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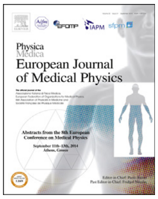

Original paper

Characterization of a microDiamond detector in high-dose-per-pulse electron beams for intra operative radiation therapy

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ABSTRACT

Purpose: To characterize a synthetic diamond dosimeter (PTW Freiburg microDiamond 60019) in high dose-per-pulse electron beams produced by an Intra Operative Radiation Therapy (IORT) dedicated accelerator.

Methods: The dosimetric properties of the microDiamond were assessed under 6, 8 and 9 MeV electron beams by a NOVAC11 mobile accelerator (Sordina IORT Technologies S.p.A.).

The characterization was carried out with dose-per-pulse ranging from 26 to 105 mGy per pulse. The microDiamond performance was compared with an Advanced Markus ionization chamber and a PTW silicon diode E in terms of dose linearity, percentage depth dose (PDD) curves, beam profiles and output factors.

Results: A good linearity of the microDiamond response was verified in the dose range from 0.2 Gy to 28 Gy. A sensitivity of 1.29 nC/Gy was measured under IORT electron beams, resulting within 1% with respect to the one obtained in reference condition under ^{60}Co gamma irradiation. PDD measurements were found in agreement with the ones by the reference dosimeters, with differences in R_{50} values below 0.3 mm. Profile measurements evidenced a high spatial resolution of the microDiamond, slightly worse than the one of the silicon diode. The penumbra widths measured by the microDiamond resulted approximately 0.5 mm larger than the ones by the Silicon diode. Output factors measured by the microDiamond were found within 2% with those obtained by the Advanced Markus down to 3 cm diameter field sizes.

Conclusions: The microDiamond dosimeter was demonstrated to be suitable for precise dosimetry in IORT applications under high dose-per-pulse conditions.

Introduction

Intraoperative radiotherapy (IORT) is a special technique allowing the delivery of a single high radiation dose (9–25 Gy) during the surgical procedure. IORT can be combined with external beam radiation therapy (EBRT) or used as a single radiation dose [1]. This technique has been tested in several different tumour sites, histological types and disease status and its effectiveness has been successfully evaluated in the treatment of breast, rectal, gynaecological and prostate cancer. In the past, IORT technique has been limited because of logistical problems, such as the need for transporting the anesthetized patient to a shielded bunker. With the advent of mobile electron accelerators especially designed for IORT these problems have been overcome. Dedicated commercially available accelerators provide electron beams with energy from 4 MeV to 12 MeV. Such mobile accelerators exhibit relatively different characteristics with respect to the conventional ones. In particular, the main distinctive feature of such accelerators consists in the higher dose per pulse (2–100 mGy/pulse) compared to standard accelerators (≤0.5 mGy/pulse). Such a higher dose per pulse implies a higher dose rate, allowing to deliver high doses in

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short time even with a low number of pulses per second. On the other hand, the high dose rate used by mobile accelerators can affect the accuracy of the dosimetric systems utilized for accelerator commissioning and quality assurance measurements. For instance ionization chambers, that are the most suitable detectors for reference dosimetry in conventional radiotherapy beams [2,3], can overestimate more than 10% the absorbed dose in high-dose-per-pulse electron beams if the standard two-voltage method is used for determining the ion recombination correction factor [4,5].

In IORT beams with dose per pulse larger than 10 mGy per pulse, dosimetric methods independent of dose rate such as ferrous sulphate chemical dosimetry (e.g. Fricke dosimetry) or radiochromic films have been used to obtain a reliable beam output. Indeed, ferrous sulphate dosimetry is dose-rate independent, but it has some disadvantages, such as low spatial resolution and low sensitivity. Moreover, this technique requires specific expertise and equipment. Therefore, calibration of IORT clinical beams based on ferrous sulphate dosimetry is often performed through a mailed dosimetry service provided by a standard laboratory with the inconvenience of a long time for the dose reading after the dosimeter irradiation [6]. These features make the use of ferrous sulphate dosimetry very time consuming and not suitable for relative dose measurements.

Radiochromic films allow the 2D characterization of the field size, shape and uniformity. However, they are sensitive to the temperature and humidity and require accurate calibration procedures. Moreover, the elapsed time between irradiation and readout is as long as about 48 h [7].

