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Evaluation of patient-specific quality assurance of gated field-in-field radiation therapy techniques using two-dimensional detector array

Dražan Jaroš[1,2*], Goran Kolarević[1,2], Aleksandar Kostovski[1], Milovan Savanović[3,4], Dejan Ćazić[1,2], Goran Marošević[1,2], Nataša Todorović[5], Dragoljub Mirjanić[2]

[1]Affidea, International Medical Centers, Center for Radiotherapy, Banja Luka, Bosnia and Herzegovina, [2]Faculty of Medicine, University of Banja Luka, Banja Luka, Bosnia and Herzegovina, [3]Department of Radiotherapy, Hospital Tenon, Paris, France, [4]Faculty of Medicine, University of Paris-Saclay, Le Kremlin-Bicetre, France, [5]Faculty of Science, University of Novi Sad, Novi Sad, Serbia

ABSTRACT

Introduction: Gated tangential field-in-field (FIF) technique is used to lower the dose to organs at risk for breast cancer radiotherapy (RT). In this study, the authors investigated the accuracy of the delivered treatment plan with and without gating using a two-dimensional detector array for patient-specific verification purposes.

Methods: In this study, a 6MV beams were used for the merged FIF RT (forward Intensity Modulated Radiation Therapy). The respiration signals for gated FIF delivery were obtained from the one-dimensional moving phantom using the real-time position management (RPM) system (Varian Medical Systems, Palo Alto, CA). RPM system used for four-dimensional computed tomography scanner light-speed, GE is based on an infrared camera to detect motion of external 6-point marker. The beams were delivered using a Clinac iX (Varian Medical Systems, Palo Alto, CA) with the multileaf collimator Millennium 120. The MapCheck2 (SunNuclear, Florida) was used for the evaluation of treatment plans. MapCheck2 was validated through a comparison with measurements from a farmer-type ion chamber. Gated beams were delivered using a maximum dose rate with varying duty cycles and analyzed the MapCheck2 data to evaluate treatment plan delivery accuracy.

Results: Results of the gamma passing rate for relative and absolute dose differences for all ungated and gated beams were between 95.1% and 100%.

Conclusion: Gated FIF technique can deliver an accurate dose to a detector during gated breast cancer RT. There is no significance between gated and ungated patient-specific quality assurance (PSQA); one can use ungated PSQA for verification of treatment plan delivery.

Keywords: Patient-specific quality assurance; gated radiotherapy; detector array

*Corresponding author: Dražan Jaroš, Affidea, International Medical Centers, Center for Radiotherapy, Dvanaest beba bb, 78000 Banja Luka, Bosnia and Herzegovina. Phone: +387 65 936141. Fax: +387 51 223340. E-mail: jarosdrazan@yahoo.com

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INTRODUCTION

The radiotherapy (RT) techniques have developed from two-dimensional (2D) RT trough three-dimensional conformal RT (3D-CRT) to intensity-modulated RT (IMRT) and volumetric modulated arc therapy (VMAT) (1). IMRT is

UNIVERSITY OF SARAJEVO
FACULTY OF HEALTH STUDIES

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an advanced treatment technique where radiation beams are conformally shaped around the target with a multileaf collimator (MLC). VMAT is a more advanced technique; the beam is delivered by the movement of MLC in both directions. During the movement of MLC, variation in the dose rate and gantry speed is used for beam modulation. Furthermore, forward IMRT-field-in-field (FIF) technique has become standard treatment technique instead of conventional RT technique for breast cancer because of the clinical benefits of reduced radiation toxicity to surrounding normal tissues and dose conformity to the target volume. If used in gated treatment such as deep inspiration breath-hold (DIBH) RT of left breast cancer, it provides even better results for organs at risk (OAR), especially the heart (2).

The study of Sasaoka et al. showed that there is an improved dose distribution in breast cancer patients treated with FIF technique and decreased radiation therapy oncology group Grade II acute skin toxicity compared with conventional tangential field RT with physical wedges (3). Furthermore, the study of Al-Rahbi et al. showed that FIF technique is efficient in reducing the hot-spot regions within the breast volume and is straight forward, resulting in an overall reduction of doses for OAR compared to 3D-CRT and inverse planned IMRT (4).

Gated delivery has been used in studies as a method for reducing the size of the clinical target volume to planning target volume margin needed to account for respiratory motion (5,6). This method consists of triggering the radiation beam on and off based on the tumor surrogate. A respiratory gating system is used for monitoring of respiratory motion by tracking an external marker using an infrared (IR) light source and a charge-coupled device (CCD) detector (7). This system determines the patient's respiratory motion and displays it as a waveform and triggers the delivery of radiation on the linear accelerator (LINAC) at a specified point in the respiratory cycle based on either amplitude of the marker or the phase of the respiratory cycle (7). Treatment dose delivered to the patient may not be the same as planned mostly because of the respiratory motion of the target.

The previous studies recommend the need for patient treatment plan specific quality assurance (QA) (patient-specific QA [PSQA]) (8). PSQA is a procedure done before the treatment for verification of the planned dose compared to the dose delivered to the detector for the individual patient. For the FIF technique, it is done without gating on a 2D detector array.

