Study of 2D ion chamber array for angular response and QA of dynamic MLC and pre-treatment IMRT plans

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ABSTRACT

AIM: To study of 2 Dimensional ion chamber array for angular response and its utility for quality assurance of dynamic multileaf collimator and pretreatment intensity modulated radiotherapy plans.

MATERIALS AND METHODS: The MLC QA test patterns and IMRT plans were executed on 2D ion chamber array having 1020 vented pixel ionization chambers. The dynamic MLC QA test patterns were chair test, x–wedge, pyramid, open swipe field, garden fence and picket fence. Performance of Dynamic wedges was compared with physical wedges. For IMRT verification, five patients with localized prostate carcinoma were planned using dynamic IMRT technique. Angular response of MatriXX was measured by exposing the system from different gantry angles.

RESULTS: Dynamic MLC QA tests such as chair, x-wedge, pyramid, and open swipe field were successfully verified. MatriXX was not able to recognize the bar pattern of picket test and garden fence test. The response of MatriXX gradually decreases from 0° to 180° angles and it was 7.7% less at 180° angle. The dynamic wedge profiles were matching with corresponding physical wedge profiles. For pretreatment IMRT QA, the average dose difference between planned and measured dose was 1.26% with standard deviation of 1.06.

CONCLUSION: I'mRT MatriXX can be used for routine dynamic MLC and IMRT pretreatment QA but care should be taken while taking measurements in penumbra region because of its limited spatial resolution.

KEY WORDS: IMRT QA; Angular response of array; I'mRT MatriXX

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BACKGROUND

Intensity modulated radiotherapy (IMRT) is the advance form of 3 dimensional conformal radiotherapy (3DCRT). The clinical implementation of IMRT requires special quality assurance (QA) procedures for multileaf collimator (MLC) as well as for treatment machine commissioning, including patient-related routine QA beyond the ones currently performed for 3DCRT with the MLC [1–7]. IMRT allows the clinical implementation of highly conformal non-convex dose distributions with better surrounding critical organ sparing. But it involves the complex movement of multileaf collimator leaves, so pretreatment plan verification is necessary. Absolute dose verification is usually carried out with the help of free air type ionization chambers along central axis or at any other reference point. But absolute dose verification at one or two points does not suffice the purpose of plan verification because dose delivery is not uniform through out the field. Hence planned dose fluence is compared with deliverable dose fluence usually using film dosimetry. Now a days many electronic systems are available in the market to overcome the film dosimetry related problems. These systems mostly include the electronic portal imaging devices (EPID) or closely spaced 2 dimensional arrays of vented ionization chambers or diodes. In this study we have investigated the applications of one such system containing the 2 dimensional arrays of vented ionization chambers.

AIM

To study of 2 Dimensional ion chamber array for angular response and utility of ion chamber array for quality assurance of dynamic multileaf collimator and pretreatment intensity modulated radiotherapy plans.

METHOD AND MATERIALS

Linear Accelerator

Clinac DHX (Varian Medical Systems Inc., Palo Alto, CA), high energy linear accelerator (Linac) with photon energies 6 MV & 15 MV and fitted with Millennium 80 multileaf collimator was used in this study. Millennium 80 MLC system has 40 pairs of leaves in each bank and MLC leaf width projected at isocentre is 1 cm. The MLC leaf ends are rounded. The inter leaf leakage is minimized by tongue and groove arrangement. The maximum leaf speed is 3 cm/sec at isocentre.

Eclipse Planning system:

3 dimensional treatment planning system Eclipse version 7.5.51 (Varian Medical Systems Inc., Palo Alto, CA) with inverse plan optimization, was used for creating different treatment fields using 6 MV photon beam. The optimal fluence profiles calculated by inverse plan optimization were used by the leaf motion calculator program to produce MLC motion patterns. The dose calculation was done by Pencil Beam Convolution (PBC) algorithm incorporated in the 3D-TPS. The MLC workstation records the system status (MLC leaf positions) during dMLC treatment delivery every 50 ms to calculate leaf deviation statistics and histogram data. All the systems were networked through networking system ARIA (Varian Medical Systems Inc., Palo Alto, CA).

