Technical Note

Evaluation and Validation of IBA I'MatriXX Array for Patient-Specific Quality Assurance of TomoTherapy®

N. V. N. Madhusudhana Sresty, A. Krishnam Raju, B. Nagarjuna Reddy, V. C. Sahithya, Yakub Mohmd, G. Deleep Kumar, T. Anil Kumar, Tasneem Rushdi, S. Aparna, G. Durga Prasad[1], Harjot Kaur Bajwa

Department of Radiotherapy, Basavatarakam Indo American Cancer Hospital and Research Institute, Hyderabad, Telangana, [1]Department of Radiotherapy, Government Medical College and General Hospital, Anantapuramu, Andhra Pradesh, India

Abstract

TomoTherapy® is a modern radiation treatment technique in which intensity-modulated radiation therapy (IMRT) is delivered in helical fashion. A two-dimensional (2D) array which has been existing for IMRT patient-specific quality assurance (PSQA) verifications for many years is I'MatriXX. Our objectives were to validate this I'MatriXX and to evaluate it for different patient sites and fractionation schedules of TomoTherapy treatment. Twenty-five plans were created with virtual target for different possible pitch values and field widths for validation. Gamma index criteria of 3%/2% dose differences and 3/2 mm distance to agreement were used. QA plans of 26 different treatment sites and different fractionation schedules were used. Results indicated that the matrix response is independent of field width, pitch, and modulation factor of TomoTherapy with 3%, 3 mm criteria. High passing rate ranging from 99.7% to 90.7% was observed for selected patient plans. We found that I'MatriXX 2D array can be utilized for easy and quick TomoTherapy PSQA.

Keywords: Intensity-modulated radiation therapy, quality assurance, TomoTherapy®

Received on: 06-02-2019 **Review completed on: 15-05-2019** **Accepted on: 16-05-2019**

Introduction and Objectives

Currently, many modern radiotherapy machines deliver intensity modulation-based dose. Intensity-modulated radiotherapy (IMRT) consists of highly conformal dose distribution with steep dose gradients and sparing of normal tissues.[1,2] Hence, the most careful verification between the planned dose and measured dose is needed before successful dose delivery using computer-controlled multileaf collimators. If this IMRT is delivered with gantry rotation and variation in the dose rate of linear accelerator, then, it is called volumetric-modulated arc therapy (VMAT). A very sophisticated IMRT plan can be planned and delivered using TomoTherapy® treatment system. It uses fan beam technology and is modulated by a binary multileaf collimator. The treatment delivery with gantry rotation and couch translation into the bore resembles a computed tomography scan.[3] The leaves travel across the selected width in about 20 ms. This modulation results in a high degree of homogeneous and conformal dose distribution.[4] TomoTherapy has evolved as an efficient technology to deliver complex dose distributions.

Access this article online

Quick Response Code:

Website: www.jmp.org.in

DOI: 10.4103/jmp.JMP_11_19

Similar to all IMRT treatments, PSQA is also equally important in this helical approach.[5] Because of its dynamic nature, it is a great challenge for physicists to achieve QA goals.

For treatment verification of patient plans in helical TomoTherapy, ion chambers and films have been commonly used. Radiochromic film is an efficient tool for planar dosimetry because of its fine spacial resolution.[6-10] However, it is a tedious and time-consuming process. Helical TomoTherapy users practice with film and a specifically designed cylindrical phantom called cheese phantom.[11,12] Currently, there is also a lot of interest in using electronic array dosimeters because of their instantaneous readout of results.[13] These array detectors have been proved reliable, and the results are comparable with films and also better in some cases.[14] A planar dose

Address for correspondence: Dr. N. V. N. Madhusudhana Sresty, Department of Radiotherapy, Basavatarakam Indo American Cancer Hospital and Research Institute, Road No. 14, Banjara Hills, Hyderabad - 500 034, Telangana, India.
E-mail: srestybarc@gmail.com