Ionization chambers can also be used to perform the dosimetric measurements at dose per pulse larger than 10 mGy per pulse, but charge collection efficiency must be determined taking into account the free electron effects on the charge transport in the air cavity [8,9]. Accordingly, starting from the Boag's et al. work, two methods for determining the ion recombination correction factor, k_s, have been proposed in literature [9,10]. The method described in Di Martino et al. [10] requires an initial cross-calibration of the ionization chamber in the high dose per pulse beams against a dosimetric method independent of dose rate such as the Fricke dosimetry, in order to determine the parameters needed for k_s calculation according to one of the three theoretical models for ion recombination proposed by Boag et al. [8]. The method proposed by Laitano et al. [9] allows to determine k_s numerically solving equations derived from the three theoretical models by Boag et al., using the ionization current measured in the high dose per pulse beam with two different chamber polarizing voltages.

Among available solid state dosimeters, silicon diodes and MOSFET systems have been used in IORT electron beams. Because of their high spatial resolution, silicon diodes are suitable for dose profile measurements and dosimetry of small beams even though possible dose rate and energy dependence should be evaluated [11]. MOSFET systems are dose rate independent [12], however, their accuracy in dose determination is appropriate for in-vivo dosimetry but it is not comparable with that of ionization chambers for commissioning purpose [13].

The dosimetric characterization of IORT beams is therefore a non-trivial and time-consuming procedure, often requiring the use of different detectors. For the above reasons, the availability of a dosimeter not suffering of such limitations would be welcome in medical physicist community.

A novel diamond based dosimeter was recently introduced in the market by PTW Freiburg (microDiamond 60019). Such device was developed at the University of Rome “Tor Vergata” and it is based on a synthetic single crystal diamond Schottky diode [14]. Unlike other synthetic diamond detectors [15], no dose rate dependence has been found for such dosimeter in conventional radiotherapy beams. The microDiamond dosimeter is recommended by the manufacturer for relative dosimetry in large and small electron and photon beams [16–18]. In addition, the microDiamond dosimeters have been recently evaluated for absolute photon dosimetry [19], evidencing its suitability in different radiotherapy techniques such as IMRT, VMAT and proton therapy [20–24].

In this work, a dosimetric characterization of the PTW microDiamond 60019 dosimeter is reported under high-dose-per-pulse electron beams produced by an IORT mobile accelerator.

Materials and methods

IORT accelerator

All measurements reported in the present paper were carried out with 6, 8 and 9 MeV electron beams generated by a NOVAC11 accelerator produced by SIT (Sordina IORT Technologies S.p.A.). The NOVAC11 is a mobile accelerator specifically designed to perform intraoperative radiotherapy. The most relevant features of such an accelerator are the dose rates as high as about 60 Gy/min and the very high dose per pulse, up to about 100 mGy/pulse, which is about 100 times larger than the one by a conventional accelerator. In addition, the present accelerator doesn't have a bending magnet so that a low energy component is always present in the electron beam spectrum.

The output beam was collimated through cylindrical applicators made of PMMA to be fastened to the radiating head. In this work, applicators with diameters of 100 mm, 80 mm, 70 mm, 60 mm, 50 mm, 40 mm and 30 mm were used. In normal operating condition, the applicator is placed in contact with the patient. The interaction of the electron beam with the PMMA applicator generates low energy electrons releasing their energy in a region very close to the surface. This leads to a higher value of the delivered skin dose with respect to conventional accelerators.

Detectors and electrometers

The dosimetric measurements were performed with a microDiamond dosimeter, PTW 60019 (mD), an Advanced Markus ionization chamber, PTW 34045 (AM-IC), and a diode E, PTW 60012 (Si-D), all by PTW Freiburg.

The microDiamond was positioned with its axis parallel to the beam direction as recommended by the manufacturer (vertical orientation). The reference point was assumed to be positioned on the central axis of the device, 1 mm below the detector surface. The utilized microDiamond dosimeter was previously calibrated in terms of absorbed dose to water (D_w) in a reference ^{60}Co gamma beam, at a dose rate of 0.5 Gy/min, and a sensitivity of 1.28 nC/Gy was obtained.

The Advanced Markus is a well-guarded plane parallel ionization chamber, with an air cavity diameter of 0.5 cm and electrodes spacing of 1 mm, suitable for high energy electron measurements in water and plastic phantoms. The chamber reference point is located 1.3 mm (0.106 g cm^{-2}) below the external surface of the chamber waterproof protection cap. In accordance with the IAEA TRS 398 code of practice [2] the chamber was positioned with its reference point at the measurement depth in water, taking into account the non-water equivalence of the chamber entrance window including the waterproof cap (i.e. the effective point of measurement was shifted 0.24 mm from the reference point towards the source).

In the present work the AM-IC was used as reference dosimeter for establishing the accelerator output. The chamber was calibrated in terms of absorbed dose to water in a reference ^{60}Co gamma beam and beam quality correction factors, k_Q, provided by the

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