Dosimetric and qualitative analysis of kinetic properties of millennium 80 multileaf collimator system for dynamic intensity modulated radiotherapy treatments

ABSTRACT
The aim of this paper is to analyze the positional accuracy, kinetic properties of the dynamic multileaf collimator (MLC) and dosimetric evaluation of fractional dose delivery for the intensity modulated radiotherapy (IMRT) for step and shoot and sliding window (dynamic) techniques of Varian multileaf collimator millennium 80. Various quality assurance tests such as accuracy in leaf positioning and speed, stability of dynamic MLC output, inter and intra leaf transmission, dosimetric leaf separation and multiple carriage field verification were performed. Evaluation of standard field patterns as pyramid, peaks, wedge, chair, garden fence, picket fence test and sweeping gap output was done. Patient dose quality assurance procedure consists of an absolute dose measurement for all fields at 5 cm depth on solid water phantom using 0.6 cc water proof ion chamber and relative dose verification using Kodak EDR-2 films for all treatment fields along transverse and coronal direction using IMRT phantom. The relative dose verification was performed using Omni Pro IMRT film verification software. The tests performed showed acceptable results for commissioning the millennium 80 MLC and Clinac DHX for dynamic and step and shoot IMRT treatments.

KEY WORDS: Dynamic intensity modulated radiotherapy (IMRT), IMRT protocol, multileaf collimator, quality assurance tests

INTRODUCTION
Intensity modulated radiotherapy (IMRT)[1-5] has become the treatment of choice for the tumor sites where concave dose distributions are required with critical organ sparing. IMRT has proven its superiority in better dose distribution and target conformity over 3-dimensional conformal radiotherapy (3D-CRT), but it is too early to say about the clinical outcomes. Multileaf collimator (MLC)6-10 based IMRT can be performed either by segmental (step and shoot) technique or dynamic (sliding window) technique. In step and shoot (S and S) technique different sub field are defined depending on beam intensity within the same field and radiation beam is on when MLC shape is constant and turns off when MLC moves for field shape change. But in dynamic MLC (dMLC) based IMRT, beam remains continuously on and each leaf pair moves continuously and unidirectionally with leaf speed depending on beam intensity.

Commissioning of MLC for IMRT for patient treatment requires more rigorous quality checks than 3D-CRT. Because of complexity involved in planning and execution of dynamic IMRT, absolute and relative verification of dose delivery is required. There is no set protocol or guidelines for dMLC commissioning for dynamic IMRT. A few reports describe the QA procedures for implementation of MLC based IMRT.11-13 QA and acceptance tests procedures of dMLC should be performed before implementing IMRT for clinical use.

The aim of the present paper is to present the commissioning and QA procedures for dMLC based IMRT with Omnipro IMRT verification software.

MATERIALS AND METHODS
The high energy linear accelerator Clinac DHX (Varian Medical Systems Inc., Palo Alto, CA) with photon energies 6 MV and 15 MV and equipped with Millennium 80 MLC installed in our department was used. 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. The 3-dimensional treatment planning system Eclipse with inverse plan optimization engine Helios and MLC shaper version...
The reproducibility of leaf gap between opposite leaves was checked using the:
1. Picket fence test.[11]
2. Garden fence test.[12]

The Picket fence test consists of eight consecutive leaf movements of a 5 cm wide rectangular field spaced at 5 cm intervals. This test field was exposed on a ready pack film Kodak EDR-2 at SSD 100 cm, placed over treatment table with 1.5 cm solid water buildup. The garden fence test consists of a narrow band 2 mm width spaced at 2 cm intervals. The garden and picket tests were performed at four gantry angles 0°, 90°, 180°, and 270° [Figure 1]. Each leaf match line was analyzed either visually or using full-width half-maximum.

**Leaf speed stability**

The stability of leaf speed was verified using a test field generated by MLC shaper that requires the leaf pair to move at seven constant speeds, generating a step wise homogeneous dose delivery of well defined intensity. The stability of different speed levels was analyzed, comparing the uniformity of each profile to the open field profile.

