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SCIENTIFIC PAPER

Measurement and effects of MOSKIN detectors on skin dose during high energy radiotherapy treatment

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Abstract During in vivo dosimetry for megavoltage X-ray beams, detectors such as diodes, Thermo luminescent dosimeters (TLD's) and MOSFET devices are placed on the patient's skin. This of course will affect the skin dose delivered during that fraction of the treatment. Whilst the overall impact on increasing skin dose would be minimal, little has been quantified concerning the level of increase in absorbed dose, in vivo dosimeters produce when placed in the beams path. To this extent, measurements have been made and analysis performed on dose changes caused by MOSKIN, MOSFET, skin dose detectors. Maximum increases in skin dose were measured as 15 % for 6 MV X-rays and 10 % for 10 MV X-rays at the active crystal of the MOSKIN device which is the thickest part of the detector. This is compared to 32 and 26 % for a standard 1 mm thick LiF TLD at 10 × 10 cm^2 field size for 6 and 10 MV X-rays respectively. Radiochromic film, EBT2 has been shown to provide a high resolution 2 dimensional map of skin dose from these detectors and measures the effects of in vivo dosimeters used for radiotherapy dose assessment.

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Introduction

Skin dose can vary quite considerably with the use of high energy X-ray clinical radiotherapy. Many of these changes can be attributed to variations in electron contamination and phantom scatter. Large variations are observed for changes in beam parameters such as field size, the use of beam modifying devices and beam angle of incidence [1, 2] or for changes in the material which may be in the direct or indirect path of the radiation beam in question [3]. During in vivo dosimetry this can include the detectors used such as diodes [4, 5], Thermo luminescent dosimeters (TLD's) [6–9] and MOSFET detectors [10–12]. Often these detectors are only used for a few fractions of the treatment therefore their overall impact on increasing skin dose are minimal in terms of overall radiotherapy skin dose. However, this effect is measureable and non-negligible and requires quantitative information to be gathered concerning the level of increase in skin dose. Little has been quantified concerning the level of increase in absorbed dose, in vivo dosimeters produce when placed in the beams path as these detectors are normally quite small and measurement of their impact is difficult. However with the use of EBT2 radiochromic film, a 2-dimensional dose map of the extra dose delivered to the skin region can be accurately measured on a small scale to quantify dose increase. Devices such as the MOSKIN, MOSFET [13, 14] detector system are designed specifically for skin dose measurement and are also quite thin and minimalistic devices.

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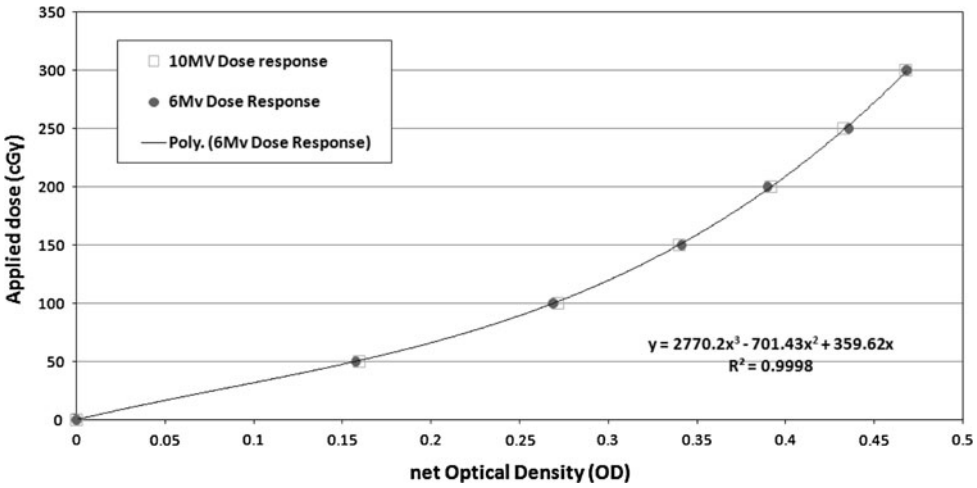


Fig. 1 Calibration curves produced for 6 MV X-rays and 10 MV X-rays as a function of applied dose up to 300 cGy for net Optical density of EBT2 Gafchromic film

The aim of this study is twofold. It is firstly to show that EBT2 Gafchromic film can be used as a high resolution dosimeter for skin dose assessment when required and secondly to show and highlight the increase in skin dose caused by a skin dose detector, namely the MOSKIN, MOSFET dosimetry system on skin dose when used during high energy X-ray radiotherapy applications. This type of information, although assumed to have a relative small increase or impact was not currently available and thus this work has quantified the impact on skin dose of this type of detector. Similar work could be performed on other skin dose detectors which due to their physical size, could have a more substantial impact on skin dose.

