Original Article

Free full text available from
www.cancerjournal.net

Dosimetric verification of brain and head and neck intensity-modulated radiation therapy treatment using EDR2 films and 2D ion chamber array matrix

ABSTRACT

Background: The evaluation of the agreement between measured and calculated dose plays an essential role in the quality assurance (QA) procedures of intensity-modulated radiation therapy (IMRT).

Aim: The purpose of this study is to compare performances of the two dosimetric systems (EDR2 and I'matriXX) in the verification of the dose distributions calculated by the TPS for brain and head and neck dynamic IMRT cases.

Materials and Methods: The comparison of cumulative fluence by using Kodak extended dose rate (EDR2) and I'matriXX detectors has been done for the evaluation of 10 brain, 10 head and neck IMRT cases treated with 6 MV beams. The parameter used to assess the quality of dose calculation is the gamma-index (γ -index) method. The acceptance limits for γ calculation we have used are 3% and 3 mm respectively for dose agreement and distance to agreement parameters. Statistical analyses were performed by using the paired, two-tailed Student *t*-test, and $P < 0.01$ is kept as a threshold for the significance level.

Results: The qualitative dose distribution comparison was performed using composite dose distribution in the measurement plane and profiles along various axes for TPS vs. EDR2 film and TPS Vs I'matriXX. The quantitative analysis between the calculated and measured dose distribution was evaluated using DTA and γ-index. The percentage of pixels matching with the set DTA and γ values are comparable for both with EDR2 film and I'matriXX array detectors. Statistically there was no significant variation observed between EDR2 film and I'matriXX in terms of the mean percentage of pixel passing γ for brain cases (98.77 ± 1.03 vs 97.62 ± 1.66, $P = 0.0218$) and for head and neck cases (97.39 ± 2.13 vs $97.17 \pm 1.52\%$, $P = 0.7404$).

Conclusion: Due to simplicity and fast evaluation process of array detectors, it can be routinely used in busy departments without compromising the measurement accuracy.

KEY WORDS: EDR2film, gamma index, I'matriXX, intensity-modulated radiation therapy

C. Varatharaj, M. Ravikumar, S. Sathiyan, Sanjay S. Supe, T. R. Vivek[1], A. Manikandan[1]

Department of Radiation Physics, Kidwai Memorial Institute of Oncology, Hosur Road, Bangalore - 560 029, [1]Department of Radiation Oncology, Manipal Hospital, Airport Road, Bangalore - 560 017, India

For correspondence:
Dr. M Ravikumar, Department of Radiation Physics, Kidwai Memorial Institute of Oncology, Hosur Road, Bangalore - 560 029, Karnataka, India.
E-mail: drravikumarm@gmail.com

DOI: 10.4103/0973-1482.65233

INTRODUCTION

In general, brain and head and neck cancers are devastating and life threatening. With the improvement in treatment technology and through multidisciplinary approaches more lives are being saved or prolonged. Radiation therapy has become one of the basic components of multidisciplinary treatment.[1] Several critical organs in the brain and head and neck regions are usually in close proximity to the tumor. This spatial characteristic makes radiation therapy for these types of cancers a very challenging task. For example, tumors originating in the pharyngeal wall are usually concave and wrap around the spinal cord and the parotid gland which is in proximity to the lymph nodes, which are usually involved; tumors arising from the paranasal sinuses often invade the space adjacent to the optic nerves or optic chiasm. The tolerance dose to these critical organs lie in the range of 30-60 Gy;[2] however, the dose needed to control gross tumor often exceeds 70 Gy.