**Sensitivity to treatment interruptions**

During the leaf speed test, two beam interruptions were introduced to test the potential effect of acceleration and deceleration. The stability of the intensity levels was analyzed by comparing the uniformity of each profile to the open field.

**Dosimetric checks**

**Output stability with dMLC**

The output stability with dMLC was verified with a sweeping gap of 1.0 cm creating a uniform field of 20 x 20 cm². The ion chamber was placed at the central axis and off-axis, at positions ± 5 cm. The measurement was normalized to the reference dose. To evaluate the gravity effect, four different gantry angles were used (0°, 90°, 180°, 270°). To check the leaf gap stability between runs, measurements were taken using various gap widths.
Determination of average leaf transmission

Average leaf transmission was determined with ion chamber and radiographic films as the ratio of the dose delivered through a fully closed and fully opened static MLC field. The ion chamber dose measurement was done in solid water phantom at the depth of dose maximum by averaging inter and intra leaf transmission. The leaf transmission using radiographic films was obtained at 5 cm depth using solid water phantom. Films were placed perpendicular to the incident beam and dose was measured using OmniPro I’mRT software.

Determination of dosimetric leaf separation

The dosimetric leaf separation was determined by using Kodak EDR-2 films placed at isocenter at 5 cm depth in solid water phantom. Multiple static MLC fields with gap widths from 0.2 cm to 10 cm were used. All films were scanned and dose profiles in the direction of leaf movement were obtained. The dosimetric leaf separation was determined by extrapolating the average integral profile dose versus MLC gap width to the zero dose.

Dosimetric verification of complete treatment system

To determine the accuracy of the dose distribution with dMLC for the combination of TPS and LINAC, computer generated dose calculations were compared with film measurement dose distributions. The fluence patterns created for MLC speed and dose verification were pyramid, X-wedge, Y-wedge, peaks and chair. The dose distribution was calculated by the TPS in coronal plane in flat scanned solid water phantom at 5 cm depth using 2.5 mm calculation grid. Comparisons between TPS calculated fluence and measured doses with films for different standard patterns were performed by using in line and cross line dose profiles and Gamma method.

Machine quality control checks

To guarantee the ongoing stability and geometrical precision of dMLC, it is necessary to add special tests to the standard QA program. These checks must be carried out each time when preventive maintenance for the MLC is performed.

Absolute dose measurement for all treatment fields

The IMRT field’s fluences were imported to verification phantom for absolute dose measurement. The dose distributions were calculated and dose measurement point was chosen from dose volume histogram by choosing the points having least dose gradient in the field. The calculated dose was compared with measured dose. 0.6 cc Farmer type ion chamber (PTW-UNIDOS) was used for absolute dose measurement. If the difference between measured and calculated dose was ≤ 3% plan was accepted otherwise plan was rejected.

Dynalog file analysis

At the end of every IMRT treatment delivery, dynamic dynalog files created by MLC controller were analyzed using Dynalog file viewer software (Varian Medical Systems, Palo Alto, CA), which is part of the Varian MLC workstation software. This file contains the information about the planned versus actual position for all leaves, every 50 ms while the beam is on. The software generates data tables and plots an error histogram (the information for all leaf position deviations), error RMS (calculated root-mean square value for individual leaf deviations) and beam hold-off versus time plot. For each field the error histogram result is considered acceptable if 95% or more of the error counts have misplacements <0.1 cm and there is no error count with misplacement > 0.3 cm. The largest accepted RMS is 0.05 cm. The maximum number of beam hold-off accepted per field is two. If beam hold off is more than two, then dose rate was reduced to decrease beam hold off. The error histogram and error RMS were saved for each IMRT field. The data obtained were also used to screen for initial MLC motor failure and determine the need for motor replacement.

Relative dosimetry

For relative dose measurement, the fluence for each field was imported into a scanned solid water phantom with normal incidence. Dose distribution was calculated at 5 cm depth in solid water phantom with Eclipse. The Kodak EDR-2 ready pack films were exposed at 5 cm depth using solid water phantom for each fields in coronal plane. The comparison between TPS calculated dose and film measured dose was carried out using OmniPro I’mRT software.

