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Jacobs Journal of Radiation Oncology

Research Article

Anatomy Based Patient Specific IMRT QA Using EPID or MLC Log Files

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Received: 06-18-2014

Accepted: 09-11-2014

Published: 09-24-2014

Abstract

In this project, we investigated the use of an Electronic portal imaging device (EPID), together with the treatment planning system (TPS), in order to determine the delivered doses to the patient and evaluate the agreement between the treatment plan and the delivered dose distribution. The QA analysis results are presented for ten IMRT patients using the EPID measurements, the Scandidos Delta [1] dosimeter and the beam fluence calculated from the multi-leaf collimator (MLC) log file. EPID fluence images were acquired in integrated mode for each of the patients and they were processed through an in house MatLab program to create an opening density matrix (ODM), which was used as the input fluence for the dose calculation in the TPS. The EPID used in this study was the aSi1000 Varian on a Novalis TX linac equipped with high definition MLC. The factual MLC positions and gantry angles were retrieved from the MLC log files and the data was used to calculate the delivered dose distributions in Pinnacle. The resulting dose distributions were then compared against the corresponding planned dose distributions using the 3D gamma index with 3mm-3% passing criteria. The Scandidos Delta [1] phantom was also used to measure a 2D dose distribution for all the 10 patients and a 2D gamma was calculated for each patient using the Delta4 software. The average 3D gamma using the EPID images was 98.2% ± 2.6%. The average 3D gamma using the log files was 99.4% ± 0.5%. The average 2D gamma from the Delta4 was 98.1% ± 2.5%. Our results indicate that the use of the EPID, combined with a TPS is a viable method for QA of IMRT plans.

Keywords: Intensity Modulated Radiation Therapy; Electronic Portal imaging Device; Quality Assurance; MLC Log File

Introduction

Dosimeters used for pre–treatment quality assurance (QA) can vary in accuracy, practicality, configuration and cost. Typically, a 2D array of diode detectors such as the MapCHECKTM (Sun Nuclear, Melbourne, FL), Octavius ITM (PTW, Freiburg, Germany) or MatriXXTM (IBA, Schwarzenbruck, Germany) is used to measure a planar dose at isocenter. The major disadvantage of a 2D array is the angular dependence of the detector, which can be as large as 20% [2,3]. When measuring dose of intensity modulated radiotherapy (IMRT) plan with a 2D array, the angular dependence of the detector needs to be accounted for all the beams that have an oblique incidence to the array. There are methods to avoid the angular dependence of 2D array detectors such as measuring the entire IMRT plan with all the beams oriented perpendicularly to the detector or by mounting the detector to the gantry head. However, both methods have the disadvantage of losing the ability to detect gantry angle errors.

To eliminate angular dependence, the PTW Octavius 4DTM QA system utilizes a motorized cylinder that rotates with the gantry as directed by an inclinometer attached to the gantry. The motorized motion of the detector, enforces a perpendicular geometry at all times between the incident beam and the detector plane and resulting in good agreement between measurements and calculations [4]. The Delta [1] (ScandiDos) utilizes orthogonal diode detector arrays to reduce angular dependence. Although these devices have been widely used for QA measurements they present their own challenges. Each of these devices require an accurate setup, which increases the overall time of the test and if not done correctly will affect the accuracy of the results. Accuracy is also affected by the number of diodes or ion chambers in the plane of measurement.

There are many publications [1,5-26], supporting the use of the Electronic Portal Imaging Device (EPID) as a QA device. There are commercially available QA systems that utilize EPID such as the EPIDoseTM (Sun Nuclear) and the Portal Dosimetry TM (Varian Medical Systems). Although both of these systems use different algorithms for dose comparison they are both ideal alternatives to the traditional QA systems [27,28]. The advantages of using EPID for IMRT QAs mainly stem from its simple set up and high resolution of the detector plane (1024 x 768). Fredh et al. have shown that EPID is more efficient in detecting planning errors than conventional QA devices [29]. Some disadvantages of the EPID as a QA device are the non-water equivalence of the detector and its inability to detect gantry angle errors through measurements of the fluence.