Materials and methods

Measurements were made using a Varian 2100iX linear accelerator, 6 and 10 MV X-ray beams and a fixed SSD of 100 cm. Similar patterns in skin dose delivery are expected at other SSD's although it is acknowledged that the magnitude will change mainly due to effects of electron contamination contributions [1, 2, 15–17]. To measure the impact of the MOSKIN, MOSFET dosimetry system detectors on skin dose, the detectors were placed on top of a solid water slab phantom [18] with the radiochromic EBT2 film placed directly behind the MOSKIN detector as to simulate the position of the skin. Field sizes ranging from 5×5 cm^2 up to 20×20 cm^2 were used for irradiations with the 6 and the 10 MV X-ray beams as these fields represent the majority of clinical field sizes used for radiotherapy treatment at our centre. Profile and 2-dimensional map measurements of skin doses were made using EBT2 Gafchromic film [19–21] with the thin surface layer positioned upwards to the radiation beam. In this manner the effective depth of measurement would be approximately 95 μm which is the combination of the over laminate and top adhesive layer thickness and half the thickness value of the active component. All X-ray beams were irradiated perpendicular to the MOSKIN device and phantom. It is acknowledged that for clinical in vivo dosimetry that oblique angles are used as well and the dosimeters would be irradiated at angles other than perpendicular however, the general trend and magnitude will be represented by perpendicular irradiations. As the MOSKIN device is relatively thin (approximately 0.25 mm thick), angular irradiation will not substantially affect the delivered skin dose compared to the perpendicular irradiation and the already known angular effects of irradiation on skin dose [2, 22]. A schematic of the MOSKIN device is shown in [13].

The EBT2 Gafchromic film (ISP Technologies Inc, lot number A08161004) was used and handled as outlined in Butson et al. [23]. During storage and film analysis the films were kept in temperatures of 22 ± 4 °C thus reducing the effects of temperature dependent evolution of the absorption spectra of the film [24]. During analysis no corrections were made for intra film non uniformity. Previous work by Saur et al. [25] has shown that film uniformity has been found to be within 4 % (2SD) for EBT2 film. A schematic of the EBT2 film is shown on ISPCORP's EBT2 product specification web page (ISP, Accessed 2012) [26].

All films were analysed using a PC desktop scanner and Image J software on a PC workstation at least 24 h after irradiation to minimize effects from post irradiation colouration [27]. The films were kept in a light proof container when not being analysed to reduce coloration from ambient light and UV sources [28, 29]. The scanner used for quantitative analysis of uniformity was an Epson Perfection V700 photo, dual lens system desktop scanner using a scanning resolution of 50 pixels per inch. The images produced were 48 bit RGB colour images and analysis was performed using the red component of the data. The films were examined in reflectance mode with a matt white backing paper to minimise scanner non uniformity and improve accuracy [30]. In reflectance mode, Reflective