Advances in computer and linac technology have also significantly impacted treatment of brain, head and neck cancers by improving our ability to maximize tumor dose while minimizing the dose to adjacent normal critical structures. Image-based treatment planning and multileaf collimators have both been widely implemented, facilitating both the planning and delivery of three-dimensional conformal radiation therapy (3DCRT). Recently, the development of delivering non-uniform radiation intensities is being used in the era of intensity-modulated radiation therapy (IMRT), representing the state of the art in the treatment of many head and neck cancers.[3]

IMRT is capable of generating complex 3D dose distributions to conform closely to the target volume even in tumors with concave features. With IMRT, the beam intensity (fluence) is optimized as it is oriented around the patient using computer algorithms. This form of computer algorithm considers not only the target and normal tissue dimensions but also user-defined constraints such as dose limits. This process is based on the "inverse treatment planning method" and is capable of generating significant dose gradients between the target volume and tissue structures to accomplish the intended dose-volume prescription.[4] Because of this specific feature, a precise mechanical system to deliver and validate the intended radiation dose to the desired area is crucial. An inverse prescription guideline that optimizes tumor target coverage and normal tissue sparing is an other pertinent component of IMRT treatment.

A number of studies have demonstrated the superiority of the physical dose distributions of IMRT compared to other modalities, with application in brain tumors, head and neck cancer treatment.[5-9] As the use of IMRT becomes more widespread in clinical practice, it is important to be able to verify that the planned and delivered dose distributions are appropriate. A variety of inverse planning techniques and delivery methods are in use,[10,11] and each of these presents its own challenges in terms of obtaining the optimal treatment plan for the patient and ensuring that the delivered dose distribution closely matches the planned distribution.

The evaluation of the agreement between measured and calculated dose plays an essential role in the quality assurance (QA) procedures of IMRT.[12] The qualitative evaluation of the treatment planning system calculation is made by superimposing the isodose distributions, either using software tools or by hand using printed isodose distributions and a light box. Beside the qualitative evaluation, the parameters used in our centre for quantifying the agreement between the calculations and measurements are the mean deviation in the absolute dose, evaluated in low dose gradient points and the distribution of the γ-index.[13-15]

The γ-index method has suggested dual criteria for the low (e.g., 3% dose differences) and the high (e.g., 3 mm distance) dose-gradient regions. The γ-index is formulated such that when it is smaller than 1, either the dose difference or the distance is less than its criterion, and when it is larger than 1, either the dose difference or the distance is larger than its criterion. In other words, the patient plan is accepted when $\gamma \leq 1$ and rejected when $\gamma > 1$.[16] The results of dose verification using this method includes all the systemic and random errors that are generated by the measurement procedure.

The relationship or association between two quantitatively measured variables is called correlation and the strength of that relationship between two sets of figures is measured in terms of a parameter called correlation coefficient, which is denoted as *r*. The extent of correlation coefficient varies between minus one and plus one i.e., $-1 \leq 0 \geq 1$. If $r = -1$ indicates perfect inverse correlation between the two variables, while $r = +1$ indicates perfect direct linear correlation. If *r* lies between 0 and 1, i.e., $0 < r > 1$, it is described as moderately positive correlation.[17]

Film dosimetry has been widely adopted for this purpose due to excellent film characteristics in terms of spatial resolution; unfortunately, it is a time-consuming procedure and requires great care if film has to be used as an absolute dosimeter.[18] If this is not the case, then an independent ionometric measurement is mandatory to assess the absolute dose agreement. Arrays of detectors are now replacing films for routine IMRT QA, since they permit very simple verification procedures. They show excellent characteristics in terms of linearity, repeatability, and independence of the response from the dose rate, but at the same time present a moderate spatial resolution, due to limited number of detectors available.

In our institute, an ionization chamber array matrix (I'matriXX, Scanditronix Wellhofer) is used for routine IMRT QA. The aim of this study is to compare the performances of the two dosimetric systems (Kodak EDR2 film and I'matriXX) in the verification of the dose distributions calculated by the TPS for the brain and head and neck dynamic IMRT cases.

MATERIALS AND METHODS

Starting from January 2007, more than 200 patients have been treated in our center with IMRT for prostate, brain, breast, and head and neck cancer diseases. All treatments have been delivered by means of a dynamic multileaf collimator (dMLC, with 120 Millennium MLC) using Clinac 2100 - DHX linear accelerator (Varian Medical Systems, Palo Alto, CA). Absolute dose calibration is performed according to IAEA TRS 398(13) code of practice in a low dose gradient region using a FC-065 Farmer ionization chamber, coupled with a DOSE1 electrometer (Scanditronix Wellhofer). The adopted treatment planning system is ECLIPSE.

