, the dosimetric characterisation of M512 in term of percentage depth dose and dose per pulse dependence has been completed and shows that the M512 is suitable for use as a quality assurance detector in small radiation fields [10], the angular response of the M512 detector for dose verification in arc therapy delivery has to be studied. The purpose of this study is to investigate the angular response of the M512 detector to 6 MV photon beam irradiation for different field sizes.

2. Materials and Methods

2.1. M512 and Data Acquisition system

The M512 is a two-dimensional monolithic detector array comprised of 512 active square pixels each with size 0.5 x 0.5 mm^2 and 2 mm pixel pitch. The detector is fabricated on a bulk p-type silicon substrate with thickness 470 µm and an active area of 52 x 52 mm^2. The M512 is wire bonded to a 500 µm thick printed circuit board (PCB) that provides the connection for the pixels to the readout electronics. To avoid mechanical damage, the detector array has been covered with a thin protective epoxy layer. The M512 was placed on a 5 mm thick PMMA slab and covered with a PMMA top providing a 1 mm air gap (figure 1) to maximize the detector response relative to radiochromic film for small normally incident radiation fields similar to the "air diode" [11].

The charge generated by the radiation beams in the M512 pixels was read out with a data acquisition (DAQ) system based on a multichannel (64 channel) electrometer chip, AFE0064 (Texas Instrument). The system provides accurate measurements of charge because each current integrator is equipped with a double sampler for the baseline [12]. The AFE chip enable simultaneous measurement of 512 channels and are connected to a series of analogue to digital converters (ADC), synchronized with the linac electron gun pulses and read out using a field programmable gate array (FPGA). The data is transferred from the DAQ to an in-house software interface named Magic Suite on a host computer via USB2.0 communication protocol.

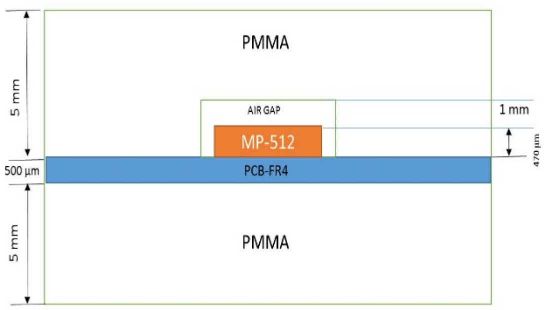

Figure 1. The cross section schematic diagram of the M512 packaging (not to scale).

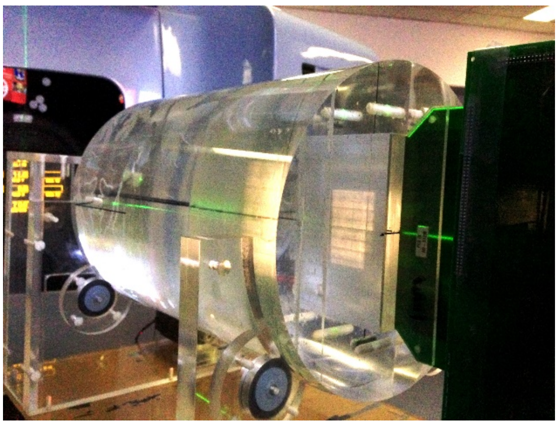

Figure 2. The Experimental setup for measurement of the angular response of M512 inside the cylindrical PMMA phantom.

2.2. Angular dependence

The M512 array was placed at the iso-centre of a cylindrical PMMA phantom with a diameter of 30 cm. The detector was set in a vertical position to avoid attenuation from the couch (figure 2) and the front surface of the detector was aligned perpendicular to the iso-centre of the radiation beam at the gantry angle 270° (incident beam angle zero). The angular response measurements were performed for square fields of sizes 3x3 cm^2 and 10x10 cm^2 using a 6 MV photon beam. A fixed dose of 100 monitor units (MU) at a dose rate of 600 MU/min was delivered for each incident beam angle from 0° to 180° in 15° increments. The angular response of M512 was determined to be the ratio over an average of the responses of 4 central pixels at a certain angle, normalized to the same pixels' response at the incident angle zero. The directional response and beam profiles acquired by the M512 were compared with EBT3 films which were irradiated at the same geometric orientation for angles 0°, 45°, 90°, 135° and 180°**.**

3. Results

The full-width at half maximum (FWHM) of the beam profiles between EBT3 and M512 at incident angle zero are in good agreement, within ±2%, and the penumbral width agrees within less than 1 mm (not presented in this paper)). Figure 3 shows the significant difference in angular response at the central pixels for M512 compared to EBT3 film. The maximum difference was found at the incident angle 90° to be -20% and -18.58% for a field size of 3 x 3 cm^2 and 10 x 10 cm^2, respectively. In addition, the relative response of M512 which is normalized at the incidence angle zero showed less angular dependence for the angles between 0°- 45° but showed a response change of -19% for the 3 x 3 cm^2 field size and -17.70% for 10 x 10 cm^2 field at incident angle 90^0-105^0. However, the results showed no significant difference between the reference field size (10 x 10 cm^2) and a field size of 3 x 3 cm^2 ($p>0.05$) (Figure 4).

