Clinically evaluating directional dependence of 2D seven29 ion-chamber array with different IMRT plans

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Original Article

Abstract

Purpose: This study aims to clinically evaluate the directional dependence of a 2D seven29 ion-chamber array with different intensity-modulated radiotherapy (IMRT) plans. **Methods:** Twenty-five patients who had already been treated with IMRT plans were selected for the study. Verification plans were created in an Eclipse treatment planning system (TPS) for each treatment plan. The verification plans were executed twice for each patient. The first IMRT plan used a true gantry angle (plan-related approach), and the second plan used a 0° gantry angle (field-related approach). Measurements were performed using a Varian Clinac 2100 iX linear accelerator. The fluence was measured for all the delivered plans and analyzed using Verisoft software. A comparison of the fluence was performed between IMRT with a static gantry (0° gantry angle) and real gantry angles. **Results:** The results indicate that the Gamma average was 98.8% for IMRT with a 0° gantry angle and 96.616% for IMRT with a true gantry angle. Average percent difference of normalized doses for IMRT delivered with zero degree gantry angle and IMRT with actual gantry angles is 0.15 and 0.88 respectively. **Conclusion:** The ion chamber of the 2D array used in IMRT verification has angular dependence, reducing the verification accuracy when the 2D array is used for measuring the actual beams of the treatment plan.

Keywords: IMRT; 2D Array; Octavius Phantom; Gamma Analysis

Introduction

Intensity-modulated radiotherapy (IMRT) is a special type of three-dimensional conformal radiotherapy (3D-CRT) in which modulated fluence is delivered to the patient from any given position of the treatment beam to optimize the composite dose distribution. IMRT machines can vary the strength of beams across the tumor during each dose of treatment. Thus, the machine administers very precise doses to an entire tumor or specific areas within the tumor. Intensity modulation is achieved using a multileaf collimator (MLC), and the field shape can be altered either step-by-step or dynamically while the dose is delivered. In the step-and-shoot mode (static IMRT) the intensity-modulated fields are delivered in a sequence of small segments, i.e., subfields, with a uniform intensity. This technique requires that the beam is only turned on when the MLC leaves are stationary in each of the prescribed subfield positions. There is no MLC motion while the beam is turned on. A more technically advanced method is the dynamic MLC technique (often called the sliding-window method). Here, the fluence profile along the moving direction of a leaf pair is created by sweeping the leaf pair with different openings over the field while the beam is always on.[1–7]

IMRT is a complicated procedure that involves the delivery of complex intensity patterns from various gantry angles. Owing to the complexity of the treatment plans, IMRT requires their dosimetric verification, as it produces a steep gradient inside tumors. Thus, patient-specific quality assurance (QA) is very important. The pretreatment verification of patient plans is typical for IMRT treatment. Verification of patient-specific IMRT plans using two-dimensional (2D) detector arrays with Octavius phantoms has become increasingly popular because of its easiness and the immediate readout of the results. A planar dose at a certain depth can be extracted from the treatment planning system (TPS) and compared with measurements using 2D detector arrays in the same geometry at the depth of interest. 2D dose-distribution analysis tools based on the percent dose difference, distance to agreement (DTA), and gamma index have been developed and implemented commercially. The capabilities to acquire 2D dose

distributions and perform real-time analysis make 2D detector arrays preferable to single ion chambers and film measurement for IMRT pretreatment verification.[8]

The ion-chamber-based Octavius 2D-array detector (PTW, Freiburg, Germany) is a step toward measuring the absolute dose and dose distribution for patient-specific IMRT QA. However, the directional dependency of this detector makes it unsuitable for angle-dependent IMRT QA. However, a new Octavius system (PTW, Freiburg, Germany) has an air cavity that compensates for the reduced response due to directional dependence. In the present study, we clinically investigated the effects of the directional dependence of the 2D ion-chamber array on different IMRT plans.