Dose reconstruction using information from the log files of the Multi-leaf Collimator (MLC) of the treatment machine is another useful method for performing an IMRT QA [30-33]. Since there are no requirements for physical measurements with this method, all the calculations must be done based on the MLC positions, collimator angle, gantry angle and cumulative dose per control point that have been recorded in the MLC log file. This method relies on the ability of the machine to accurately record the parameters with which the treatment plan was delivered, and it can be a very efficient and reliable way to perform IMRT QAs [32].

One of the disadvantages of using 2D detector arrays for performing patient specific QAs is the difference in geometry between the phantom used and the patient. Hence, there is no correlation between the phantom measurements and the plan quality. In this study, the EPID and MLC log file methodologies we proposed, are using the TPS ability to calculate the delivered dose in the patient's anatomy and in this way to compare it against the approved, optimized treatment plan.

A major advantage of using the TPS for dose calculations is that the quality of the dose distribution can be evaluated in the same software as the initial plan and on the original patient CT image set. By doing so, the user can evaluate the location of the maximum dose points, isodose lines, cold spots and perform region of interest statistics as well as dose volume histogram comparisons. Having the same algorithm for both the original plan and the dose reconstruction, removes any ambiguity in the calculations and any differences in the plan comparison are entirely attributable to changes in anatomy or the beam fluence.

This study focuses on the comparison of the three aforementioned QA methods, which are based on physical dose measurements, fluence measurements using EPID and dose calculations using data from MLC log files. The physical dose measurements were only used in comparisons using the gamma index and they were not imported into the TPS. For each patient, the comparisons between the treatment plan and the EPID or MLC log file method, were performed using the corresponding DVHs of the organs and dose distributions. Furthermore, the gamma index was used to evaluate the agreement of the delivered dose distribution against the planned one.

Methods and Materials

Clinical Cases

Ten cancer patients (5 liver, 4 lung and 1 pelvis) that were treated with step and shoot IMRT, were used in this study. Five of the patients (one liver and two lung cancer patients) were treated with SBRT (5 fractions). The number of beams for each patient ranged from 7 to 10 while the MU per fraction ranged from 588 for an IMRT lung to 2534 for a SBRT lung patient. A list of patients is shown in table 1.

Patient Specifics			
Tx Site	Mod	Tot MU	# of Beams
Liver	IMRT	875	8
Liver	IMRT	1111	9
Liver	IMRT	1007	9
Liver	SBRT x 5	2255	9
Liver	IMRT	1108	10
Lung	SBRT x 5	2534	8
Lung	IMRT	2139	8
Lung	SBRT x 5	2449	9
Lung	IMRT	588	9
Pelvis	IMRT	589	7

Table 1. Treatment information foar the 10 patients.

Physical Measurements

For comparison, physical dose measurements were made

using the Delta4 on a Novalis TX linac (Varian Medical Systems, Palo Alto, CA) equipped with a high definition MLC. The Delta [1] utilizes two orthogonal detector planes with a total of 1,069 p-type diode detectors each with a 0.78mm^2 active volume enclosed in a cylindrical phantom. The detectors cover a 20cm x 20cm area and are spaced at 0.5cm grid in the central 6cm x 6cm area of the detector planes and at 1cm intervals outside the central region.

The Delta4 is unique because the orthogonal detector planes reduce angular dependence and allows the Delta4 software to estimate a 3D dose distribution. This is done by using the planned dose distributions and by interpolating along the ray lines passing through one of the two detector planes. An evaluation of the Delta's [4] performance by Sadagopan et al. has shown that the interpolated values show good agreement with diode measurements at the interpolated points [34].