RESULTS AND DISCUSSION

The initial MLC installation data is very important as it becomes reference for future MLC errors. Picket and Garden fence tests were designed to accurately detect leaf position errors. The profiles obtained from leaf speed stability test for all intensity levels were uniform and dose differences to the open field profile were always below 2%. When interruptions were introduced during treatment delivery, the dose profiles with these interruptions were not different from the tests without interruptions. Leaf speed remained stable and dose delivered was not affected by these interruptions.

A qualitative analysis of all standard Varian pattern tests shows straight field boundary and match lines between different intensity segments. For all cases match line segments fell within the positional limit error of ±1 mm. However, for dMLC with dynamic technique an uncertainty of ±1 mm in leaf positioning may not be sufficient for accurate dose delivery for highly modulated beams. The average variation in output of sweeping gap across the field with ion chamber at three different points was 1.4%. Due to narrow leaf gap of 5 mm used in sweeping slit test, the measured dose is very sensitive to actual gap width. A dose difference of about 2% corresponds to a gap width deviation of about 0.1 mm. So in our measurements the stability of gap width was very good, with maximum deviations smaller than 0.1 mm.

With ion chamber and film, average leaf transmission found for 6 MV and 15 MV was 1.81% and 1.93% respectively. The dosimetric leaf separation determined by film for 6 MV was 1.51 mm [Figure 2].
Comparison between TPS calculation and measured relative dose was done for all standard patterns. For Pyramid test field, the agreement between TPS and measured film profile was better than 2% and 3% in MLC movement direction and perpendicular to MLC movement direction respectively. The dose differences in high gradient regions increases due to less film resolution and bigger calculation grid size. Gamma value was $\leq 1$ for delta dose difference ($\Delta d$) 3% and DTA 2 mm. The percentage of dose points was $\geq 98.7\%$ for gamma value between 0 and 1 [Figure 3].

For Y wedge test field profile superposition in the direction of leaf movement shows an agreement better than 2% in high dose low gradient region for the five dose levels. Gamma value was $\leq 1$ for delta dose difference ($\Delta d$) 3% and DTA 2 mm. The percentage of dose points was $\geq 97.2\%$ for gamma value between 0 and 1 [Figure 4].

For X wedge test field profile superposition in the direction of leaf movement shows the peaks of different widths: 2.5 mm, 5 mm, 7.5 mm, 10 mm and 15 mm in the direction of leaf movement with 10 mm height equal to MLC thickness. The normalization was done at the center of 10 mm width peak. The profile superposition shows the agreement better than 2% for 15 mm and 10 mm peaks, 3% for 7.5 mm, 5% for 5 mm and 7% for 2.5 mm width peak. Dose profiles in perpendicular direction show an agreement better than 2% in the high dose low gradient region. Gamma value was $\leq 1$ for delta dose difference ($\Delta d$) 5% and DTA 3 mm. The $\Delta d$ was higher in Gamma analysis because for peaks of smaller width the dose...
difference was large between film and TPS fluence comparison. The region showing red color in gamma analysis graph was due to inter leaf transmission between two leaf banks when films were exposed. Because of this, the percentage of dose points was ≥ 95.6% for gamma value between 0 and 1 [Figure 6].

For chair test field the dose profile superposition in the direction of leaf movement and perpendicular direction show agreements similar to pyramid test field. In low dose region differences increases due to scatter radiation. Gamma value was ≤ 1 for delta dose difference (Δd) 3% and DTA 2 mm. The dose difference was higher in upper portion of chair field (White portion in gamma analysis). The percentage of dose points was ≥ 97.6% for gamma value between 0 and 1 in area of interest [Figure 7].

