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# IMRT implementation and patient specific dose verification with film and ion chamber array detectors

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Implementation of Intensity Modulation Radiotherapy (IMRT) and patient dose verification was carried out with film and I'mariXX using linear accelerator with 120-leaf Millennium dynamic multileaf collimator (dMLC). The basic mechanical and electrical commissioning and quality assurance tests of linear accelerator were carried out. The leaf position accuracy and leaf position repeatability checks were performed for static MLC positions. Picket fence test and garden fence test were performed to check the stability of the dMLC and the reproducibility of the gap between leaves. The radiation checks were performed to verify the position accuracy of MLCs in the collimator system. The dMLC dosimetric checks like output stability, average leaf transmission and dosimetric leaf separation were also investigated. The variation of output with gravitation at different gantry angles was found to be within 0.9%. The measured average leaf transmission for 6 MV was 1.6% and 1.8% for 18 MV beam. The dosimetric leaf separation was found to be 2.2 mm and 2.3 mm for 6 MV and 18 MV beams. In order to check the consistency of the stability and the precision of the dMLC, it is necessary to carryout regular weekly and monthly checks. The dynalog files analysis for Garden fence, leaf gap width and step wedge test patterns carried out weekly were in good agreement. Pretreatment verification was performed for 50 patients with ion chamber and I'matiXX device. The variations of calculated absolute dose for all treatment fields with the ion chamber measurement were within the acceptable criterion. Treatment Planning System (TPS) calculated dose distribution pattern was comparable with the I'matriXX measured dose distribution pattern. Out of 50 patients for which the comparison was made, 36 patients were agreed with the gamma pixel match of > 95% and 14 patients were with the gamma pixel match of 90-95% with the criteria of 3% delta dose (DD) and 3 mm distance-to-agreement (DTA). Commissioning and quality assurance of dMLC for IMRT application requires considerable time and effort. Many dosimetric characteristics need to be assessed carefully failing which the delivered dose will be significantly different from the planned dose. In addition to the issues discussed above we feel that individual MU check is necessary before the treatment is delivered.

**Key words:** IMRT, dMLC, quality assurance, I'matriXX, DTA, delta dose.

## Introduction

Intensity modulated fields have the potential to deliver optimum dose distributions which results in greater dose uniformity in the target and lower doses to the neighboring critical organs and normal healthy structures as compared to conventional external beams employing wedges and cerroband blocks [9]. Multileaf collimator (MLC)-based Intensity Modulation Radiotherapy (IMRT) can be delivered by two main modalities namely segmental IMRT (step and shoot) and dynamic IMRT (sliding window). In the step-and-shoot modality, the MLC shape remains constant while the beam is on and changes while the beam is off and in the sliding window, each leaf pair moves continuously, unidirectionally, and with independent speed while the beam is on. Any shape of intensity profile can be obtained by controlling the leaf movement, subject to the mechanical constraints, such as leaf width, maximum speed, field size, etc. imposed by the multileaf collimator (MLC) system. As leaf motions are controlled by a computer, the IMRT technique lends itself to automated treatment delivery eliminating the need for re-entry into the room between fields. During treatment the leaf positions are verified by computer, ensuring better quality control than when using customized field shaping blocks.

The clinical implementation of IMRT requires special commissioning procedures including machine and patient-related routine quality assurance (QA) in addition to the QA checks currently performed for 3D-CRT with the MLC [1, 3, 6, 11, 12, 16]. There are many publications and recommendations describing additional procedures to be carried out for the implementation of IMRT [2, 4, 5, 8, 14, 15]. Palta et al [13] indicated that each facility offering IMRT must develop its own guidance and criteria for the acceptance and QA of IMRT planning and delivery. AAPM Task group 142 [10] recommends the picket fence test to be performed weekly with a careful examination of the image acquired by static film or on-line portal image for assessing the deviation in leaf stability. It is also recommend that the leaf position accuracy and leaf speed tests be carried out routinely on monthly basis. The annual tests to be performed for the MLCs and their tolerances also tabulated in the report. The AAPM task group 119 introduced the IMRT commissioning report which is based on multiple Institution planning and dosimetry [7]. In this article our experience with the implementation of IMRT and patient dose verification with film and I'matriXX is discussed.