I'MRT MatriXX Array

The relative dosimetry was performed using OmniPro I'mRT software version 1.4.3.3 (IBA Dosimetry AB, Uppsala, Sweden) with 2D ionization chamber array, I'mRT MatriXXTM (IBA Dosimetry AB, Uppsala, Sweden). 2D ion chamber array, I'mRT MartiXX has 24.4 x 24.4 cm^2 active area and 1020 vented pixel ionization chambers with center-to-center distance of 7.62 mm (Fig. 1). The ionization chambers are cylindrical in shape with 4.5 mm diameter and 5 mm height, having total volume 0.08 cc. They are placed in a square pattern of 32 x 32 matrix. 4.5 cm and 4 cm solid water phantom slabs (SP34, Gammex Inc., Middleton, WI) were kept above and below the MatriXX, respectively. By putting 4.5 cm solid water phantom thickness, the effective point of measurement was at 5 cm from the top surface. Although MatriXX has sufficient inbuilt backscatter thickness (2.2 cm) for dose measurement from front side, but we kept additional 4 cm solid water phantom slabs below MatriXX for measuring its response from all directions. Radiation dose of 200 cGy was planned at iso-center from different gantry angles at an interval of 5° and corresponding reading were measured. This we carried out to check the feasibility of pretreatment IMRT QA and dose verification at actual treatment angles in spite of dose verification at gantry angle 0°. For warm up of MatriXX, 15 Gy radiation bath was given over 24 x 24 cm^2 active area. MatriXX calibration was performed for absolute dose measurement using 0.6 cc PTW UNIDOS (PTW-FREIBURG, Germany) free air type cylindrical ionization chamber. Appropriate temperature and pressure correction factors were also applied during absolute dose measurement. As in dynamic IMRT both dose and dose rate changes in space and in time, so MatriXX response was tested for dose linearity and dose rate dependence. The sampling time was kept 150 mSec during all measurements.

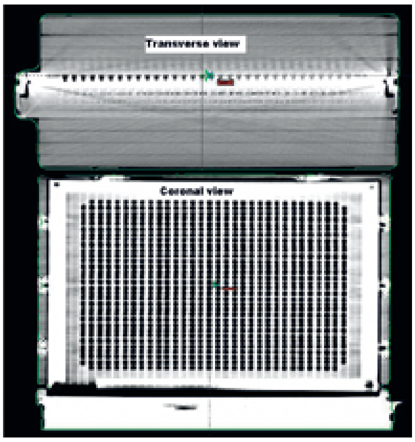

Fig. 1. Transverse and coronal view of MatriXX on CT slices.

MLC and Linac QA Procedures:
The MLC QA test patterns were designed for millennium 80 multileaf collimator using MLC shaper. The dynamic MLC QA test patterns were chair test, x–wedge, pyramid, peak test, open swipe field, garden fence and picket fence [8–10]. X-wedge test was designed using five different intensity levels, in 2 cm distance each. Pyramid test was designed using constant movement of opposing leaf pairs towards central axis. Peak test was designed using single leaf pair movement at 2.5, 5, 7.5, 10, and 15 mm gaps. Open swipe field was designed using 10 mm leaf gap with uniform MLC speed over 15 cm field width. The picket test was designed using the 15 leaf movements of 1 cm width at 1 cm interval. Garden fence test was designed using 2 mm leaf gap with 2 cm interval.