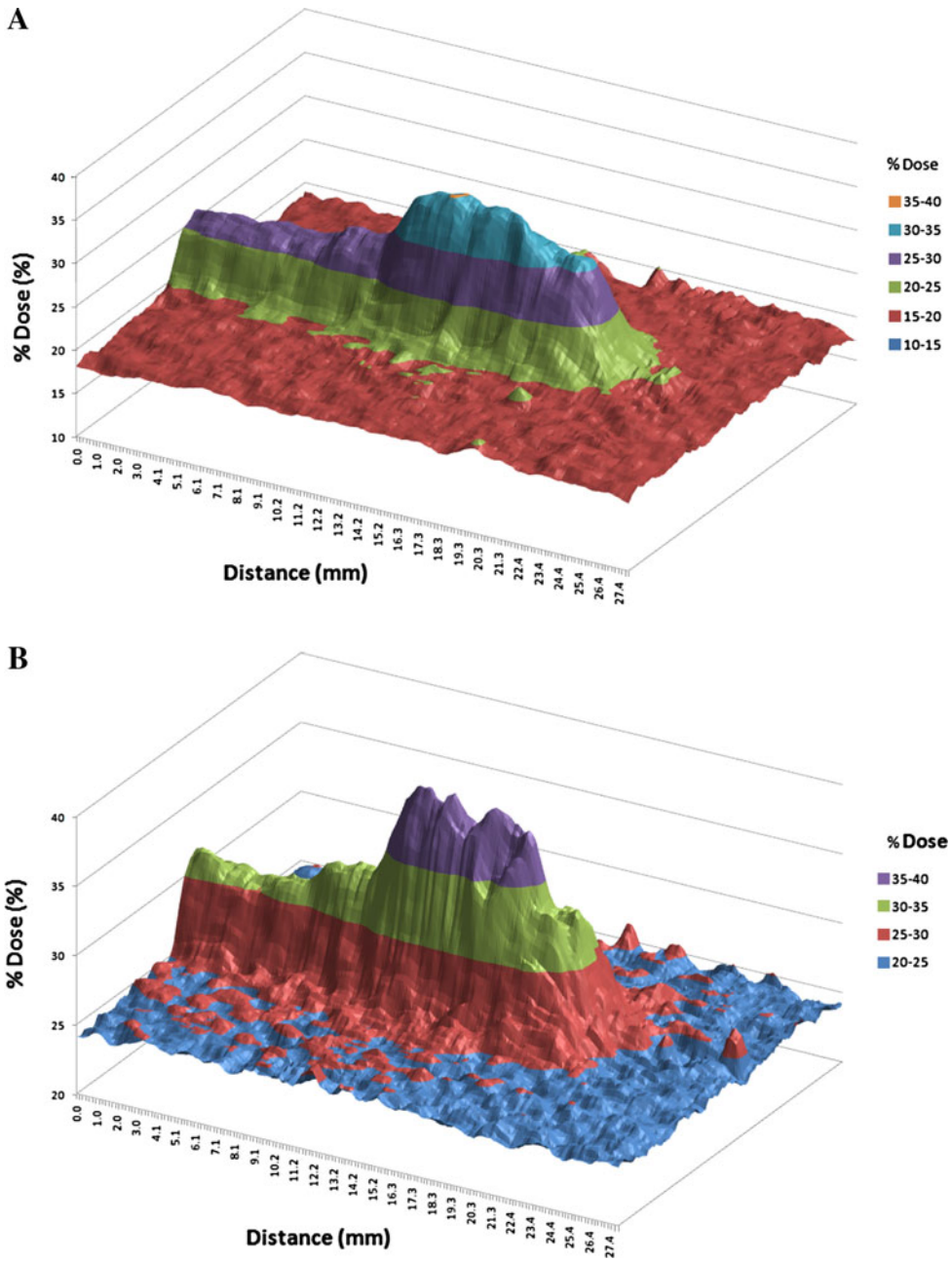


Fig. 2 Two dimensional map of skin dose measured around a MOSKIN detector for differing fields sizes for 6 MV X-rays. Field sizes are **a** 5 × 5 cm^2, **b** 10 × 10 cm^2, **c** 15 × 15 cm^2 and **d** 20 × 20 cm^2

optical density (ROD's) for all films were calculated to evaluate uniformity response in landscape and portrait directions. ROD is defined as Eq.1:-