The planned planar dose distribution for each patient was imported into the Delta [4] software and after the dose distribution was measured a 2D gamma was calculated using a global gamma (normalization at 90% of max dose) with 3mm–3% criteria.

MLC Log Files

MLC log files contain information on the parameters of the treatment machine and MLC recorded every 50ms during treatment. Information from these files such as MLC leaf positions, gantry angle and cumulative dose fractionation are integral in reconstructing the dose delivered by the machine. A table of parameters recorded in an MLC log file is shown in table 2.

	Precision
# MLC Leaves	Exact
Cumul Dose Fractionation	10^{-4}
Beam On	Binary
Beam Off	Binary
Gantry Angle	10^{-1} degrees
Collimator Angle	10^{-1} degrees
x1 Jaw Position	10^{-1} mm
x2 Jaw Position	10^{-1} mm
y1 Jaw Position	10^{-1} mm
y2 Jaw Position	10^{-1} mm
Carriage Posiition	10^{-2} mm
Leaf Position	10^{-4} mm

Table 2. The recorded parameters and their precision based on the MLC log files.

An MLC log file was created for each MLC bank of every beam. For example, for a treatment plan that has 7 beams there are 14 log files, each beam will have a file for bank A and a file for bank B. An in house MatLab program was used to convert the log files into a structure of variables that can be easily accessed and determine the log entries that correspond to beam control points.

The locations of the control points were determined by using the beam on/off designation in the log file. During an IMRT step and shoot treatment the beam is disabled while the MLC leaves are moving to a new location; this corresponds to a control point. When the MLC leaves reach the desired position the beam is reinitiated and a new control point starts. The MLC locations, gantry angle and cumulative dose fractionation for each control point in the MLC log file were used in place of the planned locations to recalculate the dose distribution in the Pinnacle TPS. The actual MLC leaf positions and cumulative dose fractionation recorded in the MLC log file were substituted in place of the planned parameters in the patient plan file and the dose was recalculated using the MLC log file data. The dose was then exported to Verisoft and a 3D gamma was calculated using 3mm–3% criteria.

EPID

The EPID used in this study was the aSi1000 (PortalVision, Varian Medical Systems, Palo Alto, CA) on a Novalis TX linac equipped with high definition MLC. The aSi1000 has an amorphous silicon detector with an active imaging area of 40 x 30 cm^2 and a 1024 x 768 array of pixels. With a center to center pixel spacing of 0.0392cm the EPID has a much higher resolution than the Delta [4].

Images for each beam were captured in integrated mode with the EPID located at isocenter. A calibration image was taken at the time of measurement to obtain an accurate intensity to MU conversion (figure 1). A MatLab in-house software program (MU-EPID) was used to convert the fluence map captured by the EPID into an Opening Density Matrix (ODM) for import into Pinnacle [35].

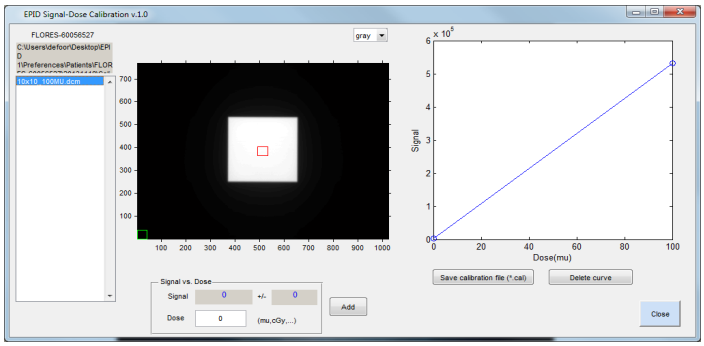
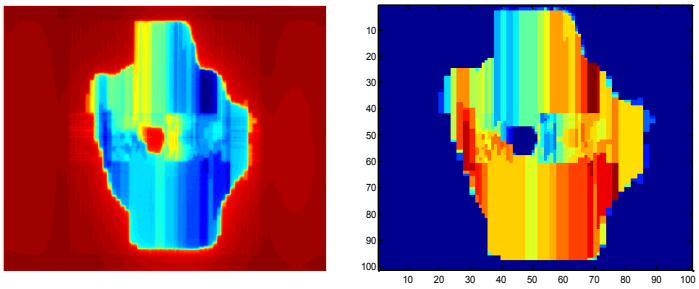


Figure 1. Example of a calibration curve for a 10 cm x 10 cm EPID image at 100 MU.

