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EVALUATION OF PATIENT SPECIFIC PRE-TREATMENT QUALITY ASSURANCE TEST FOR HEAD AND NECK CANCER BASED ON A TRAJECTORY LOG FILE AND MEASUREMENT ON EPID BEFORE TREAT FOR PATIENT

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Abstract

For the clinical implementation of a new technique, it is necessary to check the dose calculated by the dose calculation algorithm. The Intensity-modulated radiotherapy (IMRT) technique make isodoses conform to tumor volume and reduce the dose to the organ at risk (OAR), there are increasing the complexity of it. The purpose of the paper is based on the sensitivity of the Trajectory log file to patient-specific pre-treatment quality assurance test and detecting the leaf position errors of Multileaf collimator (MLC), the gantry angle error, the collimator angle error that are the parameters obtained from the Trajectory log file. Comparing the resultspatient-specific quality assurance of accepting the plan between built by Trajectory log file and treatment planning system (TPS) with the results of accepting the plan measured by an electronic portal imaging device (EPID) and TPS in the same tolerance criteria DM/ dM (3%/3mm).

Key words: Trajectory log file, IMRT plan QA, Pylinac.

I. Introduction

For conventional radiotherapy, the 3-dimension conformal radiotherapy technique (3DCRT) deliver dose conform to the tumor volume while keeping the dose to the normal organ adjacent to the tumor as low as possible. To implement this, the accelerator needs to be equipped with an MLC to create the shape radiation field consistent with the tumor volume while still shielding the normal organ. The IMRT which is a complex radiotherapy technique is able to deliver the appropriate dose to a higher tumor volume than the 3DCRT technique while keeping the dose low for the normal organ. IMRT uses dynamic MLC or sliding window with leaves of MLC that are constantly changing position to modulate the desired dose distribution while beam on radiation, creating a steep dose gradient conform to tumor volume and reducing the dose to normal organ, there are increasing the complexity of it. However, any deviation from the actual MLC position from the treatment plan may affect the accuracy radiation distribution. Besides, there are also additional error parameters such as gantry angle error, collimator angle error. To prevent these errors, occur during delivery radiation need to patient-specific quality assurance implemented pre-treatment, to ensure the calculated dose and the measured dose are accepted that the planned and distribution indicators are within tolerance acceptance.

There are several methods to check the IMRT pre-treatment plan, such as point dose measurements using an ionization chamber to verify accuracy in the beam distribution of the treatment plan, and planar measurements (film, 2D diode, the array of ionization chamber) confirming the modulation or fluency test of the intensity-modulated beam is performed before treatment. Both of these methods are affected by insensitivities from within the device. Recently, several programs have been built to evaluate the fluency distribution of segmental step-and-shoot techniques and sliding window dynamic MLC fields to automatically check for leaf position errors of MLC, beam hold-off flags sent to MLC control system, using information from the DynaLog file of the Varian 2100EX accelerator system with 120 leaves MLC [12]. On the Truebeam accelerator system, some software development software uses Trajectory log file to detect MLC position error and check the IMRT pre-treatment plan [13], [14], [15].

II. Material and Method

1. Material

1.1. Truebeam accelerator, TPS and EPID

The investigation performed on 30 cases Head and neck cancer with IMRT plan at HCM Oncology Hospital. The plans get QA and delivery on Varian's True-

Beam accelerator system. Each plan is designed with 9 fields and has different Gantry angles, collimator angles, depending on the stage of the disease, there are different treatment protocol. In addition to IMRT technique, a combination of simultaneous integrated boost with different doses fraction (SIB) including doses of 70/66/60/54Gy with doses fraction is 2.12/2/1.8 /1.6Gy, patients were treated about 33 days, 5 days/week. The author collects and evaluates data on 270 trajectory log files.

All plans are performed on the Varian Eclipse system using the Anisotropic Analytical Algorithm (AAA) for dose calculation, Dose Volume Optimizer (DVO) and Progressive Resolution Optimizer (PRO) version 13.6 [1]. All plans are performed QA on Truebeam version 2.5, equipped with a multi-leaf collimator HD MLC120 that can perform jaw tracking.