How to cite this article: Madhusudhana Sresty NV, Raju AK, Reddy BN, Sahithya VC, Mohmd Y, Kumar GD, *et al*. Evaluation and validation of IBA I'MatriXX array for patient-specific quality assurance of tomotherapy®. J Med Phys 2019;44:222-7.

distribution can be calculated from the treatment planning system (TPS) and compared with the measured distribution using a two-dimensional (2D) detector array. Dose analysis tools based on distance to agreement (DTA), percentage dose difference (DD), and gamma index are used for verification. Detector arrays are becoming more popular than traditional films and single detectors because of their simpler usage and real-time analysis.[15,16]

There are several commercially available 2D array dosimeters. Sun Nuclear Corporation developed the MapPHAN phantom along with its MapCHECK diode array[17] to serve this purpose. PTW also introduced the OCTAVIUS phantom for the QA of rotational treatment, along with their 2D-array ion chamber device.[18] One of such 2D arrays in use for IMRT verifications for many years is I'MatriXX with blue phantom. These array detectors have shown to be adequate when used for IMRT patient plans delivered by linear accelerators. However, their applicability to helical TomoTherapy is not much discussed in the literature. Xu *et al*. tested this matrix for helical TomoTherapy IMRT plans of head-and-neck cancer cases.[19] However, its dependency on the pitch and field width of TomoTherapy was not discussed. In addition, this study was limited to a single treatment site. Hence, our objectives of this study were to examine and validate the response of I'MatriXX to different pitches and field widths commonly used in planning and to evaluate this device for IMRT/image-guided radiation therapy/ stereotactic body radiation therapy (SBRT) plans of different cancer sites.

Materials and Methods

We installed and commissioned TomoTherapy (TomoH) machine in our institute recently. TomoH system (Accuray, Sunnyvale, CA) consists of a linear accelerator that produces 6 MV photon beam. It has a source-to-axis distance of 85 cm with an 85-cm diameter bore through which the patient moves in and out of the gantry. It also comes with a built-in image detector. The linac is detuned to a lower energy of 3.5 MV for imaging purpose. The beam is collimated to a fan width of 40 cm and three possible thicknesses (1, 2.5, and 5 cm) by tungsten collimators. Below the collimators, there exists a binary multileaf collimator with 64 leaves. Each leaf can open or close independently. Intensity modulation is achieved by varying the fraction of leaf's open time. For treatment delivery, the full gantry rotation is divided into 51 projections. Each projection has its own leaf-opening pattern. The modulation at all gantry angles and in all the successive rotations are stored in a delivery sinogram. The extent of modulation is characterized by modulation factor which is defined as the ratio of the maximum to the average leaf open time. This factor affects the treatment time.[20] Another factor which influences the modulation especially in superior and inferior direction is pitch. The pitch is defined as the ratio of couch travel per rotation to the field width used.

I'MatriXX (IBA dosimetry, GmbH, Germany) planar QA verification system has been used for a long time for the purpose of IMRT/VMAT verification in linear accelerators. This was validated for TomoTherapy machine. It is a 2D array with 1020 ion chambers, arranged in a square. Each chamber volume is 0.08 cm^3 with a height of 5.0 mm and a diameter of 4.5 mm. The maximum field of view is 24 cm × 24 cm, and the separation between the chambers is 7.6 mm. Dose rate ranges from 0.1 to 20 Gy/min which can be measured with a dose resolution of 0.5 mGy/min. The array was inserted into the virtual water phantom called MultiCube. The size of MultiCube is 31.5 cm × 34 cm and height is 34 cm. The verification plans were generated by VoLO planning system version 5.1.2.12 (Accuray, Sunnyvale, CA). These plans were delivered in the TomoTherapy machine.