## Methods and materials

### Equipment

A linear accelerator Clinac DHX, supplied by Varian Medical Systems, Inc., Palo Alto, CA. equipped with a 120-leaf Millennium MLC, 6 and 18 MV photons and five different electron energies (6, 9, 12, 16 and 20 MeV), dynamic IMRT was commissioned at our centre. The treatment planning is being carried out by Eclipse-Helios inverse treatment planning system. All these systems were interfaced with ARIA networking system. The beam profiles and the percentage depth dose curves were obtained by RFA 300 (Scanditronics, Wellhofer, Germany) and the relative dosimetry was performed by using I'matriXX 32 $\times$ 32 matrix ion chamber array of volume 0.08 $cm^3$ each having active diameter of 0.45 cm (Scanditronics, Wellhofer) and EDR2 film. For absolute dosimetry a 0.65 $cm^3$ Farmer-type ionization chamber (FC65G, Scanditronics-Wellhofer, Germany) was used with the water phantom of dimension 40 $\times$ 34 $\times$ 35 $cm^3$ (WP1D, Scanditronics Wellhofer, Germany). The solid water (RW3, Scanditronics Wellhofer, Germany) slab phantoms was used for beam quality check and point dose verification.

### Commissioning

After standard Accelerator commissioning we have checked the basic properties of the MLC and QA chain connected to IMRT implementation. The basic MLC tests include mechanical and dosimetric checks of both static and dynamic MLCs.

### Mechanical checks

The millennium MLC-120 leaves were installed in collimator system of Varian accelerator. The collimator rotation isocenter, Gantry rotation isocenter, crosshair alignment and light field alignment were mechanically checked.

**Static MLC checks.** The leaf position accuracy and leaf position repeatability check were performed for static MLC positions. The test was performed using calibrated front pointer and taping a piece of graph paper to the couch top. The leaf position accuracy was performed for the field opening of leaf positions of 5 cm, −10 cm (A bank MLC), −10 cm and 15 cm (B bank MLC) field opening with MLC (Varian test pattern). The leaf position repeatability test was performed by marking the actual leaf position on the graph paper and executing various standard test patterns provided by Varian in auto cycle model.

**DMLC checks.** To check the stability of the dMLC mode and the reproducibility of the gap between leaves the Picket fence test and the garden fence test were carried out. The tests were performed, image pattern were analysed using I'matriXX device, film and Electronic portal imaging device (EPID). The picket fence test consists of eight consecutive leaf movements of a 5-cm wide rectangular field spaced at 5-cm intervals; the field information is contained in three separate test files which are run in sequence at the accelerator treatment console. The test field was exposed using I'matriXX at 94.6 cm SSD placed over treatment couch with 5 cm solid water build up (detector plane at 100 cm). The garden fence test consists of a narrow band (2 mm wide) spaced at 2-cm intervals. Each leaf match line was analyzed either visually or by measuring the full-width half-maximum distance.

**Analysis of standard tests.** The quality assurance test patterns provided by Varian like X wedges, Y wedges, Pyramids, complex field were tested using I'matriXX device, film and EPID. The tests are designed to achieve a qualitative analysis of the position accuracy of the leaf, kinetic properties of the dMLC, and a dosimetric evaluation of fractional dose delivery.

## Radiation Tests

The radiation tests were performed to check position accuracy of MLCs in the collimator system. The tests are collimator spoke shot, gantry spoke shot and coincidence of light and X-field for MLC field size. The collimator spoke shot test was performed for MLC field opening of 1mm with the collimator angles of 90°, 45°, 0° and 315°. The gantry spoke shot was performed for the gantry angle of 90°, 0°, 275° and 185°. The coincidence of light and X-ray field was performed for the MLC opening of $10 \times 10$ cm$^2$ field and $24 \times 24$ cm$^2$ field with the required build-up thickness placed over the film. The MLC alignment test was performed with $20 \times 15\ cm^2$ field using radiographic film. Initially left upper and right lower quadrant of the field was opened and exposed and later right upper and left lower quadrants were exposed. The processed film clearly shows the tongue and groove effect and rounded leaf end effect.

## Dose delivery checks

**Output consistency.** The output stability with the dMLC was verified using $0.65\ cm^3$ ion chamber at the depth of 5 cm along the central axis of the beam in solid water phantom with the test patterns of 4 mm sweeping gap, garden fence test and X wedge test pattern, the measurements were normalized to reference dose (the measurements were compared with the initial base line value.) The measurements were carried out weekly as a routine QA procedure to check reproducibility. To evaluate the possible effect of gravity, the measurements were also performed at four different gantry angles (0°, 90°, 180°, and 270°).

**Average leaf transmission measurement.** Average leaf transmission was determined with $0.01\ cm^3$ ionization chamber and radiographic film (EDR 2) as the ratio of the dose delivered through a fully closed and fully opened static MLC field. The ion chamber was positioned in a solid water phantom at the depth of maximum dose, averaging interleaf and intra-leaf transmission. The radiographic film was placed in a solid water phantom perpendicular to the incident beam at 5-cm depth. The leaf transmission was verified with the factory-recommended value and feed into treatment planning system.

**Evaluation of dosimetric leaf separation.** Dosimetric leaf separation was determined using $0.65\ cm^3$ Farmer ion chambers placing in air with various dynamic leaf gap widths ranging from 0.1 mm to 20 mm. A graph was drawn between the measured charge in the ordinate and the leaf gap width in the abscissa. The intercept of the line at the abscissa determines the dosimetric leaf separation.