Methods and Materials

We selected 25 IMRT plans with Sliding Window method, and the disease sites mostly included prostate, lung, head and neck, esophagus, cervix, rectum, and stomach cancer. All of the calculations for each plan were performed using Eclipse TPS (version 10) and the Analytical Anisotropic Algorithm (AAA) with dose calculation grid size of 2.5mm. The measurements were performed using a PTW 2D seven29 ion-chamber array (PTW, Freiburg, Germany) with an Octavius phantom on a Varian Clinac iX (Varian medical systems, Palo Alto, CA) linear accelerator. **Figure 1** shows the experimental setup of the pretreatment QA tests for IMRT.

PTW 2D ion-chamber array

The 2DARRAY seven29 (PTW, Freiburg, Germany) is a new concept of an ion-chamber matrix in a plane for IMRT verification and quality control (QC) in radiation therapy. Utilizing ion chambers avoids radiation damages, which are the major drawback of solid state detectors. The matrix comprises 729 vented plane parallel ion chambers, each 5 mm × 5 mm × 5 mm in size, with a center-to-center spacing of 10 mm. It is a 27 × 27matrix, yielding a maximum field size of 27 cm × 27 cm. The array is only 22 mm long and 3.2 kg in weight. The surrounding material is polyemethyl methacrylate (PMMA). Owing to the square-chamber technology, the array can be moved by 5 mm to close the gaps between the chambers. By shifting the array three times, the whole area is covered. The number of measured points can be increased to 2916. The 2D array seven29 can be used in either a flat phantom or the octagonal Octavius phantom. With Octavius, the 2D array seven29 is suitable for IMAT and Tomotherapy. The measurement ranges for PTW seven29 specified by the manufacturer are 200 mGy – 1000 Gy and 500 mGymin^{-1} –8Gymin^{-1}. The 2D array is calibrated for absolute dosimetry in a Co60 photon beam at the PTW secondary standard dosimetry laboratory. The 2Darrayseven29 can be used for IMRT plan verification, LINAC QC, and online LINAC adjustment.[3]

The data-acquisition software Matrix Scan is used to acquire dose and dose rate data. It displays 3D graphics and transfers the acquired data to the software package Verisoft. We used Verisoft to compare the dose distribution calculated in the TPS with that measured by the 2Darray. The maximum and average deviation between the treatment plan and measured beam were determined.

FIG. 1: Experimental Set-up for the pre treatment quality assurance tests for IMRT. PTW 2D ionization chamber array inserted inside the Octavius CT phantom, SSD was kept at 84 cm.

Octavius phantom

A dedicated Octavius phantom was used during measurements for the QA of the rotational treatments (Volumetric Modulated Arc Therapy (VMAT) and Tomotherapy), The Octavius phantom is dedicated for rotational and intensity modulated technique quality assurance, focusing primarily on the use of the seven29 2D ion-chamber array. It was made of polystyrene (physical density 1.04 g/cm³), 32 cm wide, and 32 cm long. A 30 × 30 ×2.2 cm³ central cavity allowed the user to insert the 2D ion-chamber array into the phantom. The position of the cavity was such that when the 2D array was inserted, the plane through the middle of the ion chambers passed through the center of the phantom.[3]

FIG. 2: Octavius phantom set (LINAC phantom and CT phantom).

The Octavius set was composed of two phantoms: a Computed Tomography (CT) phantom and a LINAC phantom as shown in **Figure 2**. The LINAC phantom had a 2 cm semicircular air cavity in its lower part to compensate for the reduced response behavior of the seven29 2D array when irradiated from the back. The LINAC phantom is used for measurements, whereas the CT phantom comes without a cavity and is used for dose planning[3].