The MU-EPID software applies a correction matrix to each image to account for the spatial variation in the EPID response.

The correction matrix was acquired by comparing dose planes in a water phantom calculated with a starting fluence measured by the EPID to a dose plane calculated with Pinnacle's starting fluence. After the correction matrix was applied the image was normalized and resized in order to be imported as a valid fluence into Pinnacle. An example of the image taken by the EPID and the resulting ODM is shown in figure 2. The ODMs were imported into Pinnacle using a script which creates a beam for each image with the parameters recorded in the DICOM image obtained from the EPID. The dose distributions were then calculated using the ODM as a starting fluence, the calculated dose was exported to PTW Verisoft (PTW-Freiburg, Freiburg, Germany) and a 3D gamma index was calculated using 3mm distance to agreement (DTA) and 3% dose difference criteria.



Results

Evaluation in Pinnacle

EPID

In order to show a dose distribution comparison for the EPID method we selected a lung patient as an example of typical results (Figures 3 and 4). The dose to 2% of the PTV (D2%) and the dose to 98% of the PTV (D98%) were within 0.9% and 5% of the corresponding treatment plan doses respectively. The deviations of D2% and D98% over all the patients were 0.63% and 5.11% respectively (tables 3 and 4). The mean dose to the PTV for all the patients was within 0.5% when compared to the treatment plan (table 5). The doses to the OARs over all the patients were within 5.30% compared to those of the treatment plan (table 6).

Dose to 2% of PTV (cGy)											
	Liver	Liver	Liver	Liver	Liver	Lung	Lung	Lung	Lung	Pelvis	Avg Diff
Approved	384.2	415.6	397.9	1315.6	398.9	1325.8	1381	1360.5	196.2	191.3	0%
EPID	386.6	415.6	398.7	1304.8	405.6	1336.8	1381	1367.7	195.2	193.5	0.63%
Dynalog	384.6	418.2	397.1	1313.1	398.9	1323.3	1381	1360.5	195.2	191.3	0.18%

Table 3. The D2% values of the EPID and the MLC log file methods against the corresponding doses of the treatment plan.

Dose to 98% of PTV (cGy)											
	Liver	Liver	Liver	Liver	Liver	Lung	Lung	Lung	Lung	Pelvis	Avg Diff
Approved	302.4	306.3	291	1012.4	292.8	999.4	958.8	984.2	182.7	175.4	0%
EPID	286.5	285.5	280.2	947.5	280.3	948.1	901.5	926.3	170.4	173.8	5.11%
Dynalog	303.2	308.8	291.9	1015.1	294.4	999.4	958.8	984.2	181.7	175.4	0.28%

Table 4. The D98% values of the EPID and the MLC log file methods against the corresponding doses of the treatment plan.

Mean Dose to PTV (cGy)											
	Liver	Liver	Liver	Liver	Liver	Lung	Lung	Lung	Lung	Pelvis	Avg Diff
Approved	376.9	402.3	390.9	1311.6	391.5	1292.9	1320.4	1335.1	190	185.5	0%
EPID	375.6	403.1	392.4	1296.7	394.3	1287	1326.2	1329.1	189.7	185.8	0.44%
Dynalog	376.9	404.9	390.7	1310	391.2	1291.2	1322.1	1334.2	189.1	185.2	0.19%

Table 5. The mean dose to the target for both methods are within 0.5% of the treatment plan.