Other than these MLC QA tests we also checked the performance of Dynamic wedges of 15°, 30°, 45° and 60° with corresponding physical wedges. Percentage depth dose (PDD) profile was also measured for 10 x 10 cm^2 field size for 6 MV photon beam using MatriXX and solid water phantom slabs. The PDD values were compared with depth dose values obtained with an ion chamber RK (0.12 cc, IBA Dosimetry AB, Uppsala, Sweden) in 3D water phantom RFA-300. For all these measurements the gantry angle was kept 0°. For IMRT verification, five patients (7 fields each, total 35 fields) with localized prostate carcinoma were planned using dynamic IMRT technique on Eclipse treatment planning system. All test patterns and planned IMRT photon fluence were exported to CT scanned solid water phantom and MatriXX combination at 5 cm depth keeping SSD 95 cm. Dose calculation was done using 2.5 mm grid spacing. The MLC QA test patterns and IMRT plans were executed on 2D ion chamber array, I'mRT MartiXX.

To check the angular response of MatriXX, radiation dose of 2 Gy was planned at the isocentre from different gantry angles and corresponding angular response of MatriXXwas checked. The treatment couch top was tennis racket type so no attenuation factor was applied for radiation beams through couch.

Gamma method
Gamma method [11] was used to compare the planned dose distribution in TPS and delivered dose distribution on MatriXX for all test patterns. Gamma (γ) method is useful in measuring distance to agreement (DTA) in high gradient region, and sensitive to dose differences between calculated and delivered plan. The value of γ calculated by OmniPro I'mRT software was used for plan acceptance criteria. The plan was accepted only if more than 95% pixels having the value of $\gamma \leq 1$ in planned active area. The delta dose difference 3% and delta distance (DTA) 3 mm were taken for calculating gamma value.

RESULTS AND DISCUSSION

MatriXX dosimetric characteristics
Dose response of MatriXX was linear in 0.2 Gy to 8 Gy with maximum variation of 0.01% (Fig. 2). MatriXX shows over response at low dose rates (100 MU/min) and less response at higher dose rates (600 MU/min). But this dose rate dependence was with in 0.20% in range of 1-6 Gy/min. This dependence on dose rate may be because of definite sampling time. Amerio et al (12) also checked the dose and dose rate dependence of similar system and the response of pixel ionization chambers was linear in the dose range from 0.1 to 10 Gy. PDD measurement results were quite similar to RFA measurement. Maximum variation was 1.9% for 3 mm depth. On other depths the variation was less than 1% (Fig. 3).

MLC QA results
Dynamic MLC QA tests such as chair, x-wedge, pyramid, and open swipe field were successfully verified. For chair test, the dose difference between TPS calculated dose and MatriXX measured dose was 0.6% at prescription reference point along central axis (Fig. 4). 96.2% pixels passed the gamma analysis criterion in region of interest (ROI). In the peak test, the peaks, other than 2.5, 5 and 7.5 mm were successfully detected with dose difference less than 2.3%. But dose difference was 6.5% for 7.5 mm, 16.3% for 5 mm, and 39% for 2.5 mm peak. MatriXX was not able to recognize the bar pattern of picket test and garden fence test (Fig. 5). For all dynamic wedges, there was good agreement between TPS calculated and measured dose profiles. The dynamic wedge profiles were matching

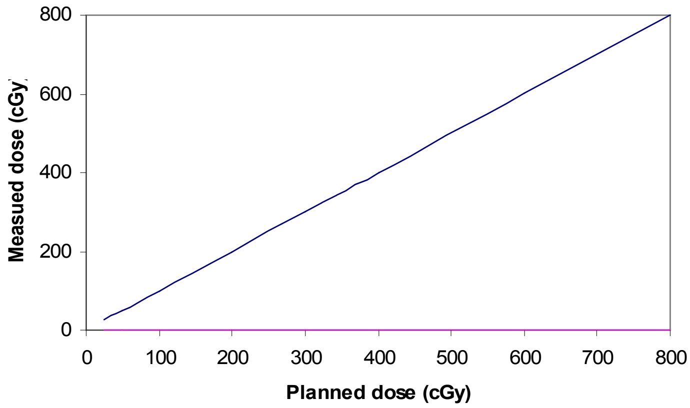

Fig. 2. Dose response of MatriXX over dose range 20 to 800 cGy.