**Dose delivery accuracy.** To determine the accuracy of the dose delivered with dMLC, computer-generated calculations were compared with I'matriXX measured dose distributions. Standard patterns were created manually for comparison with fluence editor available in Eclipse treatment planning system. The dose distribution patterns created for verification were uniform field, pyramid and chair test. The measured fluence was compared with the TPS generated fluence using Omnipro ImRT software (Scanditronix, Wellhofer, Germany).

### Weekly analysis of dynalog files

After every treatment the MLC controller generates dynalog files which gives an idea about the consistency and deviation of leaf positions at every 50 ms during the beam delivery. The generated file can be viewed by the software provided by Varian Medical Systems. The results by the software are displayed as an error histogram, error RMS and beam hold off with time. For each beam delivery 95% of the error histogram is acceptable if 95% or more of the error counts have misplacements $< 0.1$ cm and there is no error count with misplacements $>0.3$ cm. The maximum acceptable RMS is 0.05 cm.

During the beam on time a maximum of 2 beam hold-off can be accepted. The dynalog files generated at the end of beam delivery for Garden fence, leaf gap width and step wedge test patterns were saved and analyzed every week as a part of routine QA. The data obtained were compared with the baseline value obtained initially.

### Treatment delivery verification

For IMRT it is essential to verify the plan prior to the treatment. The verification includes absolute dosimetry for all treatments fields and relative dosimetry for each treatment portal.

**Measurement of dose for IMRT plan.** The solid water phantom used for dose measurement with 0.65 cm3 Farmer-type ion chamber was CT scanned with 2 mm axial cuts. The 3D image was reconstructed in treatment planning system from the image set. The IMRT fields are imported from the patient's plan into the phantom image set. Dose distributions are calculated and normalized to the isocenter, which represents the centre of ion chamber at the depth of 5 cm from the phantom surface. The dose was measured with same phantom set and compared with the calculated dose. The absolute dose measurement was carried out for 50 patients. The plan was acceptable for treatment only when the measured dose is within 3% of the calculated dose. If the difference between measured and calculated dose is 3% to 5%, the plan was reviewed and verified. When the difference is beyond 5% the plan was unacceptable and rejected.

**Comparison of calculated and measured dose distribution.** In order to verify an IMRT plan a verification plan is produced for every original plan in the planning system. The CT data of the measurement system was used to estimate the dose distribution at depth for these verification plans. The I'matriXX device with 5 cm solid water phantom positioned above and below was scanned with 2 mm CT slice thickness. The verification plan is exported to the scanned detector system with the detector plane positioned at isocentre. In the verification plan for every single field the gantry and collimator angles were set at 0 degrees. The central beam was made perpendicular to the I'matriXX measurement level at the center of the measurement area. With the treatment field the dose distribution at the detector plane was calculated and transferred to Omnipro software for comparison. All the verification fields were exported to the accelerator console and the same was delivered and measured by the I'matriXX device. The measured dose distribution was compared with the TPS generated dose distribution using Gamma Index Method.

The measurement was also carried out in the solid water phantom (RW3) using EDR2 verification film. The film was positioned at 5 cm depth in solid water phantom with 10 cm of scattering material present at the bottom. The above phantom set was CT scanned similar to I'matriXX phantom to create a verification plan in Eclipse treatment planning system.

Similarly the dose distribution patterns generated by treatment planning system like chair test and pyramidal test were exported to verification phantoms for quantitative evaluation with I'matriXX and film dosimetry systems. TPS calculated dose distribution was compared with I'matriXX measured dose distribution for 50 patients'. Two 7 field IMRT plans (1 prostate, 1 head and neck) were considered for the comparison with film dosimetry system.

## Results and discussion

After installation of Millennium-120 leaf MLC with Varian linear accelerator, the mechanical checks like collimator rotation isocenter, gantry rotation isocentre, crosshair alignment, light field alignment, static MLC position and Radiation tests were performed as part of customer acceptance procedure. All the parameters were within the manufacturers specified value of ≤ 1 mm (Table 1). The leaf position accuracy and leaf position repeatability check were performed for static MLC positions. The leaf position accuracy is < 1 mm for all static MLC positions. The leaf position reproducibility is matched within 1 mm before and after the autocycle sequence. The stability and reproducibility of dMLC were checked with garden fence test and Picket fence test. The leaf position errors can be easily detected by visual inspection and profile analysis. These tests were also performed using EPID, which gives the better resolution image.