Kodak extended dose rate (EDR2) films were used in our study. It is a very slow speed and fine-grain film. Double emulsion active layers formed by very fine mono dispersed cube micro crystals are coated on a 0.18 - mm Easter base, which allows processing of film in a conventional rapid film processor. The same batch of 10 × 12-inch EDR2 ready pack film and its calibration files were used throughout this study. The film image processing was carried out with the Omnipro IMRT software using VXR-16 Dosimetry scanner (Vidar systems corporation, Herndon, VA) at full resolution (178 μm/pixel). The scanner was calibrated using standard film with optical density ranging from 0.05 to 2.98. The film calibration was carried out for the known dose values of 20 cGy to 350 cGy.

The 2D array of ion chamber matrix device consists of a 1020 vented ion chamber array detectors arranged in 32 × 32 grids.

The each chamber volume is 0.08 cm^3 with the height of 5 mm and diameter of 4.5 mm. The maximum dose rate detectable by the detectors is 5 Gy/min and minimum of 0.1 Gy/min. The bias voltage required for the matrix system is 500±30 V. The maximum field of view is 24 × 24 cm^2. The matrix device can be directly connected to PC via standard Ethernet interface to acquire the measurement.

In order to verify an IMRT plan, a verification plan is produced from every original plan in the ECLIPSE treatment planning system. The CT data of the measurement system were used to estimate the fluence at depth for these verification plans. The I'matriXX device with 5 cm solid water phantom positioned above it was scanned with 2 mm CT slice thickness. The verification plan is exported to the scanned detector system with the detector plane positioned at isocenter. In the verification plan, the gantry and collimator angels were set to 0º. The beam central axis was made perpendicular to the I'matriXX measurement level at the center of the measurement area. With the treatment field, the cumulative fluence at the detector plane was calculated and transferred to the Omnipro software for comparison. All the plans were exported to the accelerator console and the same was delivered and measured by the I'matriXX device. The measured fluence was compared with the TPS-generated fluence using the gamma index (γ-index) method. The same fluence verification measurement was also carried out in the solid water phantom using EDR2 film. The film was positioned at a 5 cm depth in a solid water phantom with 10 cm of scattering material placed at the bottom. The above-mentioned phantom set was CT scanned similar to the I'matriXX phantom to create verification plan in the Eclipse treatment planning system.

In the present work, the comparison of cumulative fluence by using Kodak EDR2 and I'matriXX detectors have been employed for the evaluation of 10 brain and 10 head and neck IMRT cases treated with 6 MV beams. Statistical analyses were performed by using a paired two-tailed Student *t*-test to determine if there was a significant difference in any of the parameters examined. Differences were considered statistically significant at $P < 0.01$.

RESULTS

The measured dose distributions were compared with TPS-calculated distributions for 10 brain and 10 head and neck cases using both EDR2 film and I'matriXX device. The qualitative dose distribution comparison was performed using composite dose distribution in the measurement plane and profiles along various axes. The comparison between the TPS calculated and EDR2 film measured profiles for a brain case are shown in Figure 1, and Figure 2 shows the comparison of profiles between TPS and I'matriXX. The corresponding isodose comparison distributions are shown in Figures 3 and 4. Similar comparison of profiles for head and neck cases is shown in Figures 5 and 6 and the dose distribution comparison were made in Figures 7 and 8.