For most of patients treated with dynamic IMRT technique in our institution, the gamma value was between 0 and 1 with delta dose difference 5% and DTA 3 mm. For one patient who was given IMRT boost after 3D-CRT, the delta dose difference was 8% as there was large complexity in MLC movement in treatment plan. The Gamma analysis and comparison between TPS calculated fluence and measured fluence from film using IMRT Phantom for one of the head and neck cancer patient treated with dynamic IMRT technique using simultaneous Integrated Boost (SIB) method is shown in Figure 8.

CONCLUSION

Based on the results obtained from these QA checks, we have concluded that Clinac DHX installed in our department is suitable for clinical application of dynamic IMRT-based patient treatments. Gamma analysis using OmniPro I’mRT software gives the details of comparative profile analysis of planned and delivered dose and DTA for dMLC. The dosimetric leaf gap and MLC transmission values entered in beam parameters have large influence on accuracy of dose calculations.

A comprehensive dMLC QA protocol is presented here, can help to ensure for the prescribed dose delivery to patients by IMRT technique. The treatment planning system parameters must be measured and verified before IMRT in clinical practice. The patient pretreatment QA requires significant machine time for measurements and must be completed before treatment starts.

Every institution should adopt a QA protocol for IMRT based radiotherapy techniques. The QA protocol presented here has proved adequate for delivering prescribed radiation dose to patients within acceptable limits.

REFERENCES

1. Boyer AL, Yu CX. Intensity modulated radiation therapy with dynamic multileaf collimator. Semin Radiat Oncol 1999;9:48-59.
Bhardwaj, et al.: Dosimetric and qualitative analysis of kinetic properties of MLC for IMRT

2. Chang SX, Cullip TJ, Deschesne KM. Intensity modulation delivery techniques: ‘Step and shoot’ MLC auto-sequence versus the use of modulator. Med Phys 2000;27:948-59.

3. Powlis WD, Smith AR, Cheng E, Galvin JM, Villari F, Bloch P, et al. Initiation of multileaf collimator conformal radiation therapy. Int J Radiat Oncol Biol Phys 1993;25:171-9.

4. 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.

5. Jordan TJ, Williams PC. The design characteristics of a multileaf collimator. Phys Med Biol 1994;39:231-51.

6. Van Esch A, Bohsung J, Sorvari P, Tenhunen M, Pausco M, Iori M, et al. Acceptance tests and quality control (QC) procedures for the clinical implementation of intensity modulated radiotherapy (IMRT) using inverse planning and the sliding window technique: Experience from five radiotherapy departments. Radiother Oncol 2002;65:53-70.

7. Essers M, de Langen M, Dirkx ML, Heijmen BJ. Commissioning of a commercially available system for intensity-modulated radiotherapy dose delivery with dynamic multileaf collimation. Radiother Oncol 2001;60:215-24.

8. Bayouth JE, Wendt D, Morrill SM. MLC quality assurance techniques for IMRT applications. Med Phys 2003;30:743-50.

9. Boethmer D, Bohsung J, Eichwurzel I, Moys A, Budach V. Clinical and physical quality assurance for intensity modulated radiotherapy of prostate cancer. Radiother Oncol 2004;71:319-25.

10. Burman C, Chui CS, Kucher 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 treatment of carcinoma of the prostate. Int J Radiat Oncol Biol Phys 1997;39:863-73.

11. Chui CS, Spirou S, LoSasso T. Testing of dynamic multileaf collimation. Med Phys 1996;23:635-41.

12. LoSasso T, Chui CS, Ling CC. 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.

13. Ezzell GA, Galvin JM, Low D, Palta JR, Rosen I, Sharpe MB, et al. Guidance document on delivery, treatment planning and clinical implementation of IMRT: Report of the IMRT subcommittee of AAPM radiation committee. Med Phys 2003;30:2089-115.

14. Low DA, Harms WB, Mutic S, Purdy JA. A technique for the quantitative evaluation of dose distribution. Med Phys 1998;25:656-61.

15. Millennium MLC. Systems and Maintenance Guide. Varian Medical Systems, Inc: Palo Alto, CA.

16. QA test patterns and procedures. Varian Medical Systems, Inc: Palo Alto, CA.

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