Clinical verification of IMRT QA

The Octavius CT phantom was CT scanned with the 2D array. The scanned images were imported into the Eclipse 10 TPS. A verification plan was created for all the patients using the 2D array and Octavius phantom. The calculations were performed using the AAA algorithm. The dose distribution in the phantom was recalculated without changing any dosimetrically relevant treatment parameters. The newly calculated patient plan or verification plan was implemented using the LINAC phantom. In this study verification plans were produced twice for each patient. The first plan employed IMRT with a true gantry angle (plan-related approach), and the second plan employed IMRT with a 0°gantry angle (field-related approach). **Figure 3** shows verification-plan window in Eclipse TPS a) for IMRT and b) for IMRT with a 0° gantry angle. We first created the verification plan for IMRT with true gantry angles; i.e., all the fields with their correct beam-entry directions were

transferred within the TPS to a verification phantom, and the dose distribution was calculated. For the field-related approach (IMRT delivered with 0° gantry angle), each treatment field was transferred to a verification phantom with the gantry angle normally set to 0° for all beams without changing other treatment parameters. The Octavius LINAC phantom delivered each verification plan separately for the different patients. Measurements were performed on a Varian Clinac 2100 iX linear accelerator equipped with a Millennium 120 MLC. The measurement values were recorded in the 2D array seven29 ion chamber and Verisoft using an array interface and an RS 232 cable. The fluence was measured for all the delivered plans and analyzed using Verisoft. All of the individual field delivered-dose distribution patterns were added to obtain the composite dose distribution, which was compared with the TPS-generated composite dose distribution using the gamma-index method proposed by Low *et al.*[9] The spatial difference in the dose distribution (distance-to-agreement) and dose deviation (delta-dose) were within the clinical acceptance criteria of 3mm and 3%, respectively. If the gamma index was less than or equal to 1, the criteria limits were not exceeded. When it was greater than 1, the measurement result was outside the tolerance range. A comparison was performed between the fluence for IMRT with a static gantry (0° gantry angles) and that for IMRT with real gantry angles.
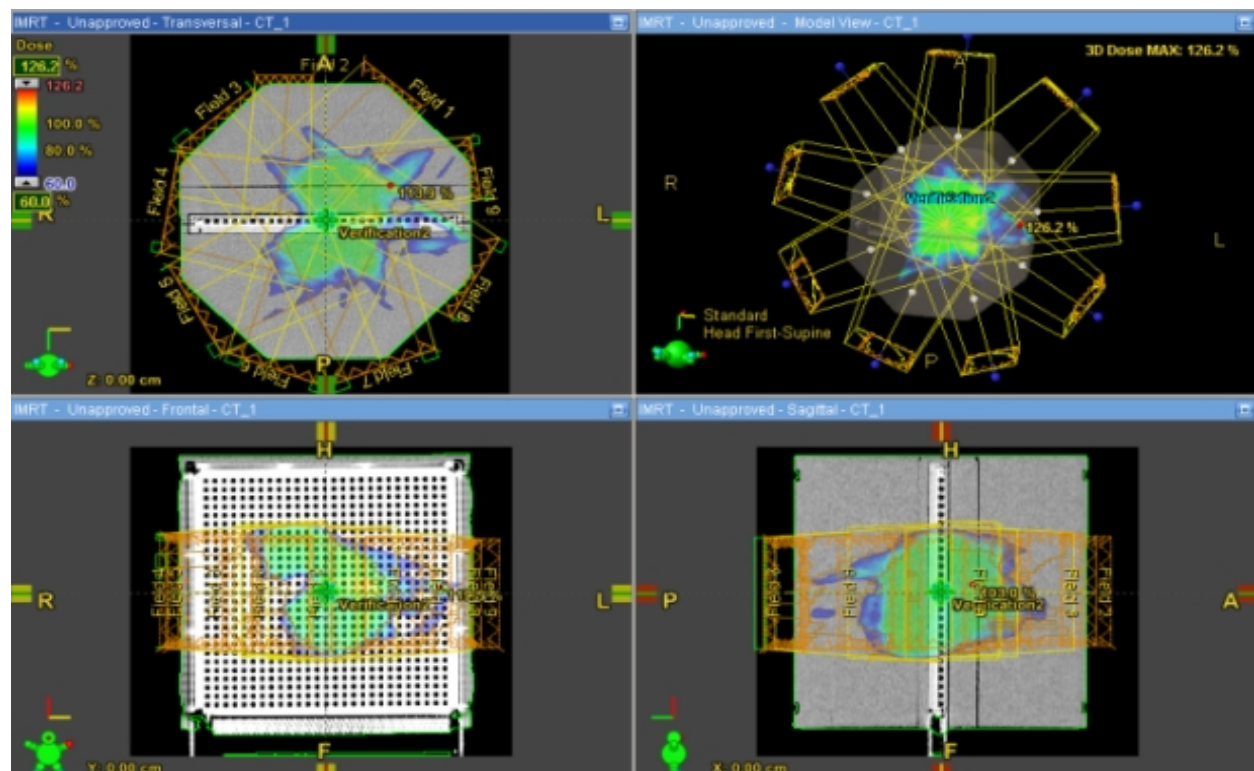