The MatriXX array was inserted into the MultiCube phantom to form an assembly as shown in Figure 1. The phantom was scanned using our Big Bore CT simulator (Philips Medical Systems, The Netherlands) with 2-mm slice thickness and stored as phantom data set in TomoTherapy planning system. There exist predesigned crosshairs on the MatriXX's slab which help to identify the center of the device on the phantom images acquired by the CT simulator. After this step, the image value-to-density table for the dose converting parameters is imported. The couch is also changed to TomoTherapy couch in the planning system.

After proper registration, isocenter position should be accurately matched with laser. Adjustments are done to properly place the target volume in the phantom. Then, lasers were kept to match with fiducials.

A virtual planning target with 3-cm diameter and 2-cm length was drawn at the center of the matrix initially. There are three different field width options available in the system as mentioned in Table 1. 2.5 and 5 cm are the most common field widths used for the patient plans, whereas 1 cm is rarely used. Pitch and modulation factor also need to be selected before proceeding for dose calculation. Pitches ranging from 0.1 to 0.5 and magic pitches 0.43, 0.287, and 0.215 as proposed

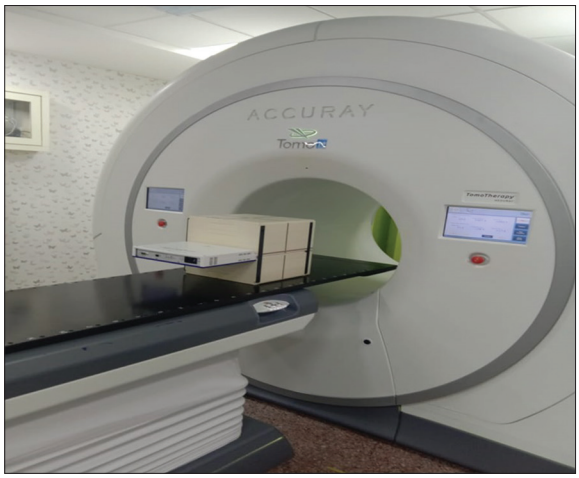


Figure 1: I'MatriXX two-dimensional array with blue phantom in TomoTherapy room

Table 1: The gamma-passing percentages in the validation process of matrix

Field width	Target dose (Gy)	Pitch	Modulation factor as per the plan	Gamma index (3%, 3 mm criterion)	Gamma index (2%, 2 mm criterion)
1.048	2	0.1	1.757	99.5	98.1
1.048	2	0.2	1.731	99.5	92.3
1.048	2	0.3	1.774	99.6	88.3
1.048	2	0.4	1.69	99.3	87.7
1.048	2	0.5	1.716	99.6	92.1
2.512	2	0.1	1.873	99.3	98.9
2.512	2	0.2	1.87	99.3	98.1
2.512	2	0.3	1.803	99.4	98.6
2.512	2	0.4	1.928	99.3	95.5
2.512	2	0.5	1.749	99.3	96.6
5.048	2	0.1	1.919	99.0	97.8
5.048	2	0.2	1.843	99.2	96.7
5.048	2	0.3	1.858	99.2	98.4
5.048	2	0.4	1.501	99.1	98.8
5.048	2	0.5	1.5	98.9	96.9
5.048	15	0.1	1.02	99.1	99.0
1.048	2	0.43	1.805	95.5	94.2
2.512	2	0.43	2.001	98.3	96.4
5.048	2	0.43	1.501	99.4	97.6
1.048	2	0.287	1.771	99.2	96.5
2.512	2	0.287	2.001	99.1	97.1
5.048	2	0.287	1.938	99.2	97.5
1.048	2	0.215	1.749	98.3	95.7
2.512	2	0.215	1.921	99.1	97.7
5.048	2	0.215	2.001	99.5	98.1

by Kissick *et al*.[21] were used for all the three different field widths. The system will not allow a pitch value more than 0.5. Twenty-five plans were created with different possible pitch values, magic pitches, and field widths as shown in Table 1. For 1–15 and 17–25 plans, 2 Gy dose was prescribed to target mean option in each plan in one fraction. 15 Gy dose was prescribed to plan 16. Figure 2 depicts one of the TomoTherapy plans in the planning system with virtual target. Dose was calculated, and treatment fraction was created as delivery quality assurance (DQA) plan. A gamma index criteria of 3% dose difference (DD) and 3 mm DTA with 90% passing rate were used in the present study. All plans created with the virtual target were then delivered using MultiCube setup. The matrix was calibrated as per the manufacturer guidelines. 15–20 min warm up and 1–2 Gy preirradiation are required for the MatriXX array in order to eliminate noises and to keep its dose response uniform.