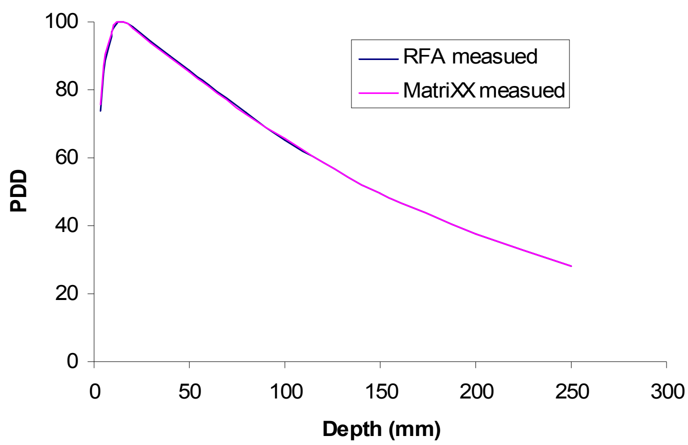

Fig. 3. PDD measurement comparison between RFA-300 and MatriXX

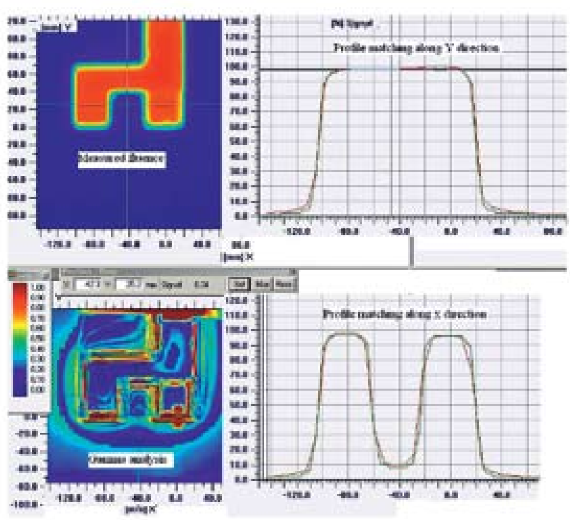

Fig. 4. Gamma Analysis and profile matching along X and Y direction for chair test.

with corresponding physical wedge profiles (Fig. 6). Table 1 shows the results of other QA tests and IMRT fields.

Most of test patterns successfully passed the gamma analysis criterion with more than 95% pixels in defined field size. But because of spatial resolution of 7.62 mm, MatriXX was not able to recognize garden fence, picket

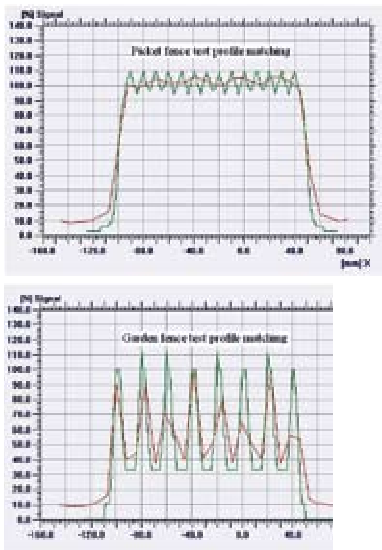

Fig. 5. Profile matching between TPS and MatriXX measurement along X direction for Picket and Garden fence test.

