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Characterization and use of a 2D-array of ion chambers for brachytherapy dosimetric quality assurance

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ABSTRACT

The two-dimensional (2D) ionization chamber array MatriXX Evolution is one of the 2D ionization chamber arrays developed by IBA Dosimetry (IBA Dosimetry, Germany) for megavoltage real-time absolute 2D dosimetry and verification of intensity-modulated radiation therapy (IMRT). The purpose of this study was to (1) evaluate the performance of ion chamber array for submegavoltage range brachytherapy beam dose verification and quality assurance (QA) and (2) use the end-to-end dosimetric evaluation that mimics a patient treatment procedure and confirm the primary source strength calibration agrees in both the treatment planning system (TPS) and treatment delivery console computers. The dose linearity and energy dependence of the 2D ion chamber array was studied using kilovoltage X-ray beams (100, 180 and 300 kVp). The detector calibration factor was determined using 300 kVp X-ray beams so that we can use the same calibration factor for dosimetric verification of high-dose-rate (HDR) brachytherapy. The phantom used for this measurement consists of multiple catheters, the IBA MatriXX detector, and water-equivalent slab of RW3 to provide full scattering conditions. The treatment planning system (TPS) (Oncentra brachy version 3.3, Nucletron BV, Veenendaal, the Netherlands) dose distribution was calculated on the computed tomography (CT) scan of this phantom. The measured and TPS calculated distributions were compared in IBA Dosimetry OmniPro-I'mRT software. The quality of agreement was quantified by the gamma (γ) index (with 3% delta dose and distance criterion of 2 mm) for 9 sets of plans. Using a dedicated phantom capable of receiving 5 brachytherapy intralumenal catheters a QA procedure was developed for end-to-end dosimetric evaluation for routine QA checks. The 2D ion chamber array dose dependence was found to be linear for 100–300 kVp and the detector response (k_{user}) showed strong energy dependence for 100–300 kVp energy range. For the Ir-192 brachytherapy HDR source, dosimetric evaluation k_{user} factor determined by photon beam of energy of 300 kVp was used. The maximum mean difference between ion chamber array measured and TPS calculated was 3.7%. Comparisons of dose distribution for different test plans have shown agreement with >94.5% for $\gamma \leq 1$. Dosimetric QA can be performed with the 2D ion chamber array to confirm primary source strength calibration is properly updated in both the TPS and treatment delivery console computers. The MatriXX Evolution ionization chamber array has been found to be reliable for measurement of both absolute dose and relative dose distributions for the Ir-192 brachytherapy HDR source.

Introduction

High-dose-rate (HDR) brachytherapy has proven to be a highly successful radiation treatment in the management of different types of cancers. Recently, HDR brachytherapy has seen innovation and advances in treatment techniques, imaging technology, and 3D treatment planning systems (TPSs). The brachytherapy TPS is an important component of the radiation treatment process, and 3D image-based TPSs have been increasingly used in most radiotherapy facilities. One of the challenges involved in the implementation of a new brachytherapy TPS into a clinical environment is verifying the dose calculation accuracy. In modern brachytherapy TPSs, many approaches can be taken during the planning process and optimization to arrive at a final plan. The complex nature of the treatment planning process makes it essential to have dose verification, especially during commissioning and quarterly quality assurance. The dose distribution generated by the TPS using the AAPM TG-43 dose formalism[1] is usually compared with the calculations using the Sievert summation,

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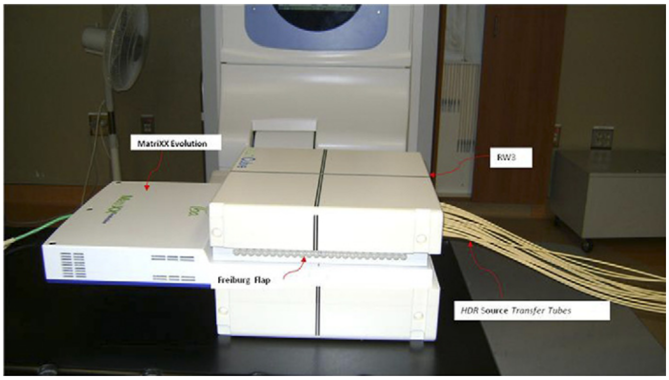

Fig. 1. The CBCT scan and measurement setup of IBA MatriXX Evolution. RW3 (thickness of 0, 1.0, 2.0 cm) added between the Freiburg Flap and the detector array.

Monte Carlo simulation, or dose distributions measured with Gafchromic film.[2] Gafchromic film is an excellent tool for dosimetry but involves a consumable cost, requires characterization of both the film and the scanner, and presents several technical challenges in yielding accurate dosimetric results.[3]

Recently, 2D ionization chamber arrays have become increasingly popular for intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) plan verification. The MatriXX Evolution (IBA Dosimetry, Germany) is one of the 2D ionization chamber arrays for megavoltage real-time dosimetry measurements. Several authors[4–7] have evaluated the performance of IBA dosimetry 2D ionization chamber array in verification of IMRT/VMAT plans. The detector was found to be linear with dose, independent of dose rate, and a suitable device for quality assurance and 2D dose verifications of megavoltage beams.

The purpose of this study was 2-fold:

(1) To determine the suitability of MatriXX Evolution as a dosimetry tool for HDR brachytherapy plan verification. To achieve this goal the performance of MatriXX Evolution for the submegavoltage photon energy range was evaluated using kilovoltage X-ray beams (100, 180, and 300 kVp). Therapy ionization chambers calibrated using kilovoltage x-ray is an alternative established method for well-type chamber for the calibration of Ir-192 brachytherapy sources.[8, 9] Therefore, the ion chamber array calibration factor was determined using 300 kVp X-ray beams.