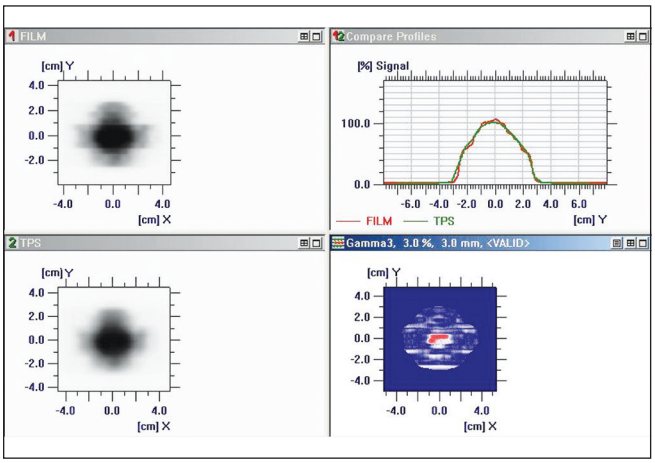

Figure 1: Comparison of EDR2 profile over the TPS plan for a brain case

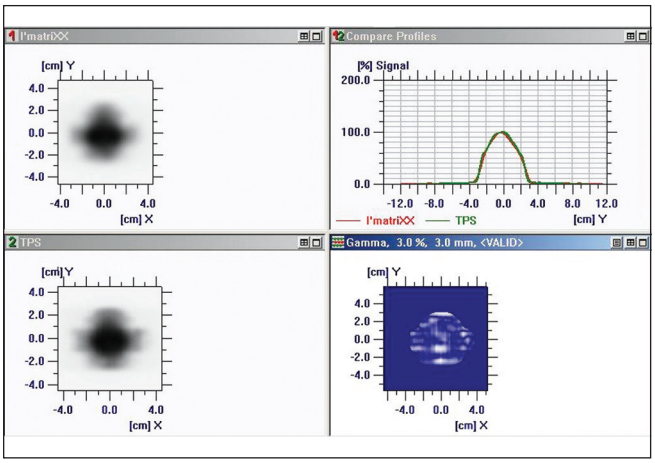

Figure 2: Comparison of I'matriXX profile over the TPS plan for a brain case

In our study, the correlation coefficients were calculated for TPS vs EDR2 film and TPS vs I'matriXX and the values lie between 0 and 1. The quantitative analysis between the calculated and measured dose distribution was evaluated using DTA and γ-index. The tolerance of 3% dose difference and 3 mm DTA and γ tolerance ≤ 1 was set for the analyses. The correlation coefficients, percentage of pixels passing DTA, and γ values for the brain and head and neck are shown in Tables 1 and 2 respectively for both detector systems.

The mean correlation coefficient was observed for brain and head and neck cases between EDR2 film and I'matriXX as 0.9967 ± 0.0008 vs 0.9948 ± 0.0047, $P = 0.2792$ and 0.9966 ± 0.0021 vs 0.9961 ± 0.0018, $P = 0.3867$, respectively. The mean percentage of pixel passing set gamma for brain cases was observed to be 98.77 ± 1.03 for EDR2 film and 97.62 ± 1.66 for I'matriXX ($P = 0.0218$ and the similar results for head and neck cases were 97.38 ± 2.13 and 97.16 ± 1.52 respectively ($P = 0.7404$). The mean percentage of pixels passing set DTA for brain cases was noted as 96.40 ± 2.17 and 95.65 ± 2.57

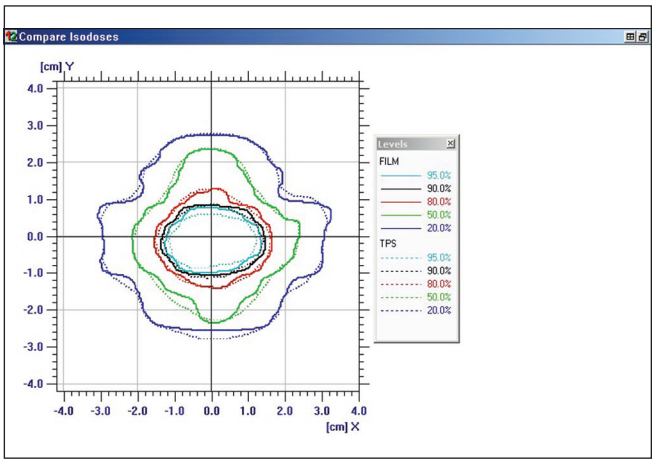

Figure 3: Comparison of EDR2 dose distributions over the TPS plan for a brain case