$$\mathrm{ROD} = \log(65536/P_t) \quad (1)$$

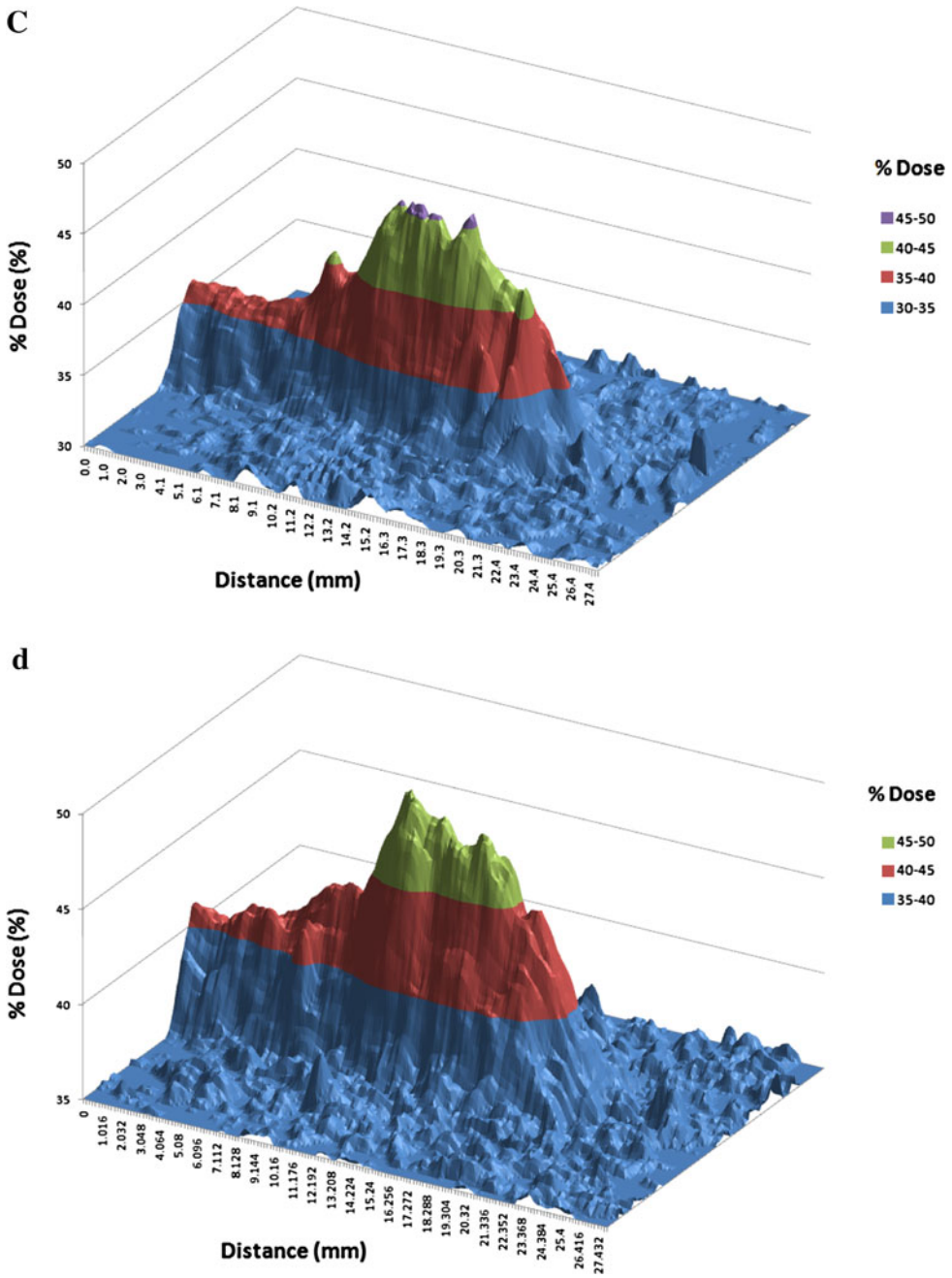
where P_t is the pixel value of the reflected intensity through the EBT film.

The films when scanned were always positioned in the scanner, landscape orientation to eliminate differences in results caused by film polarisation effects [31, 32]. For data analysis the outer 1 cm edge of the scanned film results were removed. This was performed to minimize any effects on scanner results from film edges or cutting damage [33]. Results given are the average for 5 scans of each film piece. Experiments were repeated 5 times for analysis using different films with results shown as the average of 5 scans for 1 film piece. No substantial variation in uncertainty or results were seen over the 5 experiments performed.

Results and discussion

Figure 1 shows the calibration curve and fit to results for the calculation of skin dose using EBT2 Gafchromic film.

Fig. 2 continued



As can be seen a 3rd order polynomial adequately predicts the measured dose for standard irradiations. This equation is then applied to measured film results with the MOSKIN detector placed above the film for 6 and 10 MV irradiations. Separate calibration curves were produced for both 6 and 10 MV results with the 6 MV results shown here. Both calibration curves were very similar due to the low energy dependence of the EBT2 film to X-rays [29].