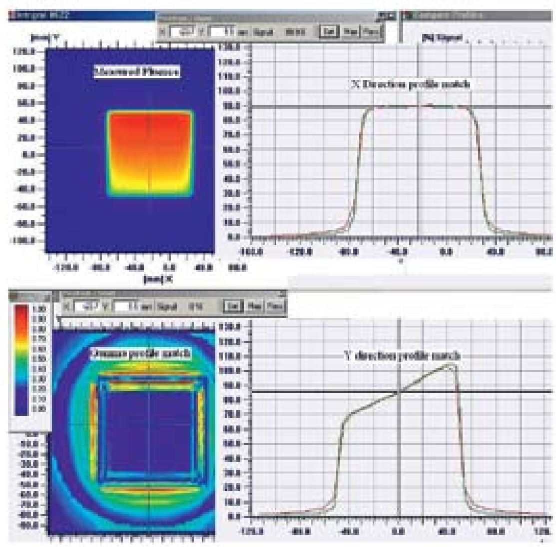

Fig. 6. Gamma Analysis and profile matching along X and Y direction for 45° wedge.

Table 1. Results of different QA tests and IMRT fields

Type of MLC QA test	% dose difference between TPS calculated and MatriXX measured dose along CAX	% of pixels passing gamma criterion in defined field size
Chair	0.60	96.20
x-wedge	0.50	98.28
Pyramid	0.45	99.20
Open swipe field	0.96	97.60
Dynamic wedge 15°	0.25	98.26
Dynamic wedge 30°	0.31	97.15
Dynamic wedge 45°	0.51	96.89
Dynamic wedge 60°	0.41	96.21
IMRT fields (Total = 35)	average =1.26 (SD = 1.06)	average = 95.12 (SD = 2.16)

fence, and 2.5 mm pattern in peak test, and was not able to reproduce the steep dose gradient in penumbra region. The measured dose difference was more than 3% in penumbra region especially in Y direction (perpendicular to MLC leaf movement) because dose distribution can not be faithfully reflected by linear interpolation in high dose gradient region by MatriXX. Other than penumbra region, all pixels successfully passed the gamma analysis.

Angular response of MatriXX

The MatriXX response shows dependence on angle of irradiation. The response of MatriXX gradually decreases from 0° to 180° angles and it was 7.7% less at 180° angle. Two sharp peaks shown in figure 7, represents the decrease in response due to radiation beam attenuation through carbon fiber side railings at these angles.

IMRT QA results

For pretreatment IMRT plan QA, the average dose difference between planned and measured dose was 1.26% with standard deviation of 1.06. On an average 95.12% pixels with SD 2.16, passed the gamma analysis test. Figure 8 shows the TPS calculated dose fluence and MatriXX measured dose fluence with gamma analysis and profile matching for one field of IMRT treatment. We also tried to perform the pretreatment IMRT QA on actual treatment angles but because of angu-