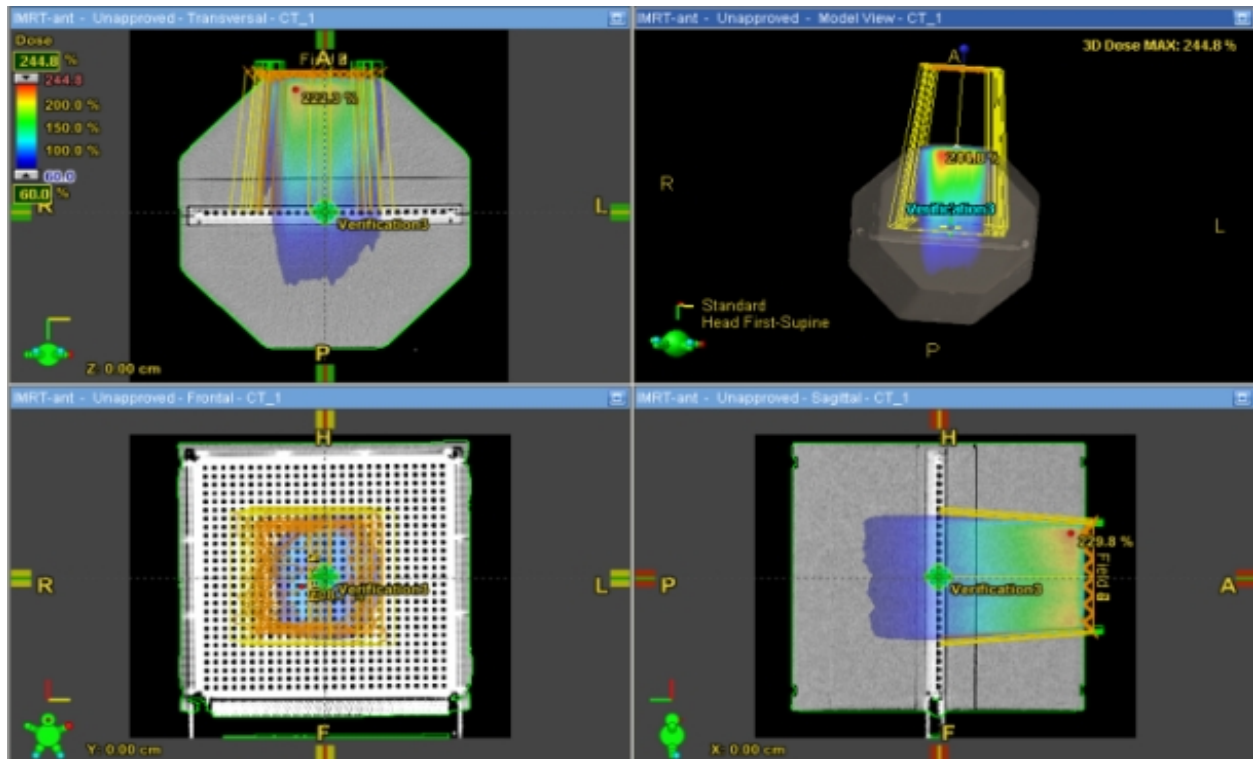**FIG. 3 a):** Verification plan window in eclipse treatment planning system for IMRT.