The primary aim of this study was to compare PSQA on a 2D detector array during ungated and gated delivery.

METHODS

Patient selection

In the period from January 2015 to March 2019, 43 patients referred for adjuvant RT of left breast cancer. The patients were treated with FIF DIBH technique using real-time positioning management (RPM) system (RPM, Varian Medical Systems, Palo Alto, CA, USA) on the Varian Clinac 2100 iX (7). All patients who underwent gated treatment were involved in this study.

Treatment planning and dose constraints

FIF RT technique was performed on DIBH CT series with two opposed segmented beams and one direct beam without segments (with dose weight <10%). The prescribed dose was 50 Gy in 25 fractions. The energy of the beams was 6 MV, and the fields were shaped with Varian Millennium 120 MLC. A maximum dose rate of 600 MU/min was used. Treatment planning was performed with the Varian Eclipse 10.0 and 13.6 treatment planning system (TPS) and calculated with Anisotropic Analytical Algorithm. Dose variation was accepted in the PTV following ICRU 50 and 62 (9,10). For each of 86 segmented beams (43 medial and 43 lateral beams), PSQA has been considered using a MapCHECK2 (Sun Nuclear Corp., Melbourne, FL, USA) device, model 1177 (11).

MapCHECK2

Before the first fraction, it was mandatory to perform PSQA verification with the MapCHECK2 device. This device is composed of 1527 n-type solid-state detectors with an active area of 26.0 × 32.0 cm^2 (11). Diagonal detector spacing is 0.707

cm, and the detector spacing parallel to X- and Y-axes is 1.0 cm (11). Active area of each detector is 0.8 mm × 0.8 mm (11).

Absolute dose calibration

The absolute dose calibration procedure consists of collecting MapCHECK 2 measurements under the conditions at which the dose delivered to the central detector is known and entering the value of that known dose in the calibration wizard (11). SunNuclear patient software correlates the counts collected by the device during the calibration to the known dose entered by the user, establishing the absolute dose calibration factor (11).

Array calibration

Array calibration determines relative sensitivity differences between MapCheck 2 detectors and stores them as individual correction factors to be applied to the unprocessed measurement signals from each detector (11).

After absolute dose calibration and array calibration, the device can be used for evaluation of the absolute dose passing rate and relative passing rate. The gamma index was applied from the ellipse formula using the dose and distance difference between measurement and calculation (12). A point that had a gamma value higher than 1.00 would not pass the criteria. The percentage of points that pass the criteria can be called the % gamma pass or gamma pass rate. The passing rate was evaluated using a 3% dose tolerance of reference values and a distance to agreement (DTA) 3 mm (gamma: 3%, 3 mm) between the measurement and calculation with 10% threshold (13). The degree of agreement between the MapCHECK2 and data calculated in the TPS was characterized using the passing rate of diode detectors failing to have gamma <1. The passing rate was evaluated for relative and absolute dose difference.

The MapCHECK2 was placed on the treatment couch with MapPHAN-MC2 (Sun Nuclear Corp., Melbourne, FL, USA) water-equivalent phantom. The source-to-detector plane distance was 1000 mm. The reproducibility for absolute dose measurement was checked using a 100 × 100 mm^2 open field before the delivery of the FIF planned dose. The measured planar dose was analyzed using accessory software version V5.00.00 included in the MapCHECK2 device. After the patient plan was approved by a radiation oncologist, medical physicists created the pre-treatment verification plan at a 0° gantry angle with the beam directed perpendicular to the verification plan. Per-field coronal planar dose was measured at a gantry angle of 0° by a MapCHECK2.

Respiratory gating system

The commercially available respiratory gating system RPM system (RPM™, Varian Medical Systems, Palo Alto, CA) consists of a marker block, an IR light source, a CCD tracking camera and a workstation that displays and records the motion data (13). The marker block consists of six reflective fiducials that are placed on the patient's abdomen, usually over the xiphoid process, and it is marked on the patient's skin because of reproducibility. For this study, the marker was positioned on the Varian breathing phantom. Varian breathing phantom with marker block was used for generating the test signal for the gating threshold used for PSQA. The breathing cycle was set to 5 s. The system monitors the motion of the phantom by tracking the external fiducials using the IR light source and CCD detector. The respiratory gating system is installed on the LINAC (Clinac 21iX, Varian Medical Systems) in our clinic.

The system has measured the phantom's respiratory pattern and range of motion and has displayed them as a waveform (7). After precise determination of the breathing phantom movement in relation to the waveform, gating thresholds were set along the waveform to mark the phantom in the desired portion of the respiratory cycle (7). These thresholds determine when the automatic gating system should turn the treatment beam on and off on the LINAC.

Three duty cycles were used to trigger the beam: 25%, 50%, and 75%.

Statistical analysis

Related samples Wilcoxon signed-rank test was used for statistical analysis of the gamma passing rate for ungated and gated FIF technique delivery. Data were considered statistically significant at $p < 0.05$. We have tested the normality of distribution (Kolmogorov–Smirnov test) with SPSS statistical software version 23.0 (IBM, Armonk, NY).