Figure 2 shows the results for skin dose (effective depth 95 μm) measured for 6 MV X-rays with field sizes of (a) 5×5 cm^2, (b) 10×10 cm^2, (c) 15×15 cm^2 and (d) 20×20 cm^2. As can be seen in all cases, the skin dose directly around the MOSKIN device has increased and is measured with a high level of spatial resolution by the EBT2 film detector. The effective depth of measurement has been calculated to 95 μm which is consistent to a depth close to the epithelial level where early skin reactions can occur. Results show that within the treatment field the skin dose on average is approximately 20, 25, 31, and 36 % in areas not underneath the MOSKIN detector for 5, 10, 15, and 20 cm field sizes respectively and this increases to a maximum of approximately 35, 40, 45, and 49 % underneath the MOSKIN device in a location which is matched to the active crystal of the detector. It is at this position

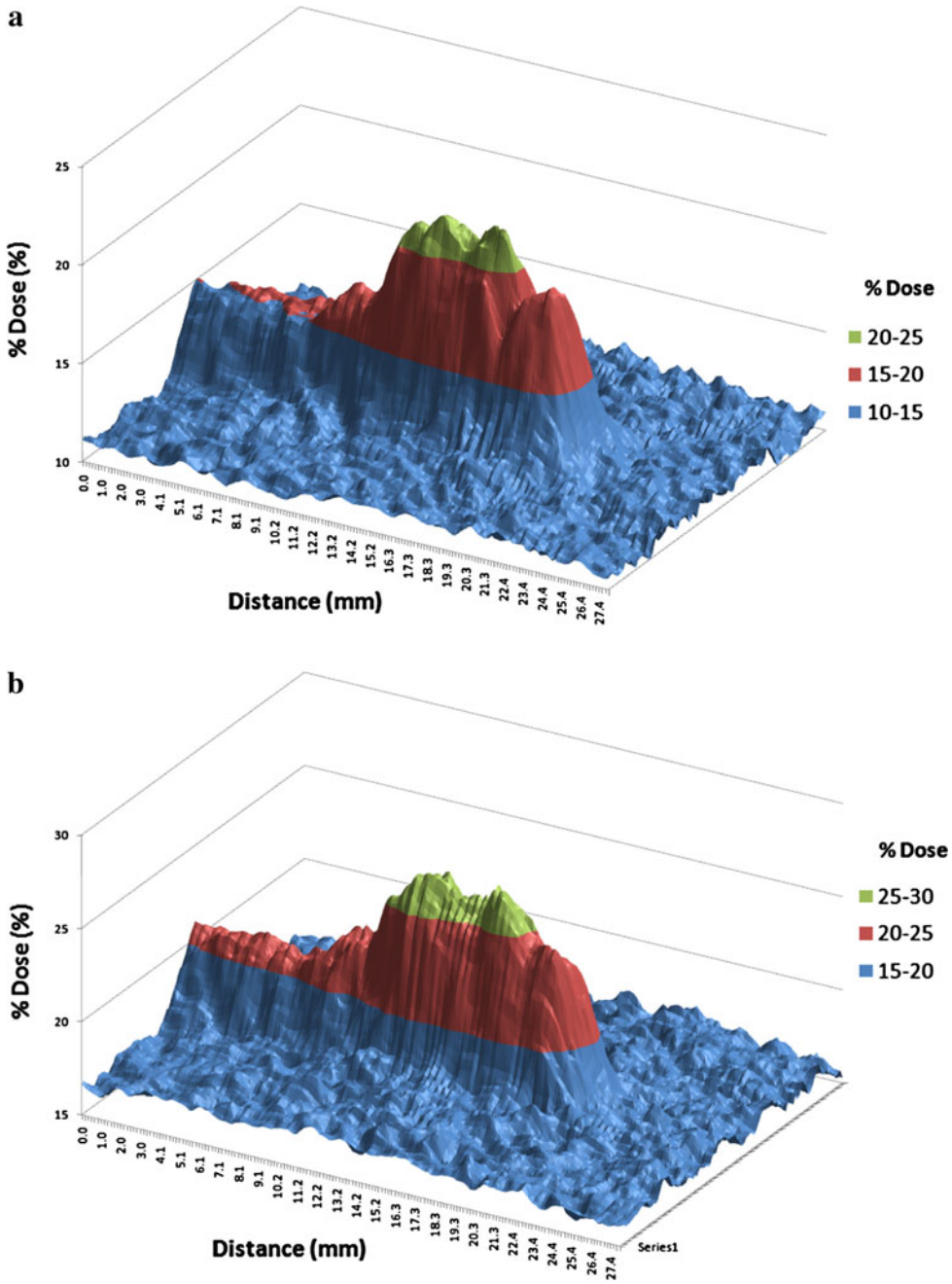


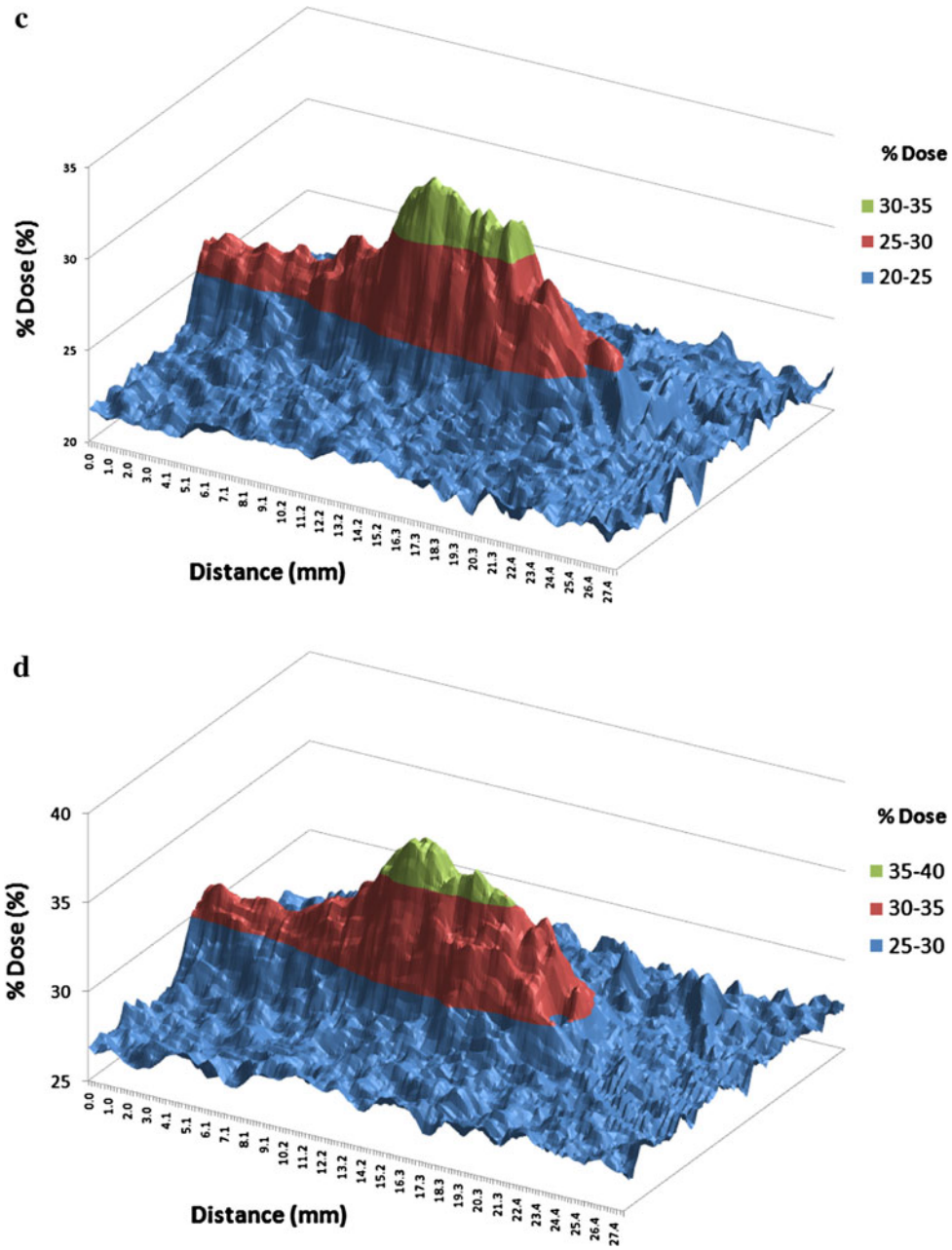
Fig. 3 2 dimensional map of skin dose measured around a MOSKIN detector for differing fields sizes for 10 MV X-rays. Field sizes are **a** 5 × 5 cm^2, **b** 10 × 10 cm^2, **c** 15 × 15 cm^2 and **d** 20 × 20 cm^2