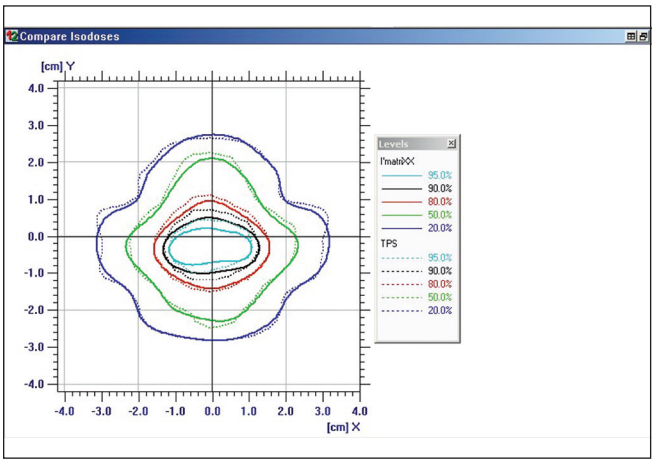

Figure 4: Comparison of I'matriXX dose distributions over the TPS plan for a brain case

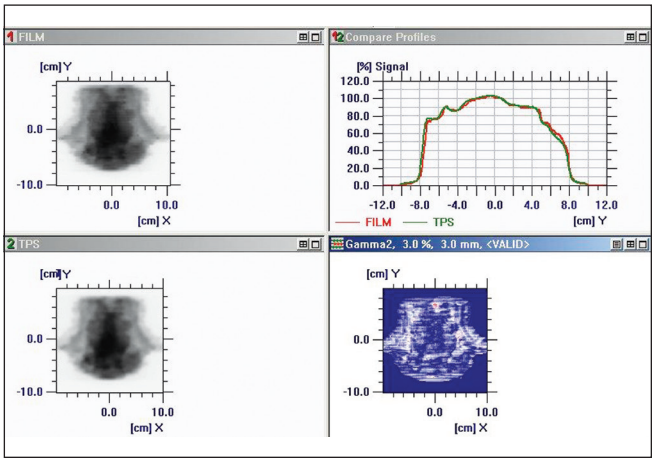

Figure 5: Comparison of EDR2 profile over the TPS plan for a head and neck case

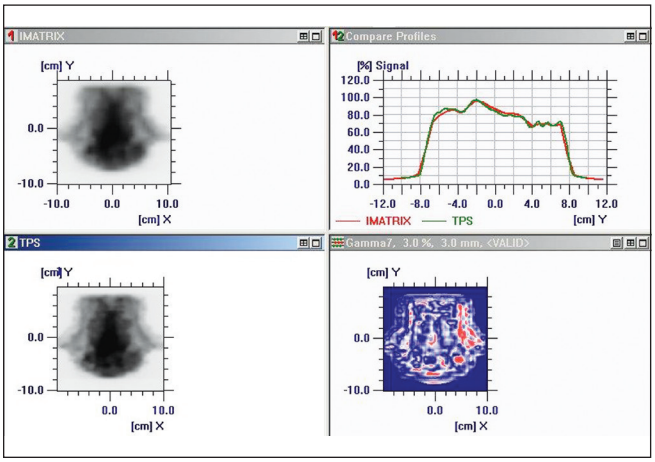

Figure 6: Comparison of I'matriXX profile over the TPS plan for a head and neck case