RESULTS

Kolmogorov–Smirnov test was used for testing the normality of distribution, and the results were <0.045. None of the distributions were normal.

The results of the gamma passing rate for relative and absolute dose differences for all ungated and gated beams were between 95.1% and 100% (Figure 1).

Median gamma passing rate for relative and absolute dose difference for medial and lateral beams during ungated and gated delivery with duty cycles 25%, 50%, and 75% are shown in Table 1.

DISCUSSION

Many of the techniques and devices for PSQA are still being verified clinically. Importantly, in some cases, gamma evaluation fails to detect failing plans (14,15). The historical standard for QA has been point dose measurement evaluation and 2D evaluation, and they have been viewed as a gold standard (16-18).

The dosimetric accuracy of gated 6MV photon beam delivery was evaluated for 43 patients for three different duty cycles: 25%, 50%, and 75%, with a breathing cycle of 5 s. The gamma passing rate of gated delivery and ungated delivery was evaluated. The results for all fields have gamma passing rate >95% using a 3% dose tolerance of reference values and a DTA 3 mm between the measurement and calculation with a 10% threshold. One can conclude that gated FIF technique can deliver an accurate dose to a detector for gated breast cancer RT.

Even though 12 results showed gamma passing rate in the interval from 95% to 96%, we cannot conclude that there will be a difference in dose to OARs. Several studies have pointed out the gamma passing rate does not necessarily detect a clinically significant dosimetric error, such as the dose deviation of OARs (14,19-21).

The negative side of the use of gated PSQA is the increased time slot on the LINAC due to a complex set-up procedure. Time slot is also increased because several duty cycles are used to verify a beam delivery. Ungated PSQA procedure is less time consuming, and set-up procedure is less complicated.

In this study, based on related samples Wilcoxon signed-rank test, there is no significance between gated and ungated PSQA except absolute dose difference for the medial beam. The median gamma passing rate for ungated treatment of medial beam is less than the median gamma passing rate for all gated treatments. If ungated treatment is used for verification of absolute dose difference with gamma passing rate >95%, results should be better for gated treatment; therefor, ungated treatment should be enough for verification of gamma passing rate of absolute dose difference for the medial beam.

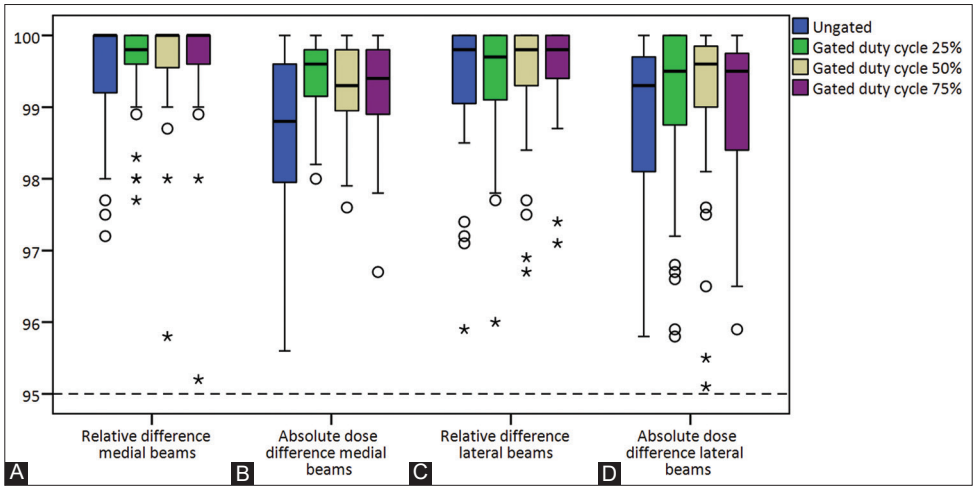

FIGURE 1. Results of the gamma passing rate (%): (A) relative difference medial beams, (B) absolute dose difference medial beams, (C) relative difference lateral beams, and (D) absolute dose difference lateral beams.

TABLE 1. Median gamma passing rate for relative and absolute dose difference

Beam		Median gamma passing rate (%)			
		Ungated	Gated		
			25%	50%	75%
Medial	Relative difference	100 IQR=0.08	99.8 (p=0.664) IQR=0.4	100 (p=0.792) IQR=0.5	100 (p=0.590) IQR=0.4
	Absolute dose difference	98.8 IQR=1.7	99.6 (p<0.001) IQR=0.7	99.3 (p=0.003) IQR=0.9	99.4 (p=0.009) IQR=0.9
Lateral	Relative difference	99.8 IQR=1.0	99.7 (p=0.885) IQR=0.9	99.8 (p=0.723) IQR=0.8	99.8 (p=0.508) IQR=0.6
	Absolute dose difference	99.3 IQR=1.6	99.5 (p=0.221) IQR=1.4	99.6 (p=0.052) IQR=1.0	99.5 (p=0.170) IQR=1.4

p value was calculated using related samples Wilcoxon signed-rank test

CONCLUSION

We can conclude that ungated PSQA can be used for verification of gated and ungated treatment plan delivery.

CONFLICTS OF INTEREST

We wish to confirm that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome.

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