Dose to OARs (cGy)							
	Brachial Plexus	Esophogus	Spinal Cord	Stomach	Bladder	Bowel	Avg Diff
Approved Plan	56.2	56.2	10.1	38.9	156.7	96.3	0%
EPID	66.1	58.8	10.5	38.8	159.8	99.3	5.30%
Dynalog	56.5	56.5	10.2	38.6	156.5	96.8	0.55%

Table 6. The EPID method has the highest deviation from the planned dose to the OARs.

The dose-volume histogram for one of the lung patients shows very good agreement in the high dose regions with minimal differences in low dose region. This pattern is representative of all the patients in the study and in some cases the DVH lines are completely overlapping. Geometrically, the dose distribution agrees with the planned distribution. The shapes of the isodose lines of the delivered dose distributions match those of the treatment plan well in all the views.

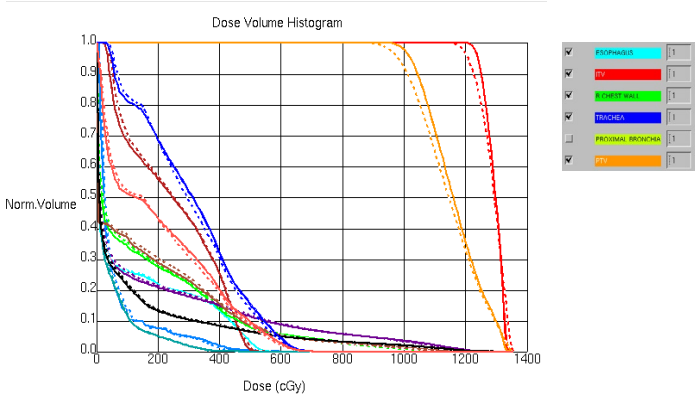


Figure 3. The DVH calculated by Pinnacle for the treatment plan (solid), EPID images (dashed) and MLC log file (thin dashed) for one of the lung patients. The MLC log file lines are hidden behind the treatment plan lines.

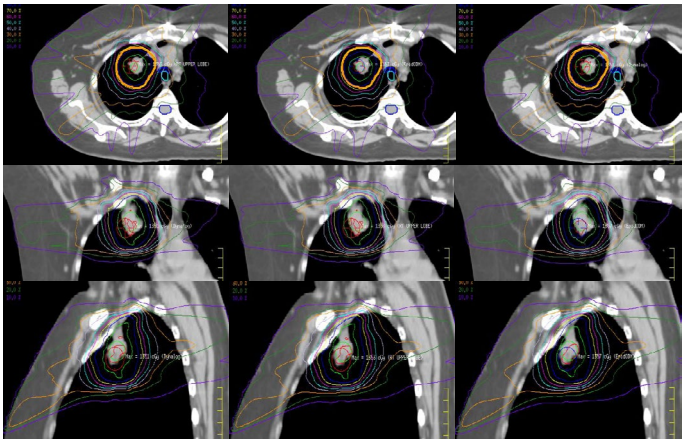


Figure 4. Dose distribution comparisons of the treatment plan (left), EPID ODM (middle) and MLC log file data (right) for a lung patient.

MLC Log Files

The dose to 2% and 98% of the PTV over all the patients is on average within 0.18% and 0.3%, respectively (tables 3 and 4). The mean doses to the PTV of the individual lung patient and over all the patients are within 0.1% and 0.19% respectively compared to those of the treatment plan (table 5). The doses to the OARs are on average within 0.55% of the treatment plan (table 6).