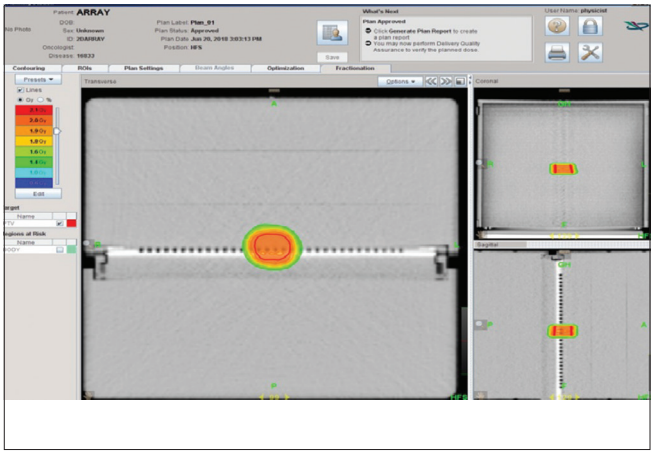


Figure 2: Treatment planning with virtual planning target volume in TomoTherapy planning station

MultiCube with 2D array was placed on the TomoTherapy couch and adjusted as per the planning laser position. It was also adjusted for couch sag. MVCT verification was done for the setup accuracy. Then, patient DQA plans were executed, and the fluence was recorded. The dose distributions measured by the I'MatriXX 2D-array ion chambers were compared with those calculated by TomoTherapy VoLO plans. First, the data file from Omnipro-IMRT software was exported to the TomoTherapy treatment planning workstation to register this file with the data file calculated by the planning station. After proper registration, analysis can be done in this planning station itself with limited options. An intensity map file was imported into matrix computer system for the analysis with Omnipro software version 1.7 b (IBA dosimetry, GmbH, Germany) which has all the options for verification, same as linac plans. The analysis is similar to our routine IMRT plans with linear accelerators. The gamma-passing percentage was determined for each plan and compared to its calculated dose

Table 2: The gamma-passing percentages of patient plans

Plan number	Field width used (cm)	Treatment site	Target volume (cc)	Dose per fraction	Passing rate	
					Using Omnipro software (3%, 3 mm)	Using Omnipro software (2%, 2 mm)
1	2.5	Prostate 1	747.87	2.7 Gy	99.1	91.6
2	2.5	Prostate 2	563.80	2.7 Gy	99.7	91.8
3	2.5	Prostate 3	511.33	2.7 Gy	98.3	94.3
4	2.5	Prostate 4	538.14	2.7 Gy	98.1	92.5
5	2.5	Esophagus 1	289.17	3.5 Gy	97.7	90.7
6	2.5	Esophagus 2	640.78	1.8 Gy	93.7	86.4
7	2.5	Larynx	288,682,748	2.2, 2, 1.8 (SIB)	96.0	80.2
8	2.5	Nasopharynx	151,683	2.12, 1.8 (SIB)	91.5	83.6
9	5	Tongue 1	660.19	2 Gy	98	89.8
10	2.5	Tongue 2	524.13	2 Gy	91.5	85.9
11	2.5	Buccal mucosa	401	2 Gy	97.3	92.3
12	2.5	Rectum 1	976	1.8 Gy	97.7	93.2
13	5	Rectum 2	1327	2 Gy	87.1	80.3
14	2.5	Cervix 1	883.52	2 Gy	94.4	90.4
15	5	Cervix 2	1189.9	2 Gy	90.7	86.5
16	2.5	Cervix 3	924.79	2 Gy	97.2	91.2
17	2.5	Cervix 4	855.42	2 Gy	98.8	95.8
18	5	Spine	382	1.2 Gy	95.4	90.1
19	2.5	Liver 1	127.3	8 Gy	95.3	88.7
20	1	Liver 2	46.1	12 Gy	96.8	89.8
21	2.5	Liver 3	110.6	8 Gy	95.1	87.4
22	1	Brain	116.77	18 Gy	97.1	92.5
23	2.5	Lung	677.86	2 Gy	93.7	81.2
24	2.5	Bladder	688	2 Gy	98.8	97.3
25	5	TBI 1	44,925.1 (ROI used)	2 Gy	95.5	92.3
26	5	TBI 2	34,200.6 (ROI used)	2 Gy	96.8	94.5