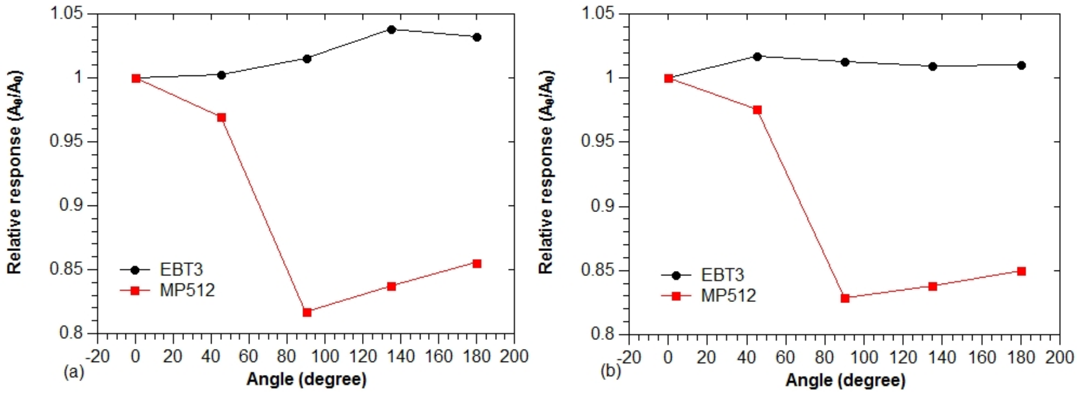

Figure 3. The comparison of the central pixel response between M512 and EBT3 for 6 MV (a) Field size 3x3 cm^2, (b) Field size 10x10 cm^2.

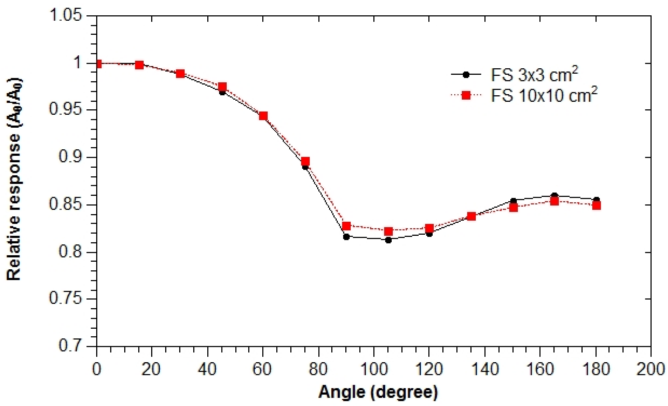

Figure 4. The angular response of a field size of 3x3 cm^2 and a field size of 10x10 cm^2.

4. Discussion and Conclusion

Although verification at gantry 0° tends to be appropriate for IMRT techniques [13], verification of treatments using complicated EBRT techniques such as VMAT and SBRT, which modulate small beamlets and gantry speed during irradiation around the patient, should be conducted considering all conditions including the beams angle of incidence. The detection of a tiny error in MLC leaf position and speed which may be transferred from the treatment planning system needs to be verified for each gantry angle in real time or retrospectively. The angular dependence of a detector must be of concern to ensure the accuracy of quality assurance. This study set out with the aim of assessing the angular dependence of a two dimensional monolithic detector array M512 and the effect of field size on its directional response.

The M512 detectors angular dependence increased as the magnitude of the incident angle increased, but showed a maximum dependence at an incident beam angle of 90°. These results are in agreement with earlier studies [7-9]. A possible reason to explain this phenomenon is the anisotropic configuration of the M512 packaging and the large size of the silicon crystal. The different material interfaces and shapes cause a variable scattering of electrons and photons into the active volume of the detector [14, 15]. The interesting result of this study found that the angular dependence of M512 showed no significant difference between a small field size of 3x3 cm^2 and the reference field size of 10x10 cm^2. However, this result has been determined through the investigation of only these two field sizes. Further field sizes should be investigated. The present results are significant to apply to the M512 for patient verification in arc therapies.

The angular correction factor is necessary to apply when using the M512 as a quality assurance tool that is easy to do as an inclinometer is providing the gantry angle continuously. Further work will be directed to clinical implementation of M512 in arc delivery verification.

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6. Reference

[1] Das I J *et al* 2008 *Med. Phys.* **35** 206
[2] Wuerfel J U 2013 *Medical Physics International* **1** 81-90
[3] Hill R F *et al* 2008 *Rad. Meas.* **43** 1258-64
[4] Greer P B *et al* 2007 *Med. Phys.* **34** 4389-98
[5] Hill R *et al* 2010 *Med. Phys*. **37** 4355-63
[6] Wol T 1998 *Brit. J. Rad.* **71** 1168-77
[7] Jursinic P A 2009 *Med. Phys.* **36** pp. 2165-71
[8] Li Q L *et al* 2010 *Chinese Journal of Cancer* **29** 617-20
[9] Jin H *et al* 2014 *J. Appl. Clin. Med. Phys.***15** 80-92
[10] Aldosari A H *et al* 2014 *Med. Phys.* **41** 091707
[11] Charles P H *et al* 2012 *Phys. Med. Biol.* **57** 6947-60
[12] Min S *et al* 2009 (http://www.ti.com/lit/ds/slas672/slas672.pdf)
[13] Stasi M *et al* 2012 *Med. Phys.* **39** 7626-35
[14] Werner B L *et al* 1987 *Med. Phys.* **14** 585-95
[15] Das I J and Kahn F M 1989 *Med. Phys.* **16** 367-75