	Gamma %										
	Liver	Liver	Liver	Liver	Liver	Lung	Lung	Lung	Lung	Pelvis	Average
EPID	100%	98.1%	99.9%	97.6%	98.7%	100%	98.6%	99.1%	98.8%	91.4%	98% ± 2.6%
Dynalog	100.0%	100.0%	100.0%	99.0%	98.7%	100.0%	99.3%	99.2%	98.9%	99.0%	99.4% ± 0.5%
Delta^{4+}	91.7%	96.9%	100%	100%	92.6%	99.8%	99.8%	98.3%	99.6%	96.3%	98.1% ± 2.5%

Table 7. The 3D gamma index by method and site. *2D gamma.

The DVHs of the MLC log file method for the lung patient are indistinguishable from those of the treatment plan and this is consistent over all the patients. The deviations in the MLC positions and dose fraction are so small that dose distribution is minimally affected. The percentage error in the MLC position and dose fractionation is manifested as a smaller percentage error in the maximum and mean dose. The percentage error in MLC position was found to be 0.64% while the percent errors in D2% and mean dose are 0.18% and 0.19%, respectively.

For this method, the delivered dose distribution agrees very well with the planned distribution and the shapes of the isodose lines match the approved plan very well in all the views. There is very little variance in the dose distributions, which was expected with such small MLC deviations.

MLC Log File Statistics

A histogram of the MLC deviations approximates a normal distribution as seen in figure 5 with a mean RMS deviation of 0.076mm. MLC positions deviated from the planned positions by an average of 0.64%. Figure 6 shows the mean RMS leaf deviation for all the beams. The outer leaves generally move the least and therefore have the smallest deviation. All the statistics were computed using all the control points for all the patients.

3D Gamma

A 3D gamma index was calculated for all the patients for both the EPID and MLC log file methods, whereas a 2D gamma index was calculated for the Delta 4. A summary of the gamma index values is shown in table 4. Not surprisingly, the MLC log file method resulted in the highest gamma index passing rate percentages while the EPID and Delta4 showed similar results. Although the EPID method calculates a gamma in 3D, its results on a 2D plane are similar to those by Delta 4.

Discussion

This study supports the argument of using alternative QA methods for pre-treatment verification. The use of the TPS as a dose calculation tool as well as a means to visualize the delivered dose distribution on patient anatomy has major advantages over the traditional QA systems.

Both the EPID and MLC log file methods are in agreement with the approved plan for all the patients in this study. The dose distributions show similar maximum dose locations and magnitudes as well as shape of the isodose lines. Dose-volume histograms have similar dose fall off in the target region for all the patients in our study. The 3D gamma percentage values are highest for the MLC log file method, which has a higher inherent agreement with the treatment plan, whereas the 3D gamma values of the EPID are as also very comparable. The EPID performed similarly to the Delta [4] regarding the 2D gamma results.

The EPID results agree with previous work by Vazquez Quino et al., 2014 [35]. The lowest gamma value that occurred with the EPID was observed on the pelvis patient. This is suspected to be due to the larger field sizes, which may have exceeded the limits of the EPID. Large field sizes combined with certain collimator angles may be prohibitive for the EPID based method if the fluence map is larger than the physical size of the EPID.

The EPID method produces an accurate representation of the photon fluence from the gantry head, which translates to an accurate calculated dose distribution in Pinnacle. The efficiency of this method is complimented by its accuracy. The ability to perform dose calculations using the TPS eliminates potential differences stemming from the use of different calculation algorithms and it has the advantage of displaying the reconstructed dose on the true patient anatomy.

For the MLC log file method, the measurements and results that were acquired in the present study regarding the DVHs, dose distributions and MLC deviations between the delivered and planned treatments are in agreement with previous work by Schreibmann et al., 2009 [32] and Agnew et al., 2012 [30]. Similarly to the EPID method, the MLC log file method requires very little time at the treatment machine and the data can be gathered by a therapist if necessary.

Conclusion

The EPID method produced results comparable to that of our established QA method. Use of the MLC log file information revealed little deviation of the delivered plans from the approved plans. Any combination of the presented IMRT QA methods could be used in the clinic since they provide very accurate

evaluation of treatment delivery without requiring extra effort.

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