where the MOSKIN device is the thickest and thus accordingly produces the largest increase in skin dose. Interesting to note is that the increase in skin dose is approximately the same for all field sizes, resulting in an average maximum increase in skin dose under the MOSKIN of 14 ± 1 % for a 6 MV X-ray beam.

Figure 3 shows similar results but for a 10 MV X-ray beam. Here results are on average 12, 17, 23, and 28 % for skin dose in field but not under the MOSKIN detectors and 22, 27, 32, and 37 maximum under the detector itself (5, 10, 15, and 20 cm) respectively. This results in an average increase of 9.5 ± 0.5 % percent for the 10 MV X-ray beam. As a direct comparison, a standard in vivo LiF thermo luminescent detector which is 3 × 3 × 1 mm^2 thick used for clinical in vivo dosimetry in radiotherapy applications produces a point dose increase of 32 % for a 10 × 10 cm field for 6 MV X-rays and a 26 % increase for 10 MV X-rays. As such the MOSKIN device, due to its quite thin design and minimalistic packaging, produces less than half the maximum dose increase for skin dose during in vivo dosimetry.

Of interest in the results is that the MOSKIN device has nearly the same influence on increase in skin dose for all field sizes for both 6 and 10 MV X-ray energies. This is

Fig. 3 continued



shown clearly in Fig. 4a, b which are profile measurements across the centre sensitive crystal of the MOSKIN detector at the various quoted field sizes. Results show that the skin dose increases by approximately 15 ± 1 % for a 6 MV beam and by 9.5 ± 0.5 % for the 10 MV X-ray beam when comparing the skin dose directly under the MOSKIN and in an area not affected by the detector. Dose to this region is contributed to by primary photon dose, phantom scatter photon dose and electron contamination. As such, the change in skin dose occurring is a combination, of the change in all three components mentioned above. Under the MOSKIN device, the skin dose would be increased by the extra material causing more primary photon dose and decreased by the same build up material, absorbing some of the electron contamination. The MOSKIN cable which will also be placed on the patients skin during radiotherapy has the impact if increasing dose as well by approximately 5 % for 6 MV X-rays beams (5–20 cm square fields) and by approximately 3 % for 10 MV X-ray beams for the same field sizes. This is due to its relatively thin design and thus shows its minimal impact of skin dose.

These results show that the MOSKIN device has a minimal impact on skin dose when used for in vivo dosimetry of skin dose in radiotherapy and also shows that EBT2 radiochromic film is an ideal detectors for measurement of high spatial resolution skin dose when