(2) To assess the 2D ion chamber array's application to routine quality assurance (QA) checks for end-to-end dosimetric evaluation that mimics a patient treatment procedure, a dedicated phantom was developed, and this QA jig is used after source change to confirm that primary source strength calibration value is properly updated in both the TPS and treatment delivery console computers.

Methods and materials

The MatriXX Evolution consists of 1020 vented, plane-parallel cylindrical ionization chambers arranged in a 32×32 matrix with a maximum field-of-view of 24.4×24.4 cm^2. The chamber size is 4.5-mm diameter and 5-mm height, center-to-center distance is 0.76 cm, active volume is 0.08 cm^3, and water-equivalent RW3 is used as backscatter material. The effective point of measurement is 3.6 mm from the surface.[4,5] The OmniPro-I'mRT software provides 1-mm resolution with linear interpolation using low-pass filter. The maximum dose rate detectable by the detectors is 5 Gy/min and the minimum detectable dose rate is 0.1 Gy/min. The bias voltage required for the MatriXX Evolution system is 500 ± 30 V. The equivalent absorber thickness on the front side of the matrix is 3.6 mm[4,5]

Kilovoltage x-ray beams dose linearity

The dose dependence of the MatriXX Evolution for different megavoltage X-ray energies was analyzed by other authors.[4,5] In the present work, submegavoltage dose and energy dependence test was performed in Gulmay D3300 kilovoltage X-ray therapy unit (Gulmay, Ltd, Chertsey, UK) using kilovoltage photon beams. The kVp X-ray beams were calibrated using the American Association of Physics in Medicine Task Group 61 protocol.[10] The dose linearity test was performed by irradiating the ion chamber array with 100, 180, and 300 kVp X-ray photon energies with circular 5–cm-diameter open-ended applicator at 30-cm focus-to-surface distance (FSD). The dose linearity test measurements were performed at the effective point of measurement of MatriXX Evolution by measuring the output for 5, 10, 20, 50, 100, 200, and 500 monitor units (MUs) set on the control console.

Variation of ion chamber array response with photon energy

Before TPS-specific dose verification can be carried out with MatriXX Evolution, absolute calibration of the detector response (k_{user} factor) must be determined experimentally by the user. k_{user} converts the charge collected by the internal electrometer of MatriXX Evolution to the dose deposited in the detector plane at a given calibration depth and field size.[4] The energy dependence of the detector was studied by calibrating with kilovoltage and megavoltage X-ray beams. Kilovoltage X-ray beam absolute calibration of the detector was performed by irradiating the detectors with an anteroposterior (AP) (100, 180 and 300 kVp) field to a known dose using a circular 5-cm–diameter, open-ended applicator at 30-cm focus-to-surface distance (FSD). For megavoltage, X-ray energies, absolute calibration of the detector Varian 600C (for 4 MV) and 2100EX (for 6 and 18 MV) linear accelerators (Varian Associates, Palo Alto, CA) were used.

Comparison between dose distributions calculated by brachy TPS and measured with ion chamber array

To be able to generate a brachytherapy treatment plan for the various experimental conditions, the Nucletron Freiburg Flap Applicator Set (Nucletron BV, Veenendaal, the Netherlands) was used. The Freiburg Flap Applicator Set is a flexible mesh style surface mold made of silicone rubber with 36 channels for implant tubes with a separation of 10 mm and a channel length of 24 cm. The Freiburg Flap maintains a fixed distance of 5 mm from the applicator to skin. The Freiburg Flap (with catheters) was positioned to cover the detector area of MatriXX Evolution. Slabs of RW3 were added (0, 1.0, 2.0 cm) between the Freiburg Flap and MatriXX Evolution to vary the distance between the detector and the catheters planes. Fixed slabs of RW3 were added below the MatriXX Evolution and above the Freiburg Flap to provide full scattering conditions. The phantom was scanned on Varian Acuity cone-beam computed tomography (CBCT) for the treatment planning with 2.5-mm slice thickness. The Acuity system is part of the brachytherapy suite. The CBCT scan was repeated by adding different thickness of RW3 ($t = 0, 1.0, 2.0$ cm) between the detector and the Freiburg Flap, so the effective distance of measurement from the catheter was 0.86, 1.86, and 2.86 cm, respectively (Fig. 1).

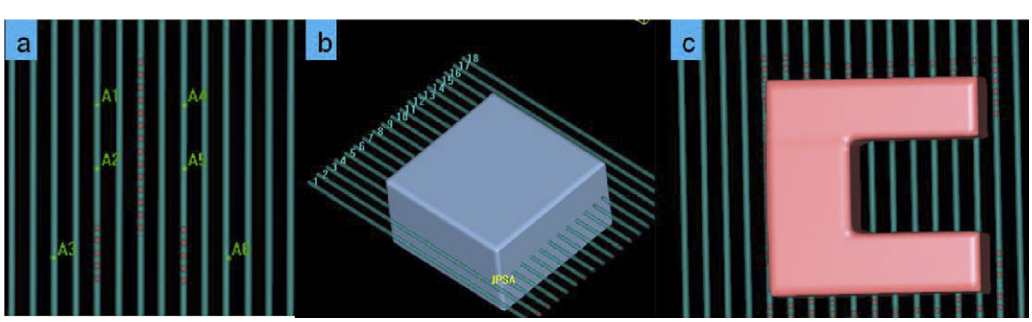

Fig. 2. Various test patterns within MatriXX Evolution phantom: mimicking (a) a GYN treatment, (b) a box, and (c) a horseshoe. Red dots correspond to active dwell positions within a catheter.