FIG. 3 b): Verification plan window in eclipse treatment planning system for IMRT with zero degree gantry angle.
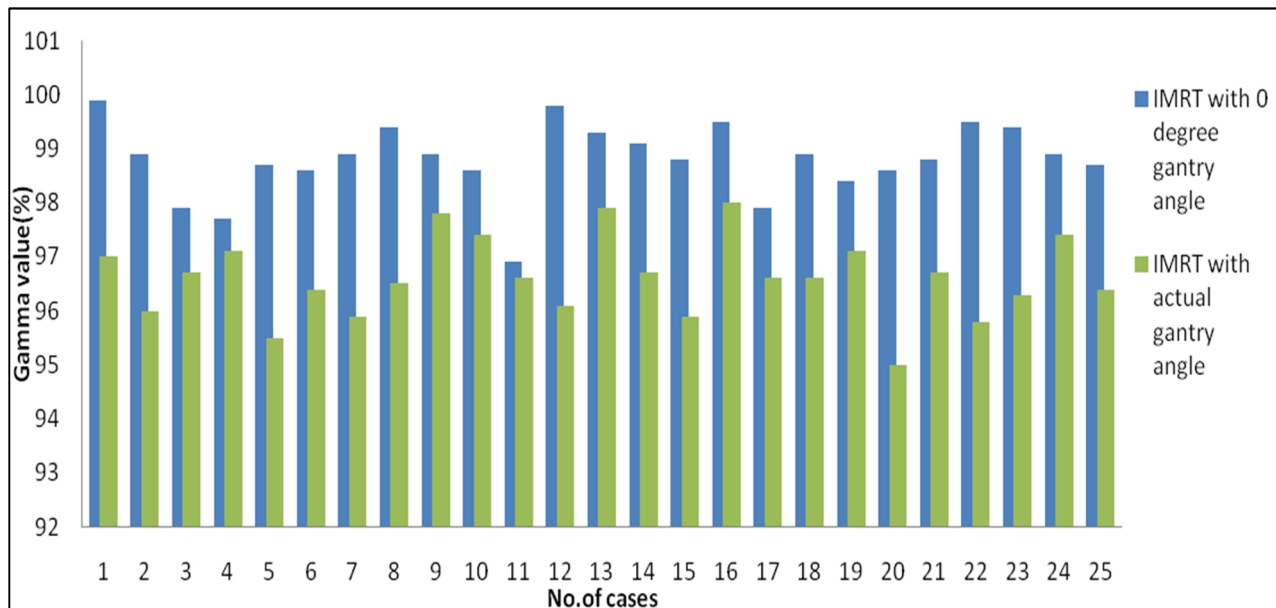