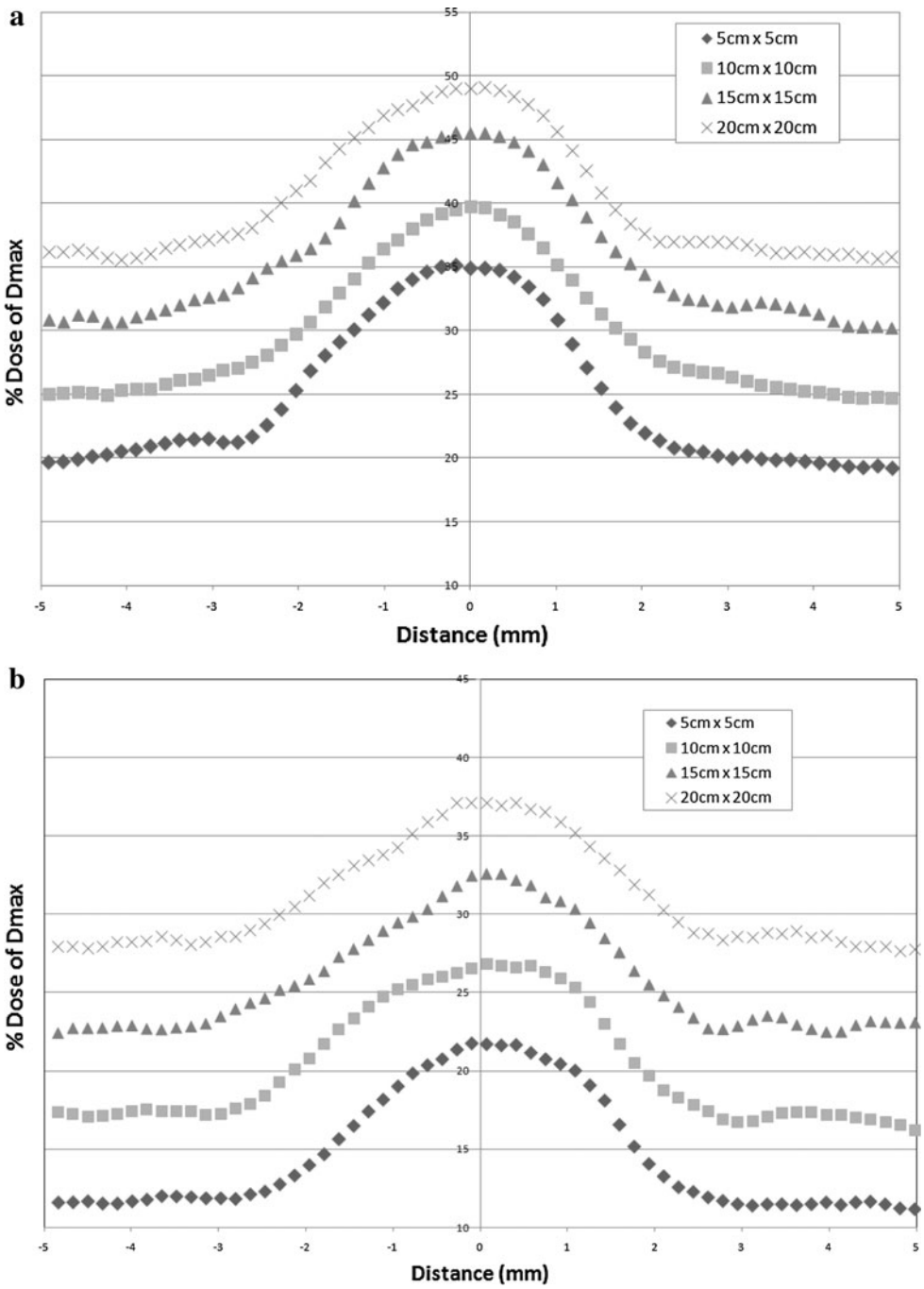


Fig. 4 Skin dose measured across the MOSKIN detectors for field sizes from 5 to 20 cm square measured using **a** 6 MV X-rays and **b** 10 MV X-rays

required. Of course, the EBT2 film has a finite thickness and would also impact or increase the dose delivered to the patient's skin during radiotherapy with this being a uniform increase over the entire area of the film piece. This has been measured (using the same technique as for MOSKIN's in this paper) to be approximately 15 ± 2 % and 12 ± 2 % of Dmax at 10 × 10 cm^2 field size for 6 and 10 MV X-rays respectively, i.e. the increase in skin dose caused by the EBT2 film over its entire region is similar in magnitude to the maximum increase in skin dose produced by the MOSKIN device.

Conclusion

The MOSKIN MOSFET dosimetry system used for in vivo dosimetry is a detector that has minimal impact on increases to skin dose during high energy X-ray radiotherapy. Maximum increases in skin dose were measured as 15 % for 6 MV X-rays and 10 % for 10 MV X-rays at the active crystal of the MOSKIN device which is the thickest part of the detector. This is compared to 32 and 26 % for a standard 1 mm thick LiF TLD at 10 × 10 cm^2 field size for 6 and 10 MV X-rays respectively. Radiochromic film, EBT2 has been shown to

provide a high resolution 2 dimensional map of skin dose from these detectors and measure the effects of in vivo dosimeters used for radiotherapy dose assessment.

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