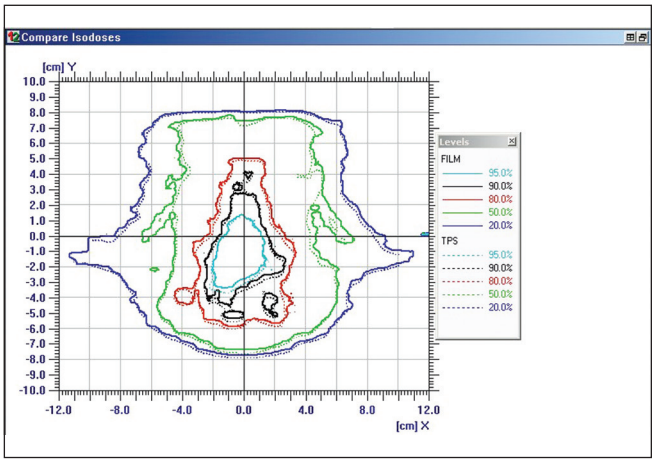

Figure 7: Comparison of EDR2 dose distributions over the TPS plan for a head and neck case

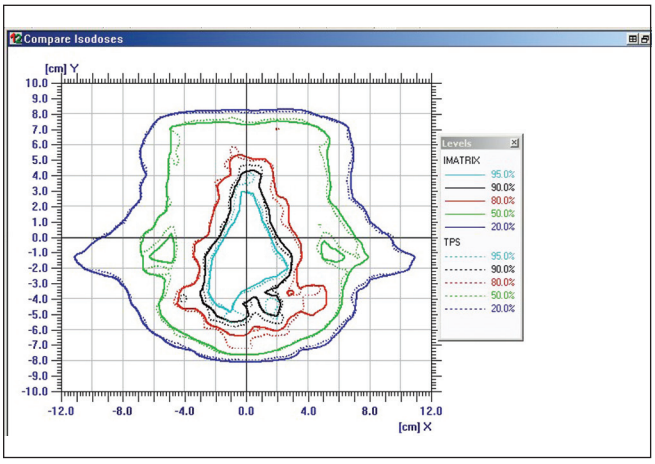

Figure 8: Comparison of I'matriXX dose distributions over the TPS plan for a head and neck case

respectively for EDR2 and I'matriXX devices ($P = 0.2394$) and the same for head and neck cases were 90.90 ± 1.83 and 92.16 ± 2.59 respectively ($P = 0.0681$).

DISCUSSION

It was noted that, from the qualitative analysis using

Table 1: Comparison of correlation coefficient, percentage of pixels passing gamma and DTA for the brain IMRT cases with EDR2 film and I'matriXX

S. no	Correlation coefficient		% of pixels passing Gamma (γ)		% of pixels passing DTA	
	EDR2	I'matriXX	EDR2	I'matriXX	EDR2	I'matriXX
1	0.9963	0.9975	99.85	99.21	99.23	98.03
2	0.9973	0.9960	97.62	96.57	94.84	94.80
3	0.9974	0.9933	98.64	97.36	94.91	94.82
4	0.9966	0.9951	99.63	98.88	97.88	97.83
5	0.9974	0.9820	99.46	94.71	96.80	91.03
6	0.9952	0.9974	97.16	96.25	97.34	95.79
7	0.9973	0.9977	99.91	99.98	99.65	99.86
8	0.9973	0.9985	97.72	96.59	94.02	94.86
9	0.9970	0.9963	99.52	98.80	96.25	96.54
10	0.9955	0.9950	98.25	97.85	93.15	92.96
Mean	0.9967	0.9948	98.77	97.62	96.40	95.65
SD	0.0008	0.0047	1.03	1.62	2.17	2.57
P	0.2792		0.0218		0.2394	

Table 2: Comparison of correlation coefficient, percentage of pixels passing gamma and DTA for the head and neck IMRT cases with EDR2 film and I'matriXX