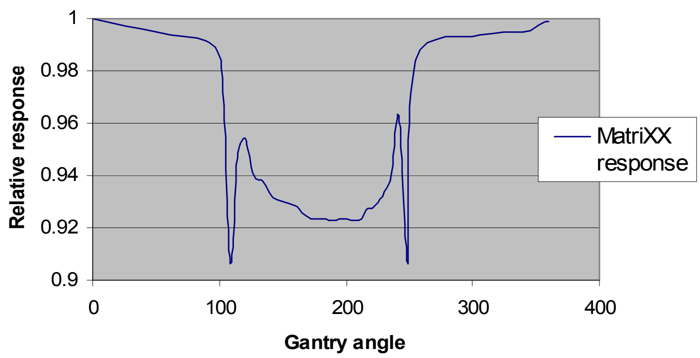

Fig. 7. Response of MatriXX with angle of irradiation

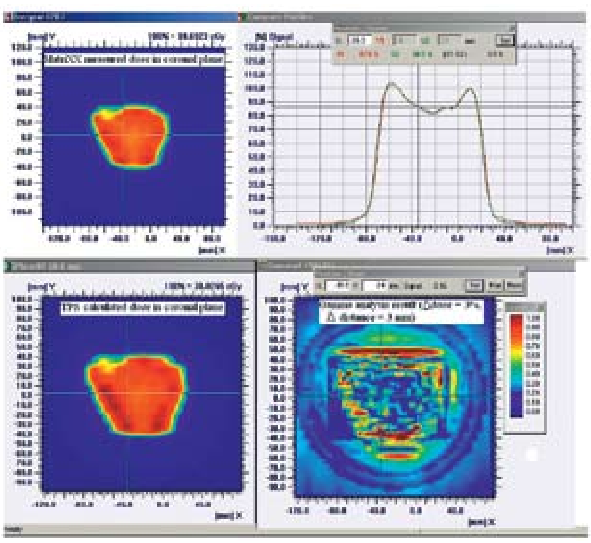

Fig. 8. TPS calculated and MatriXX measured dose profiles with Gamma analysis results with profile matching for one IMRT field

lar dependence of response of MatriXX, the variation between measured and calculated dose were more than 5%. The gamma analysis tests were not satisfied even for delta dose 5% and DTA 3 mm.

CONCLUSION

I'mRT MatriXX is able to measure absolute dose and dose distributions simultaneously. It can be used for routine dynamic MLC and IMRT pretreatment QA. As we have seen, its response was independent of dose and dose rate, so it has advantages in high dose regions over films. The MatriXX response is dependent on angle of irradiation, so it is not suitable for pretreatment IMRT QA at actual treatment angles and in rotational beam therapy such as tomotherapy. Because of its limited spatial resolution, care should be taken while taking measurements in penumbra region.

References

1. Boyer AL, Yu CX: Intensity modulated radiation therapy with dynamic multileaf collimator. Semin Radiat Oncol 1999; 9: 48–59
2. Klevin EE, Harms WB, Low DA, Willcut V, Purdy JA: Clinical implementation of a commercial multileaf collimator: Dosimetry, networking, simulation, and quality assurance. Int J Radiat Oncol Biol Phys 1995; 33: 1195–208.
3. Jordan TJ, Williams PC: The design characteristics of a multileaf collimator. Phys Med Biol 1994; 39: 231–51.
4. Kehwar TS, Bhardwaj AK, Chakarvarti SK: Evaluation of dosimetric effect of leaf position in a radiation field of an 80-leaf multileaf collimator fitted to the LINAC head as a tertiary collimator. J Appl Clin Med Phy 2006; 7: 43–54
5. Van Esch A, Bohsung J, Sorvari P, et al: Acceptance test and quality control (QC) procedures for the clinical implication of intensity modulated radiotherapy (IMRT) using inverse planning and sliding window technique: Experience from five radiotherapy departments. Radiother Oncol 2002; 65: 53–70
6. Essers M, de Langen M, Dirkx MLP, Heijmen BJM: Commissioning of a commercially available system for intensity-modulated radiotherapy dose delivery with dynamic multileaf collimation. Radiother Oncol 2001; 60: 215–24
7. Bayouth JE, Wendt D, Morrill SM: MLC quality assurance techniques for IMRT applications. Med Phys 2003; 30: 743–50
8. Bhardwaj AK, Kehwar TS, Chakarvarti SK, Oinam AS, Sharma SC: Dosimetric and qualitative analysis of kinetic properties of millennium 80 multileaf collimator system for dynamic intensity modulated radiotherapy treatments. J Can Res Ther 2007; 3: 23–8
9. Chui CS, Spirou S, LoSasso T: Testing of dynamic multileaf collimation. Med Phys 1996; 23: 635–41
10. LoSasso T, Chui CS, Ling C: Physical and dosimetric aspects of a multileaf collimation system used in the dynamic mode for implementing intensity modulated radiotherapy. Med Phys 1998; 25: 1919–27
11. Low DA, Harms WB, Mutic S, Purdy JA: A technique for the quantitative evaluation of dose distribution. Med Phys 1998; 25: 656–61
12. Amerio S, Boriano A, Bourhaleb F et al: Dosimetric characterization of a large-area pixel-segmented ionization chamber. Med Phys 2004; 31: 414–20