FIG. 4: Gamma pass percentage for IMRT delivered with 0 degree gantry angle and IMRT with actual gantry angle for different plan.
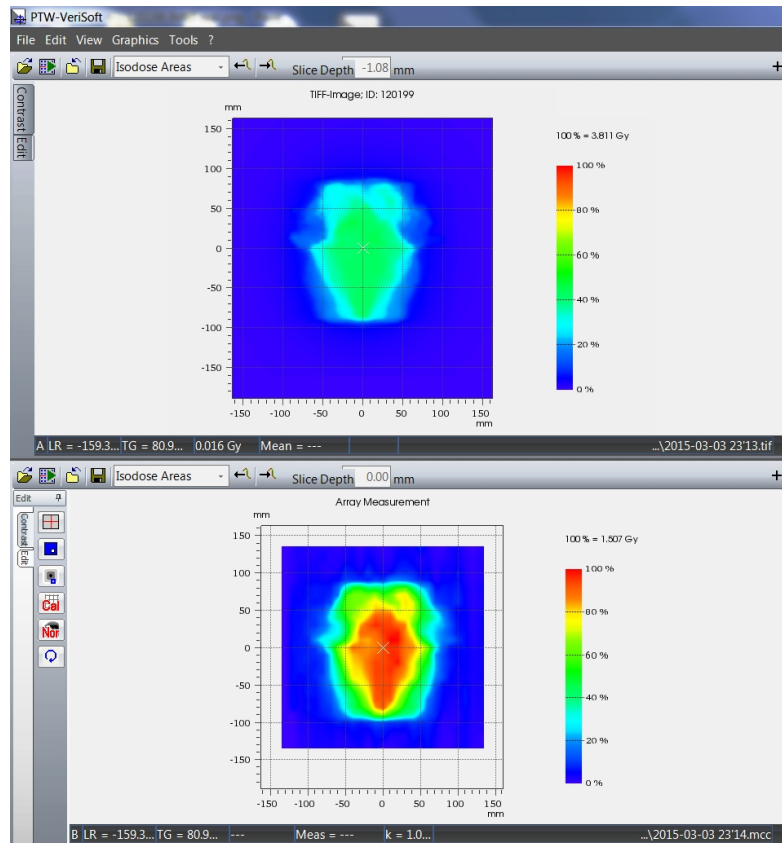
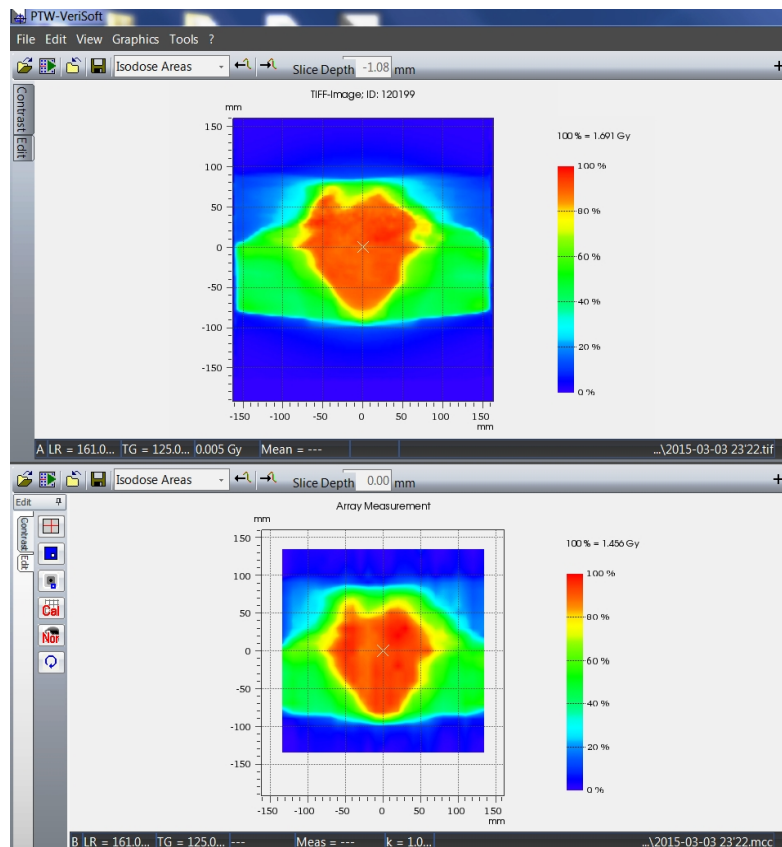**FIG. 5 a):** Gamma analysis for IMRT delivered with zero degree gantry angle.