ROI: Region of interest, TBI: Total body irradiation, SIB: Simultaneous integrated boost

in TPS. After the verification of passing rates of these plans with virtual planning target volume (PTV), we proceeded to the patient plans. QA of 26 plans from different treatment sites of the body such as brain, esophagus, larynx, cervix, tongue, prostate, and also total body irradiation (TBI) was used in this study. Plans were chosen to cover different body lesions. A variety of treatments such as conventional fractionated, hypofractionated, simultaneous integrated boost (SIB), and SBRT plans were selected. Region of interest to fit the matrix size was selected in the TBI cases. The same passing criterion was used in these cases also as shown in Table 2.

Results and Discussions

All the plans were analyzed following the above procedure. Table 1 summarizes the gamma-passing rates for 25 plans of virtual PTV. Using the 3% and 3 mm criteria, plans with various pitches, field widths, and modulation factors showed good agreement, with the percent of points <1 being more than or equal to 99% of 2-mm calculation grid. In order to further evaluate the performance, we analyzed our results using a stringent, 2% DD and 2 mm DTA also. Now, the number of points with gamma index ≤1 was reduced when compared to previous data using the 3% DD and 3 mm DTA in most of the plans though all were passed. 5-cm width had the highest passing percentages even with these stringent constraints, whereas 2.5-cm width showed slightly lower passing rate than 5 cm, and low passing rates were observed in the plans which used the lowest field width. This is mainly due to the leaf-opening inaccuracies[22] because of small leaf opening time with small width-based plans. This 1-cm leaf width is very rarely used clinically because of more treatment delivery time. These results indicated that, using 3%, 3 mm criteria, I'MatriXX response was independent of field width, pitch, and modulation factor of TomoTherapy in all our selected scenarios in which the virtual target was centrally located to the phantom and was validated successfully for performing PSQA. However, the response was not independent with stringent constraints.

The QA time has been reduced to half using MatriXX. Gamma-passing rates of patient plans are tabulated in Table 2. Comparison between planned and measured dose with MatriXX is shown in Figure 3. A high passing rate ranging from 99.7% to 90.7% was observed with an average of 95.8%. All the patient plans except one showed acceptable passing rates with I'MatriXX irrespective of cancer site using 3%, 3 mm passing criteria. However, there was a considerable difference with 2%,

