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IORT dosimetry

Real-time in vivo dosimetry using micro-MOSFET detectors during intraoperative electron beam radiation therapy in early-stage breast cancer

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Abstract

***Purpose*: In a previous paper we reported the results of off-line in vivo measurements using radiochromic films in IOERT. In the present study, a further step was made, aiming at the improvement of the effectiveness of in vivo dosimetry, based on a real-time check of the dose.**

***Materials and methods*: Entrance dose was determined using micro-MOSFET detectors placed inside a thin, sterile, transparent catheter. The epoxy side of the detector was faced towards the beam to minimize the anisotropy. Each detector was plugged into a bias supply (standard sensitivity) and calibrated at 5 Gy using 6 MeV electrons produced by a conventional linac. Detectors were characterized in terms of linearity, precision and dose per pulse dependence. No energy and temperature dependence was found. The sensitivity change of detectors was about 1% per 20 Gy accumulated dose. Correction factors to convert surface to entrance dose were determined for each combination of energy and applicator. From November 2004 to May 2005, in vivo dosimetry was performed on 45 patients affected by early-stage breast cancer, who underwent IOERT to the tumour bed. IOERT was delivered using electrons (4–10 MeV) at high dose per pulse, produced by either a Novac7 or a Liac mobile linac.**

***Results*: The mean ratio between measured and expected dose was 1.006 ± 0.035 (1 SD), in the range 0.92–1.1. The procedure uncertainty was 3.6%. Micro-MOSFETs appeared suitable for in vivo dosimetry in IOERT, although some unfavourable aspects, like the limited lifetime and the anisotropy with no build-up, were found. Prospectively, a real-time action level ($\pm 6\%$) on dose discrepancy was defined.**

***Conclusions*: Excellent agreement between measured and expected doses was found. Real-time in vivo dosimetry appeared feasible, reliable and more effective than the method previously published.**

Keywords: In vivo dosimetry; MOSFET; IORT; Breast cancer; Mobile linear accelerator; Electrons

In a previous paper, we reported the results of in vivo dosimetry using radiochromic films during intraoperative electron beam radiation therapy (IOERT) [6]. The main limitation of that procedure consisted of the delay between the exposure of the films on the patient and the analysis of their response, to achieve colour stability. This issue, combined with the single-shot nature of IOERT, did not give the chance of defining immediate corrective actions. On the contrary, some favourable features of films, such as the independence of their response on the high dose per pulse of electron beams and a negligible perturbation of the radiation field, were shown.

In the meanwhile, an increasing use of radiation detectors based on metal oxide semiconductor field effect transistor (MOSFET) technology was observed, particularly since the commercial introduction of isotropic, dual bias dual MOSFET detectors and for special applications, like as IMRT or peripheral dosimetry [2–3,5,7,11–13,16,19]. The structure of a MOSFET and the theory of operation of the detector have been widely reported elsewhere [5,16,19,21].

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The advantages of such detectors over other available dosimeters, such as TLDs or semiconductors, include immediate readout of the dose, very small active volume and nearly energy and temperature independence [4,11,13,16,19].

More recently, MOSFET detectors manufactured in a miniaturized size (1×1 mm^2, 3.5 mm long), namely Micro-MOSFETs (Thomson and Nielsen, Canada), and even prototypes sealed in implantable capsules and enabling remote readout, have been investigated [1,17,18,20]. Nonetheless, none of them had been extensively tested before in electron beams at very high dose per pulse, such as those produced by the two Italian models (Novac7, Hitesys, Aprilia and Liac, Info & Tech, Roma) of mobile linear accelerator dedicated to IOERT, both available at our Institute.

In the present work, a further step to try to improve the effectiveness of in vivo dosimetry during IOERT with respect to our previously published procedure [6] was made. The aim of this study was to perform a real-time check of the dose delivered to patients undergoing IOERT to the tumour bed for breast cancer.

Materials and methods

Between November 2004 and May 2005, real-time in vivo dosimetry was performed on 45 patients affected by early-stage breast cancer, who underwent quadrantectomy plus IOERT to the tumour bed [14,22]. Exclusive IOERT was delivered in most cases (40 patients), while as an anticipated boost in five cases, with a dose prescription, respectively, of 21 and 12 Gy at the depth of 90% isodose. IOERT was carried out using a dedicated mobile linear accelerator, a Novac7 (31 patients) or a more recently installed Liac (14 patients), each working in an operating room. Electron beams with nominal energies of 5, 7, 9 MeV (R_{50} [9], respectively, equal to 20, 24, 29 mm) for Novac7 and 4, 6, 8, 10 MeV (R_{50}, respectively, equal to 17, 22, 30, 38 mm) for Liac were used. On both machines, hard-docking beam collimation was obtained by means of perspex applicators, 5 mm thick, flat or bevel-ended (15–22.5°). Field diameters ranged between 4 and 5 cm, at a fixed nominal source to skin distance of 80 cm (Novac7) or 60 cm (Liac).