**Table 1.** Summarizes the mechanical tests

| Mechanical check list | Manufacturer specification | Measured |
|---|---|---|
| Collimator rotation isocentre | ≤ 1.00 mm | 0.10 mm |
| Cross air alignment | ≤ 1.00 mm | 0.20 mm |
| Gantry rotation isocentre | ≤ 1.00 mm | 0.60 mm |
| Light field alignment | ≤ 1.00 mm | 0.30 mm |
| Static MLC position | ± 1.00 mm | 0.50 mm |
| Couch rotation | ≤ 1.00 mm | 0.40 mm |
| Coincidence of light and X-ray field | ± 2.00 mm | 0.60 mm |

The standard patterns like X wedges, Y wedges and pyramidal tests measured by I'matriXX and EPID were compared and the results were in agreement (90% gamma match with 3% delta dose and 3 mm Distance to agreement (DTA)). The matching of Y wedge patterns (A and B) and pyramidal test patterns (A and B) shows the linear profile

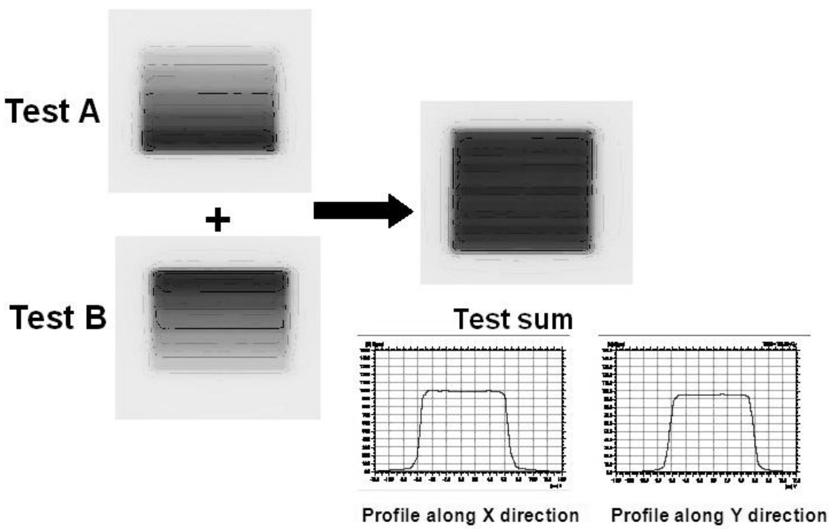


**Figure 1a.** The matching of Y wedge test patterns to analyze the dose uniformity using dMLC mode

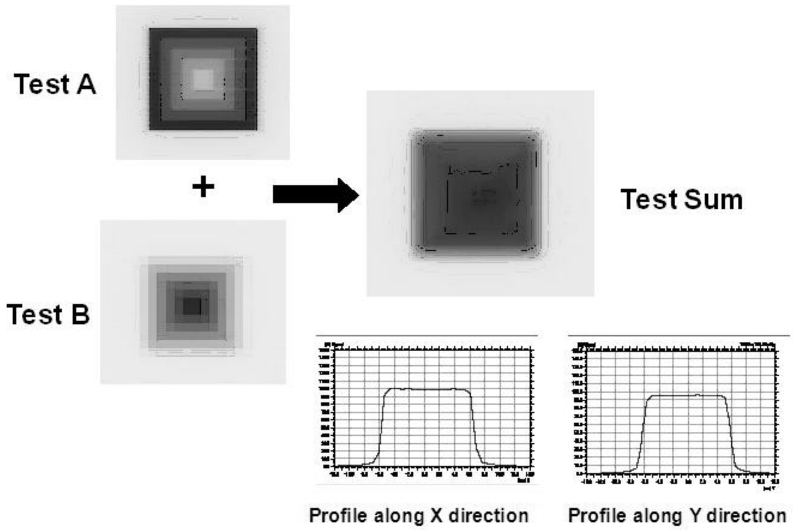


**Figure 1b.** The matching of Pyramidal test patterns to analyze the dose uniformity using dMLC mode

along x and y directions (Figures 1a and 1b). The output stability for dMLC routine QA are well agreement. The output with gravitational effect for various gantry angles is within 0.9%. The measured average leaf transmission for 6 MV was 1.6% and 18 MV was 1.8%. The dosimetric leaf separation for 6 MV is 2.2 mm and 18 MV is 2.3 m. The dynalog files analysis for Garden fence, leaf gap width and step wedge test patterns are in good agreement.

Figures 2a and 2b show comparison of TPS calculated and measured chair test pattern by I'matriXX and film dosimetry system. Comparison of TPS generated dose distribution with the dose distribution measured using film has resulted in the pixel match of 97.13% with $\gamma \leq 1$, and a pixel match of 97.86% with $\gamma \leq 1$ was noticed for TPS and I'matriXX dose distribution pattern (for 3% delta dose and 3 mm DTA). Similar results and agreement observed when the dose distribution pattern checked at different horizontal and vertical planes. Figures 3a and 3b show comparison of TPS calculated and measured pyramid test pattern by I'matriXX and film dosimetry system. The pixel match of 96.67% for $\gamma \leq 1$ was observed for dose distribution generated using TPS and measured with film. The pixel match of 96.36% with $\gamma \leq 1$ was noticed for TPS generated and I'matriXX measured dose distribution pattern (3% delta dose and 3 mm DTA).