FIG. 5 b): Gamma analysis for IMRT delivered with true gantry angle.

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Results

A gamma evaluation was conducted for the IMRT with actual gantry angles and IMRT with 0° gantry angles. **Figure 4** shows the variation between these two conditions for different plans. The Gamma average was 98.8 % for IMRT with a 0° gantry angle and 96.616% for IMRT with a true gantry angle. **Figure 5 a**) and **b**) showing gamma analysis of measured against TPS calculated for IMRT delivered with zero degree gantry angles and IMRT with actual gantry angles. The average percent difference of normalized doses for IMRT delivered with zero degree gantry angle and IMRT with actual gantry angles were 0.15 and 0.88, respectively. The gamma analysis revealed a significant difference with significance of $p = 0.002$ between IMRT with a 0° gantry angle and IMRT with actual gantry angles. The standard deviations of the gamma pass percentage for IMRT with a 0°gantry angle and with actual gantry angles were 0.678 and 0.742, respectively.

Discussions

Several researchers have investigate the angular dependence of 2D arrays in IMRT and volumetric modulated arc therapy (VMAT).[1–13] In the study 'characterization of the response of the seven29 2D array detector' [11] by Syam *et al.*, the detector's directional dependence was measured as a function of the beam angles and verified by delivering an open field. In the present study, we clinically investigated the angular dependence of a 2D ion-chamber array for IMRT dose verification and quantified the influence of the directional dependence on the effectiveness of the treatment with different IMRT plans. The percentage variations between the calculated and measured TPS values were found to be 2% for IMRT with a 0° gantry angle (field-related approach) and 5% for IMRT delivered with actual beam gantry angles. For IMRT and IMRT with zero degree gantry angle, the percentage variation of central detector value was found using the formula = (measured - planned)/planned) × 100. **Figure 4** shows the gamma pass percentage for IMRT with a static field (0° gantry angle) and IMRT delivered with actual gantry angles. This graph indicates that the gamma values for static IMRT (0° gantry angle) and IMRT with actual gantry angles were average was 98.8 % and 96.61%, respectively.

Shimohigashi *et al.* [4], Qilinli *et al.* [6], and Hussein *et al.* [7] calculated the percentage variation between gamma values calculated by a TPS and those measured by a 2D array, reporting a large variation at beam incidence angles within 90° ± 5°. These studies confirmed that 2D arrays exhibit a reduced response if irradiated from the back. In the present study, the 2D array exhibited directional dependence when IMRT QA was performed with true gantry angles but not for IMRT with a 0° gantry angle. The percentage variation of

gamma values between IMRT delivered with a 0° gantry angle and IMRT with actual gantry angles is 3%; thus, the directional dependence does not have a significant clinical impact on IMRT plans.

Because the 2D array exhibits angular dependence, the verification accuracy of IMRT with actual treatment plans is relatively small when measured using a 2D array. Consequently, all the beam gantry angles were modified to 0° for the verification of IMRT treatment plans. Furthermore, IMRT with a 0° gantry angle is quick compared with IMRT with actual gantry angles. However, the MLC assembled in the LINAC probably has some positioning errors when the gantry angle is not 0°,which cause a slight discrepancy between the actual dose distribution of the treatment plan and that computed by a TPS.[15, 16] This discrepancy cannot be detected by verification at a 0° gantry angle. In addition, the method of verification at a 0° gantry angle cannot determine where the error has happened, nor does it indicate the impact on the actual implementation of the treatment plan. Thus, the best verification method for IMRT treatment plans is to measure the composite dose distribution under real irradiation conditions, except if QA is performed with dosimetric equipment having directional dependence.

Conclusion

In a gamma analysis, IMRT with a 0° gantry angle exhibited a higher pass percentage than IMRT with true gantry angles. The 2D-seven29 ion-chamber array used for IMRT verification has angular dependence, which lowers the verification accuracy when the array is used to measure actual beam angles.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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