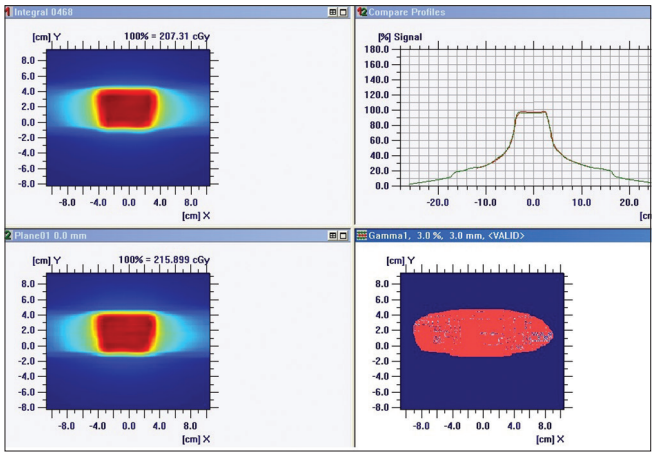
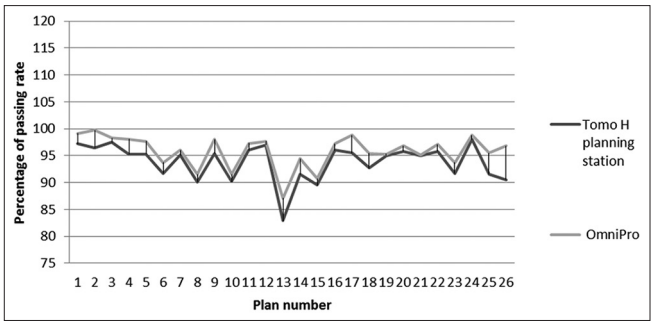


Figure 3: Plan comparison with Omnipro software in one of the prostate cases

2 mm criteria, and we observed few failed cases. One plan which had very complex dose distribution due to irregular target failed with 3%, 3 mm, as mentioned in Table 2 but passed with 4%, 3 mm criteria. The International Commission of Radiation Units and Measurements report 83[23] proposed a less stringent passing criteria of 5%/5 mm because of these types of complicated cases. Fewer rates in some of the cases, comparatively, were observed due to the complexity in the dose distribution with high dose gradients and distance from the central axis. Plans with conventional, SIB, and hypofractionation did not have any influence on the passing rates. Angular dependency of this 2D array was also found negligible because of these results. This is already observed in previous investigations.[24] Pitches and field widths were selected as per the requirements of better planning results. This shows that PSQA with matrix exhibited good agreement for most of the treatment lesions of the body with 3%, 3 mm criteria but does not agree with stringent constraints. To test its pick up, we introduced error in the setup of one QA plan, without applying couch sag. The passing result reduced 32% than its true value. Finally, we analyzed the passing rates of these plans with DQA TomoTherapy software also. The comparison between Omnipro software passing rates with TomoTherapy planning station software is shown in Graph 1. This clearly indicates that Omnipro system showed better results and is mainly due to the fact that the TomoTherapy software has limited analysis options.

Conclusions

Planar dose verification is very critical and important in the rotational intensity-modulated radiation delivery. 2D array can be utilized for easy and quick dosimetry. I'MatriXX response is independent of pitch and modulation factor of TomoTherapy and proved accurate with clinical criteria of 3% dose difference and 3 mm DTA. However, discrepancies were observed with stringent constraints. The gamma passing rates in Omnipro analysis were found to be agreeing well with those in TomoTherapy workstation analysis. Hence, it is a good and suitable option for PSQA for any conformal technique possible with TomoTherapy.



Graph 1: Comparison of the passing rates between TomoTherapy system software and Omnipro software from IBA