S. no	Correlation coefficient		% of pixels passing Gamma (γ)		% of pixels passing DTA	
	EDR2	I'matriXX	EDR2	I'matriXX	EDR2	I'matriXX
1	0.9977	0.9979	97.87	98.31	91.96	92.77
2	0.9980	0.9955	96.94	97.09	92.81	93.73
3	0.9979	0.9989	97.28	98.36	90.25	93.88
4	0.9975	0.9955	98.07	97.72	89.79	88.05
5	0.9980	0.9977	99.78	98.76	90.85	95.89
6	0.9975	0.9941	98.95	98.53	92.08	92.16
7	0.9960	0.9961	99.53	94.37	91.49	91.11
8	0.9966	0.9971	95.22	96.93	93.52	95.09
9	0.9960	0.9948	92.63	94.83	88.25	89.55
10	0.9910	0.9935	97.60	96.77	88.01	89.41
Mean	0.9966	0.9961	97.38	97.16	90.90	92.16
SD	0.0021	0.0018	2.13	1.52	1.83	2.59
P	0.3867		0.7404		0.0681	

composite dose distribution in the measurement plane and profiles along various axes, there were no significant differences in the isodose distribution as well as the profile comparisons for most of the cases.

Herzen *et al* presented the results of a dosimetric evaluation of the I'matriXX array with the objective of its implementation for quality assurance in clinical routine. The dose and energy dependence, the behavior of the device during its initial phase and its time stability, as well as the lateral response of a single chamber of the detector in cross-plane and diagonal directions were also analyzed. It has been shown that the detector's response is linear with dose and is energy independent. The measured pyramidal test and IMRT dose distribution were compared with the treatment planning system. From their study, they have concluded that the detector is a suitable device for routine quality assurance and 2D dose verifications.[19]

Film dosimetry is a well-established and standard method for verifying two-dimensional IMRT dose distributions with high spatial resolution. The film sensitivity depends on photon energy and dose rate and the film dosimetry requires a stringent processing conditions.[20] Poppe *et al* compared the film dosimetry with the 2D array for the IMRT plan verification and concluded that the 2D array has proven to be more time efficient because the analysis can be performed without any further calibration or scanning procedures.[21]

From Tables 1 and 2, it can be noted that the percentage of pixels matching with the set DTA and γ values are comparable for EDR2 film and I'matriXX array detectors. No significant variation was found between the EDR2 film and I'matrix array detectors in both brain and head and neck IMRT cases in any of the parameters analyzed. The small variation noted could be due to the set up and measurement uncertainty. Our results demonstrate that I'matriXX may be used for routine QA of IMRT treatments. As a consequence, I'matriXX may substitute for film dosimetry in routine IMRT QA tasks. Moreover, using I'matriXX as absolute dosimeter avoids the time-consuming procedure of exposing, processing, and evaluating the films for fluence verification.

CONCLUSION

In the present study a comparison has been made using I'matriXX array detectors and the EDR2 film dosimetry for the routine QA procedure of brain and head and neck IMRT treatments. The calculated dose using the Eclipse treatment planning system was compared qualitatively and quantitatively with the measured dose using I'matriXX and EDR2 films. Though it is claimed that the film dosimetry is superior due to its better resolution compared to array detectors, it was observed that the results from these two dosimetry systems does not vary much. Due to its simplicity and fast evaluation process, array detectors can be routinely used in busy departments without compromising the measurement accuracy.

ACKNOWLEDGEMENT

The authors would like to thank the service engineers, C.Gobinathan and Azmath Ulla (Varian Medical Systems) for their timely technical help. Our sincere thanks to Dr. Y. S. Pawar, Department of Radiotherapy, KMIO for his valuable discussion related to the Clinical concepts and to Dr. Shanmugam, Department of Bio-Statistics, NIMHANS for his valuable guidance on the statistical analysis.