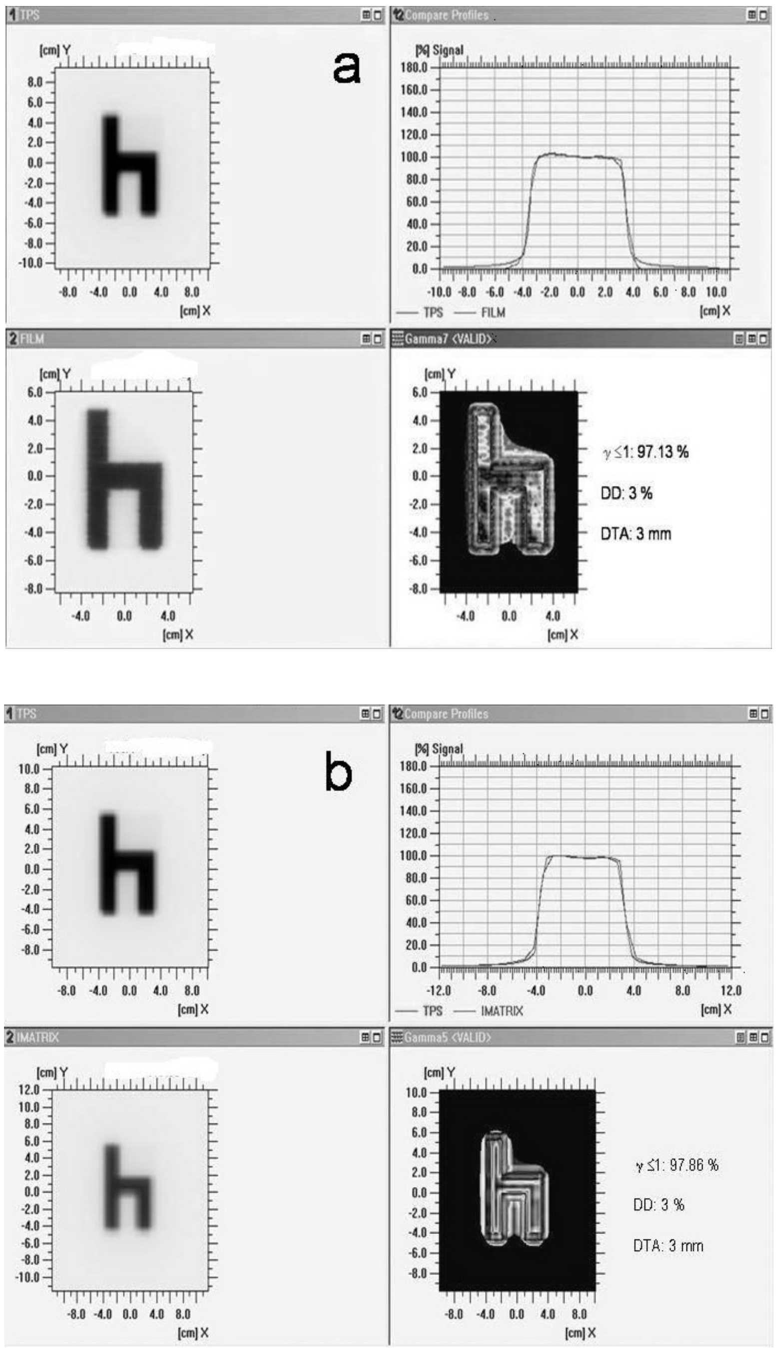


**Figure 2 (a, b).** Verification of TPS generated chair test pattern with film and I'matriXX

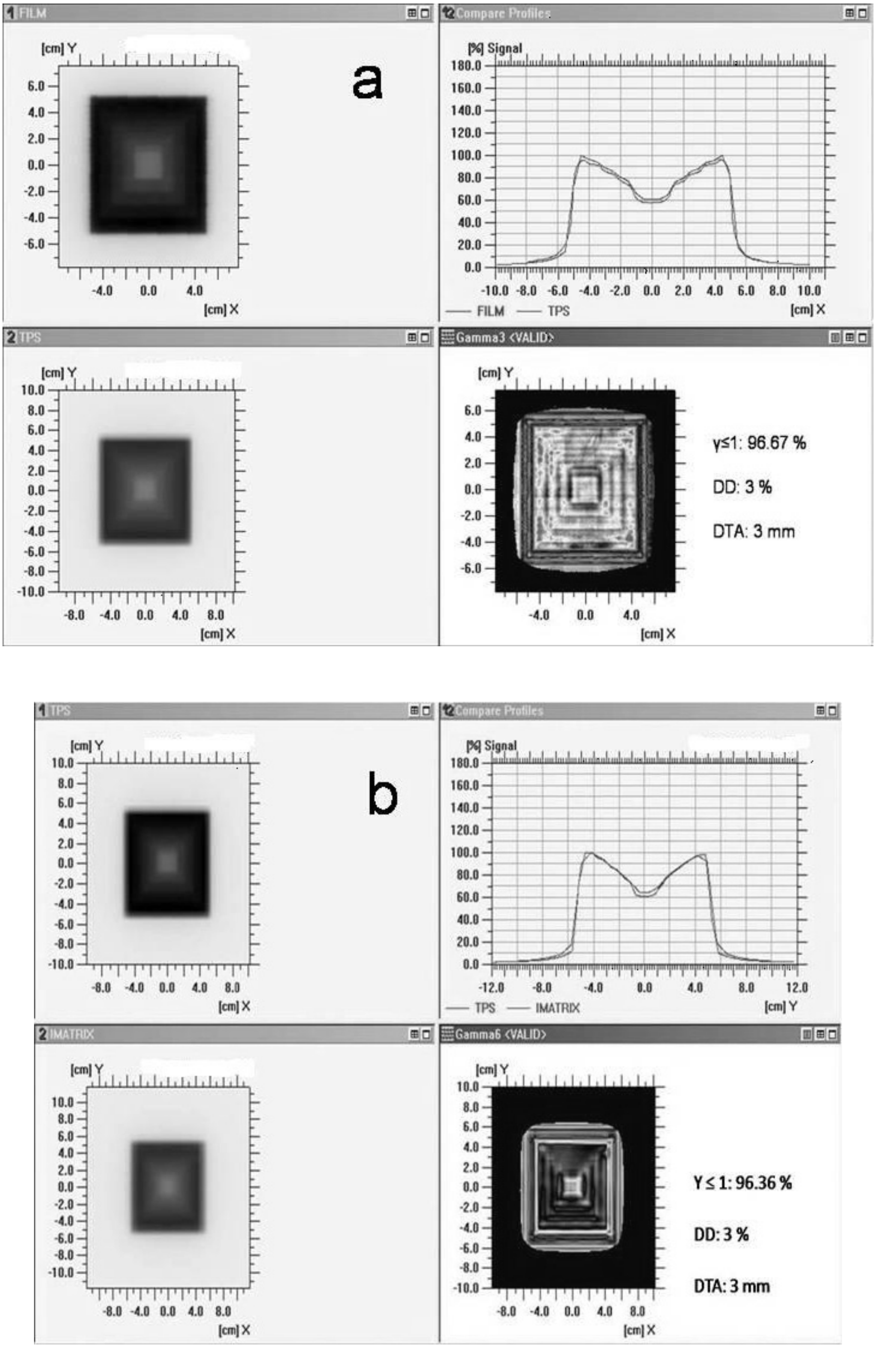


**Figure 3 (a, b).** Verification of TPS generated pyramid test pattern with film and I'matriXX

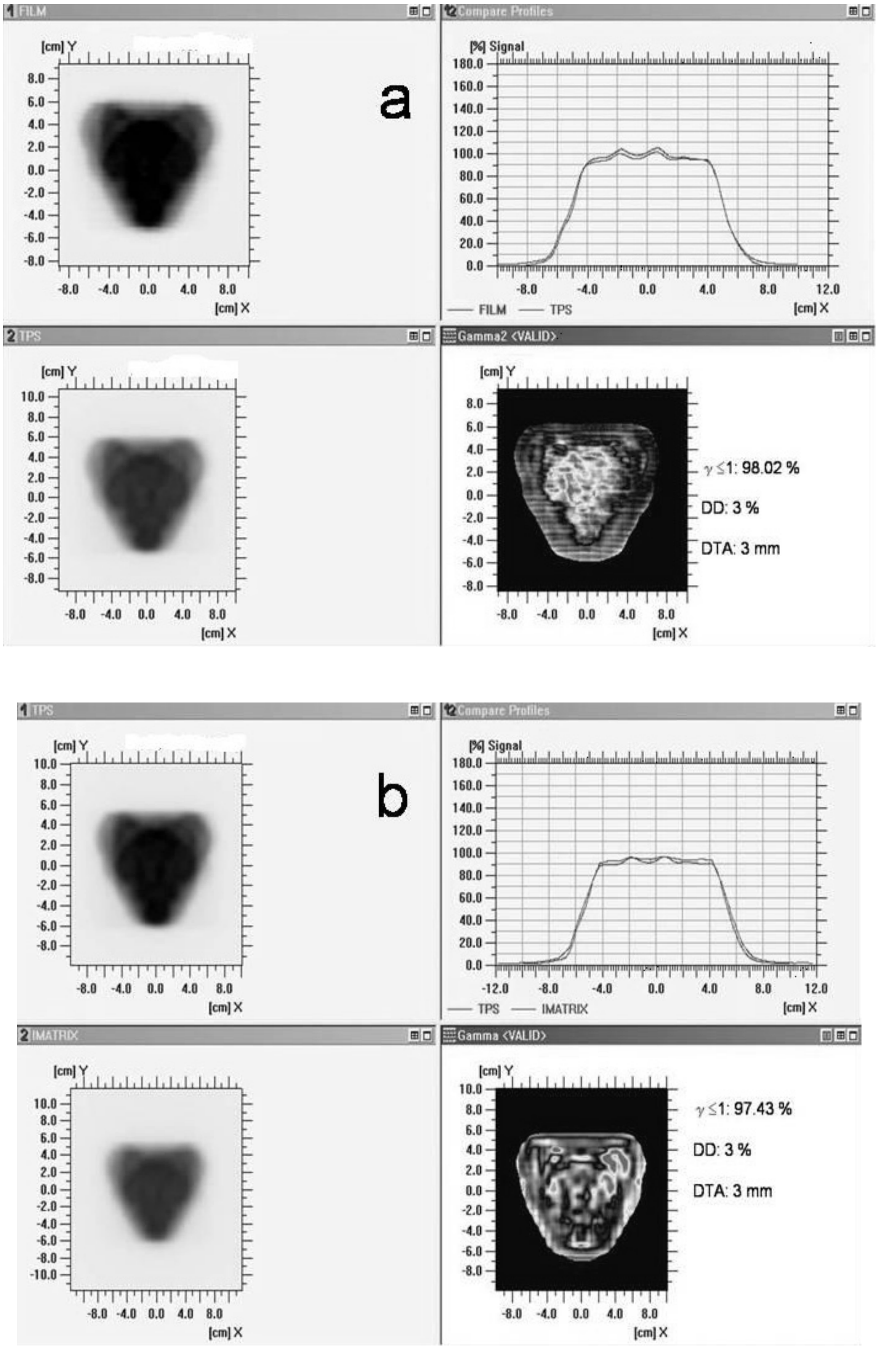


**Figure 4 (a, b).** Verification of TPS generated Prostate plan with film and I'matriXX

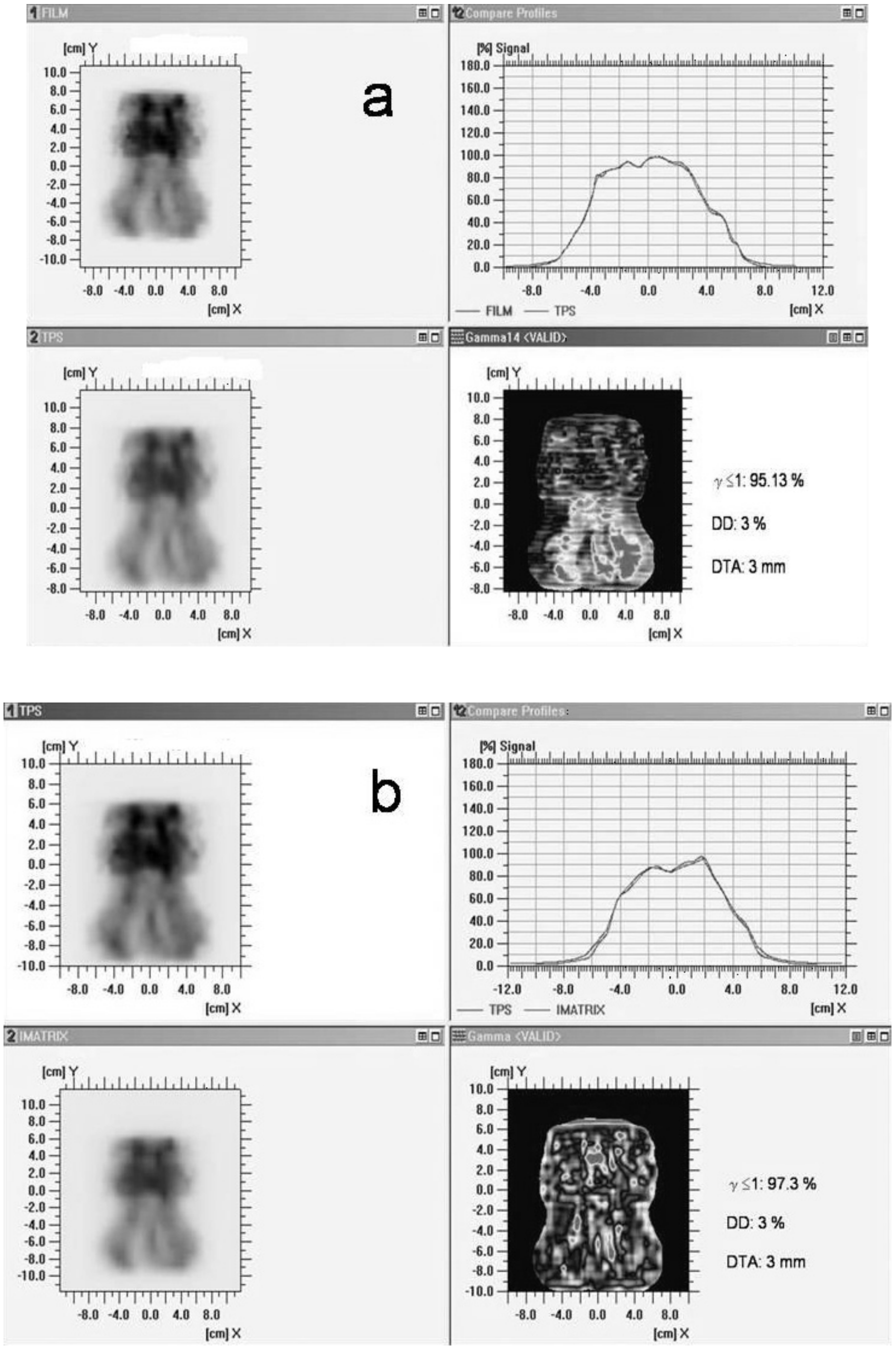


**Figure 5 (a, b).** Verification of TPS generated Head and neck plan with film and I'matriXX

TPS calculated dose distribution pattern was comparable with the I'matriXX measured dose distribution pattern. Out of 50 patients, the measurements for 36 patients were agreed with the gamma