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Teh BS, Woo SY, Butler EB. Intensity modulated radiation therapy (IMRT): A new promising technology in radiation oncology. Oncologist 1999;4:433-42.
2. Webb S, Convery DJ, Evans PM. Inverse planning with constraints to generate smoothed intensity-modulated beams. Phys Med Biol 1998;43:2785-94.
3. Fuss M, Shi C, Papanikolaou N. Tomotherapeutic stereotactic body radiation therapy: Techniques and comparison between modalities. Acta Oncol 2006;45:953-60.
4. Kinhikar RA, Jamema SV, Reenadevi, Pai R, Zubin M, Gupta T, *et al.* Dosimetric validation of first helical TomoTherapy® hi-art II machine in India. J Med Phys 2009;34:23-30.
5. Chang IC, Chen J, Yartsev S. Performance characteristics of an independent dose verification program for helical TomoTherapy®. J Med Phys 2017;42:156-62.
6. Cheung T, Butson MJ, Yu PK. Measurement of high energy x-ray beam penumbra with Gafchromic EBT radiochromic film. Med Phys 2006;33:2912-4.
7. Fiandra C, Ricardi U, Ragona R, Anglesio S, Giglioli FR, Calamia E, *et al.* Clinical use of EBT model Gafchromic film in radiotherapy. Med Phys 2006;33:4314-9.
8. Wilcox E, Daskalov G, Nedialkova L. Comparison of the Epson expression 1680 flatbed and the Vidar VXR-16 dosimetry PRO film scanners for use in IMRT dosimetry using Gafchromic and radiographic film. Med Phys 2007;34:41-8.
9. Devic S, Seuntjens J, Abdel-Rahman W, Evans M, Olivares M, Podgorsak EB, *et al.* Accurate skin dose measurements using radiochromic film in clinical applications. Med Phys 2006;33:1116-24.
10. Price S, Williams M, Butson M, Metcalfe P. Comparison of skin dose between conventional radiotherapy and IMRT. Australas Phys Eng Sci Med 2006;29:272-7.
11. Ting JY, Davis LW. Dose verification for patients undergoing IMRT. Med Dosim 2001;26:205-13.
12. Xing L, Curran B, Hill R, Holmes T, Ma L, Forster KM, *et al.* Dosimetric verification of a commercial inverse treatment planning system. Phys Med Biol 1999;44:463-78.
13. Spezi E, Angelini AL, Romani F, Ferri A. Characterization of a 2D ion chamber array for the verification of radiotherapy treatments. Phys Med Biol 2005;50:3361-73.
14. Stasi M, Giordanengo S, Cirio R, Boriano A, Bourhaleb F, Cornelius I, *et al.* D-IMRT verification with a 2D pixel ionization chamber: Dosimetric and clinical results in head and neck cancer. Phys Med Biol 2005;50:4681-94.
15. Li JG, Yan G, Liu C. Comparison of two commercial detector arrays for IMRT quality assurance. J Appl Clin Med Phys 2009;10:2942.

16. Kumar S, Cheruparambil A, Thokkayil AP, Padmini SG, Perumangat A. Clinically evaluating directional dependence of 2D seven29 ion-chamber array with different IMRT plans. Int J Cancer Ther Oncol 2015;3:348.
17. Jursinic PA, Nelms BE. A 2-D diode array and analysis software for verification of intensity modulated radiation therapy delivery. Med Phys 2003;30:870-9.
18. Van Esch A, Clermont C, Devillers M, Iori M, Huyskens DP. On-line quality assurance of rotational radiotherapy treatment delivery by means of a 2D ion chamber array and the Octavius phantom. Med Phys 2007;34:3825-37.
19. Xu S, Xie C, Ju Z, Dai X, Gong H, Wang L, *et al.* Dose verification of helical TomoTherapy® intensity modulated radiation therapy planning using 2D-array ion chambers. Biomed Imaging Interv J 2010;6:e24.
20. Metcalfe P, Kron T, Hoban P. The Physics of Radiotherapy X-Rays and Electrons. Madison: Medical Physics Publishing; 2007.
21. Kissick MW, Fenwick J, James JA, Jeraj R, Kapatoes JM, Keller H, *et al.* The helical TomoTherapy® thread effect. Med Phys 2005;32:1414-23.
22. Westerly DC, Soisson E, Chen Q, Woch K, Schubert L, Olivera G, *et al.* Treatment planning to improve delivery accuracy and patient throughput in helical TomoTherapy®. Int J Radiat Oncol Biol Phys 2009;74:1290-7.
23. ICRU: Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT), in ICRU Jot (ed), Bethesda, MD, ICRU, 2010. p. 1-96.
24. Chandraraj V, Stathakis S, Manickam R, Esquivel C, Supe SS, Papanikolaou N. Comparison of four commercial devices for rapidArc and sliding window IMRT QA. J Appl Clin Med Phys 2011;12:3367.