REFERENCES

1. Chao KS, Low DA, Perez CA, Purdy JA. Intensity-modulated radiation therapy in head and neck cancers: The Mallinckrodt experience. Int J Cancer 2000;90:92-103.
2. Emami B, Lyman J, Brown A, Coia L, Goitein M, Munzenrider JE, *et al*. Tolerance of normal tissue to therapeutic irradiation. Int J Radiat Oncol Biol Phys 1991;21:109-22.
3. Purdy JA. Advances in three-dimensional treatment planning and conformal dose delivery. Semin Oncol 1997;24:655-71.
4. Carol MP. Integrated 3D conformal planning/multivane intensity

modulating delivery system for radiotherapy. 3D radiation treatment planning and conformal therapy. In: Purdy JA, Emami B, editors. Madison, WI: Medical Physics Publishing; 1995. p. 435-45.
5. Burman C, Chui CS, Kutcher G, Leibel S, Zelefsky M, LoSasso T, *et al*. Planning, delivery and quality assurance of intensity-modulated radiotherapy using dynamic multileaf collimator: A strategy for large-scale implementation for the treatment of carcinoma of the prostate. Int J Radiat Oncol Biol Phys 1997;39:863-73.
6. Cardinale RM, Benedict SH, Wu Q, Zwicker RD, Gaballa HE, Mohan R. A comparision of three streotactic radiotherapy techniques: ARCS vs. noncoplanar vs. intensity modulation. Int J Radiat Oncol Biol Phys 1998;42:431-6.
7. Pickett B, Vigneault E, Kurhanewicz J, Verhey L, Roach M. Static field intensity modulation to treat a dominant intra-prostatic lesion to 90 Gy compared to seven field 3-dimensional radiotherapy. Int J Radiat Oncol Biol Phys 1999;44:921-9.
8. Reinstein LE, Wang XH, Burman CM, Chen Z, Mohan R, Kutcher G, *et al*. A feasibility study of automated inverse treatment planning for cancer of the prostate. Int J Radiat Oncol Biol Phys 1998;40:207-14.
9. Agazaryan N, Solberg TD, DeMarco JJ. Patient specific quality assurance for the delivery of intensity modulated radiotherapy. J Appl Clin Med Phys 2003;4:40-50.
10. Bedford JL, Childs PJ, Warrington AP. Verification of inverse planning and treatment delivery for segmental IMRT. J Appl Clin Med Phys 2004;5:1-17.
11. Webb S. Intensity - modulated radiation therapy - Series in Medical Physics, Instiute of Physics Publishing, Dirac house, Temple Back, Bristol BS1 6BE, UK, 2001.
12. Buonamici FB, Compagnucci A, Marazzo L, Russo S, Bucciolini M. An intercomparision between film dosimetry and diode matrix for IMRT quality assurance. Med Phys 2007;34:1372-9.
13. Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distributions. Med Phys 1998;25:656-61.
14. Low DA, Dempsey JF. Evaluation of the gamma dose distribution comparison method. Med Phys 2003;30:2455-64.
15. Depuydt T, Van Esch A, Huyskens DP. A quantitative evaluation of IMRT dose distributions: Refinement and clinical assessment of the gamma evaluation. Radiother Oncol 2002;62:309-19.
16. Harms WB Sr, Low DA, Wong JW, Purdy JA. A software tool for the quantitative evaluation of of 3D dose calculation algorithms. Med Phys 1998;25:1830-6.
17. Mahajan BK. Methods in biostatistics for medical students and research workers, Jaypee Brothers Medical Publishers (P) Ltd. New Delhi; 1991; p 183-91.
18. Ju SG, Ahn YC, Huh SJ, Yeo IJ. Film dosimetry for intensity modulated radiation therapy: Dosimetric evaluation. Med Phys 2002;29:351-5.
19. Herzen J, Todorovic M, Cremers F, Platz V, Albers D, Bartels A, *et al*. Dosimetric evaluation of a 2D pixel ionization chamber for implementation in clinical routine. Phys Med Biol 2007;52:1197-208.
20. Martens C, Claeys I, De Wagter C, De Neve W. The value of radiographic film for the characterization of intensity-modulated beams. Phys Med Biol 2002;47:2221-34.
21. Poppe B, Blechschmidt A, Djouguela A, Kollhoff R, Rubach A, Willborn KC, *et al*. Two-dimensional ionization chamber arrays for IMRT plan verification. Med Phys 2006;33:1005-15.

Source of Support: Nil, **Conflict of Interest:** None declared.