pixel match of > 95% and for 14 patients the gamma pixel match was between 90-95% with the criteria of 3% DD and 3 mm DTA. Two 7 field IMRT plans (1 prostate, 1 head and neck) were also compared with film dosimetry system and the results are presented. Figures 4a and 4b show the comparison of measured and calculated dose distribution pattern for 7 field prostate patient. The match result has shown 97.43% agreement for $\gamma \leq 1$ with 3% delta dose and 3 mm DTA for TPS generated and film measured dose distribution patterns and 98.02% for TPS generated and I'matriXX measured dose distribution patterns. Figures 5a and 5b show the comparison of measured and calculated dose distribution pattern for 7 field head and neck patient. The match result has shown 97.3% agreement for $\gamma \leq 1$ with 3% delta dose and 3 mm DTA for TPS generated and film measured dose distribution pattern and 95.13% for TPS generated and I'matriXX measured dose distribution patterns.

The variations of calculated absolute dose for all treatment fields with the ion chamber measurement, for the 50 patients, were within the acceptable criterion (Figure 6). The relative dose for each measured field agreed with the calculated field (95% match with 3% delta dose and 3 mm DTA), except for large dose gradient fields. The Dynalog File Viewer (DFV) analysis of dose dynamic moving window treatment has

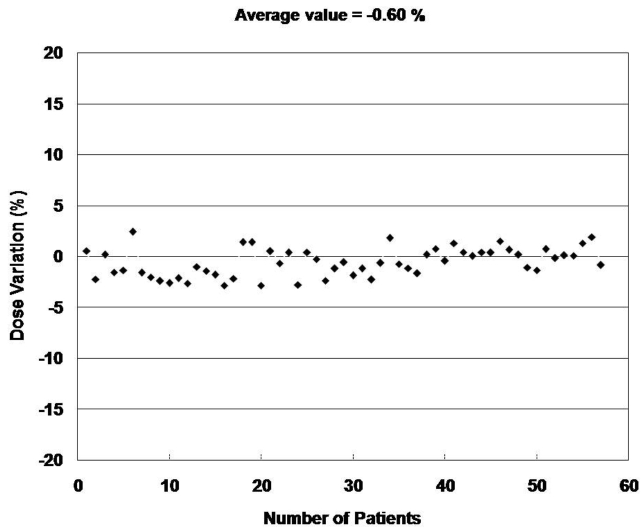


**Figure 6.** Variation of calculated absolute dose with respect to ion chamber measurement for IMRT plans

shown the maximum error RMS within 0.35 cm for either carriage and error histogram has shown 95% of the error counts in bins 1 through 8 for Garden fence, leaf gap width and step wedge test patterns which were quite acceptable.

## Conclusion

Commissioning and quality assurance of dMLC for IMRT application requires considerable time and effort. Many dosimetric characteristics need to be assessed carefully failing which the delivered dose will be significantly different form the planned dose. In addition to the issues discussed above we feel that individual MU check is necessary before the treatment is delivered.

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