For each patient, the entrance dose, defined as the dose at the depth of maximum, was determined from the dose measured at the body surface using a Micro-MOSFET detector (TN-502RDM, Thomson and Nielsen, Canada). To preserve sterility close to the surgical area, the detector was put inside a thin, sterile and transparent plastic catheter (5 French diameter, 32 cm long, close-ended, commonly used in brachytherapy), placed by the surgeon on central top of the surgical bed (Fig. 1). To enable immediate readout of the dose after the exposure, each detector was plugged into a bias supply, on its turn connected to a reader (MOSFET 20, Thomson and Nielsen). Bias supply was set at standard instead of high sensitivity, to limit the detector consumption at the high doses typically delivered during IOERT. During this investigation, 30 detectors were used.

Each detector was calibrated in a slab solid phantom (RW3, PTW, Germany) under reference conditions (i.e. 10×10 cm^2 field size, 100 cm nominal treatment distance, depth of dose maximum) using 6 MeV electron beams supplied by a conventional linear accelerator (Varian Clinac 2100), on its turn immediately before calibrated following the IAEA TRS-398 Code of Practice [8]. The detector was oriented with its flat side towards the radiation beam (here defined as 0°) and a 0.5 cm thick sheet of bolus material was placed under it to eliminate the slight air gap which would otherwise result. The reproducibility of the response of the detectors was found to improve at increasing doses (varying between 2 and 5%, corresponding to 1 SD, at 1 Gy; 1% at 5 Gy; 0.5% at 10 Gy and 0.3% at 20 Gy), so 5 Gy level was chosen for tests performed on phantom as the best compromise between detector consumption and measurement precision. All measurements were consecutively repeated at least three times and averaged.

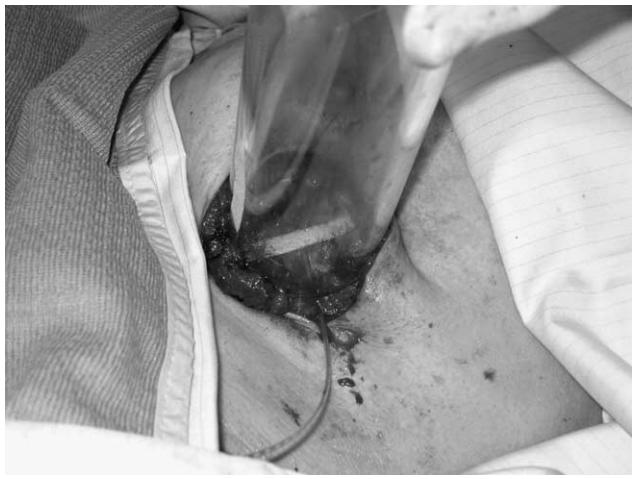

Fig. 1. Photograph showing the sterile catheter, including the micro-MOSFET detector, inside the IOERT field. A narrow strip of sterile adhesive paper is fixed to the applicator base, nearly passing through the beam axis, to prevent catheter folding inside the applicator due to the pressure by the wall of the applicator itself on patient surface. The catheters used for in vivo dosimetry were also modified, by fixing at their distal extremity a small and thin piece of plastic film to better stabilize the catheter above the patient surface.

In a first phase, the basic dosimetric properties of the detectors were investigated using electron beams from Clinac 2100. Linearity in the range 5–25 Gy, beam energy independence between 6 (i.e. the lowest available energy) and 12 MeV and temperature independence in the range 20–40 °C were found within the experimental uncertainty ($\pm$ 1%), consistently with data reported in other works [17,19]. On the other hand, consecutive measurements and spot checks along the lifetime of the detectors (170 Gy) showed that their sensitivity changed by approximately 1% per 20 Gy accumulated dose, as an average, up to 150 Gy, then stabilizing for the remaining 20 Gy. So, we routinely established a re-calibration of each detector, after the initial one, at about 100 Gy and, in the meanwhile, applied the mean correction factor found, as a function of the accumulated dose.

Concerning the directional dependence, the $\pm$2% isotropy declared by the manufacturers and confirmed by literature data [16] is related to the detector under full build-up conditions or at a greater depth, so we analysed the