Electronic Portal imaging device (EPID) system, a 2-dimensional was predicted dose distribution created with each field delivered with the PDIP algorithm (Portal Dose Imager). Measurements were delivered to the amorphous silicon portal imager (aS1200 from Varian) with a resolution of 1280x1280 pixels, MV field size 43x43 cm^2, pixel size 0.34 mm, maximum image acquisition rate 20 frames/second.

1.2. Trajectory log file

Trajectory log file version 3.0 is generated after the deliver beam of the plan had been completed. During plan delivery, Truebeam recorded all parameters of the treatment plan such as leaves position of MLC, gantry angle, collimator angle, MUs per control point. The maximum recording time for a field is 20 minutes and 20 ms sampling time, data is saved in binary format in a Trajectory log file [2]. For each value in the trajectory log file, there are two parameters, the first is the expected value from the planning system and the second is the actual value. All data are recorded in Varian unit with linear axes (cm), degree (o) and dose (MU).

1.3. Pylinac Software

Accelerators with many functions to control the operation of the machine become very difficult for a new radiotherapy Centre. The heavy workload takes a long time to perform. Pylinac provides quality assurance tools according to Task Group 142 (TG-142) [3], that is the American Association of Physicists in Medicine (AAPM). Pylinac designed for Python programmers as well as non-programmers in the field of therapy medical physics. Pylinac modules are tested by Ali Zaila et al [4], they tested software safety and accurate analysis in accelerator operation test. The group's results are deviation and accuracy similar to manual methods and reduce execution time.

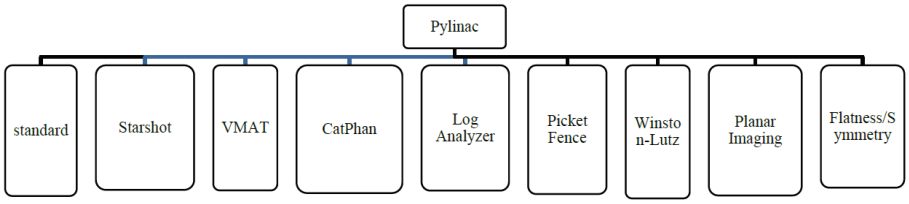

Figure 2.1 Schema describe Pylinac main modules

2. Method

2.1. Gamma (γ) evaluation

The gamma method was developed by Low [5] to compare the measured dose distribution with the calculated dose distribution from the treatment planning system. Each measured dose distribution point $\overline{r_m}D_m(\overline{r_m}))$ was compared with the calculated dose distribution points $\overline{r_c}, D_c(\overline{r_c}))$ with Different Dose (DD)ΔD_M and Distance to Agreement (DTA)Δd_M criteria

An ellipsoid represents for acceptance criterion with the surface equation:

$$1 = \sqrt{\frac{r^2(\mathbf{r}_m, \mathbf{r})}{\Delta d_M^2} + \frac{\delta^2(\mathbf{r}_m, \mathbf{r})}{\Delta D_M^2}} \tag{1}$$

where $r(\mathbf{r}_m, \mathbf{r}) = |\mathbf{r} - \mathbf{r}_m|$ and $\delta(r_m, r) = D(\mathbf{r}) - D(\mathbf{r}_m)$ is the different dose at $\mathbf{r}_m$ point.

The indexes to the right of equation (1) are used to determine the gamma index (γ) at each point on the evaluation plane ($\mathbf{r}_m - \mathbf{r}_c$) for the measurement point rm as shown in Figure 2.2.

For each measurement point, there can exist many pairs of comparisons with any point in the calculation distribution. Each pair has a value (Γ) which is a normalized vector that represents the different dose and DTA.

$$\gamma(r_m) = \min\{\Gamma(\mathbf{r}_m, \mathbf{r}_c)\}\forall\{r_c\} \tag{2}$$

where

$$\Gamma(r_m, r_c) = \sqrt{\frac{r^2(\mathbf{r}_m, \mathbf{r}_c)}{\Delta d_M^2} + \frac{\delta^2(\mathbf{r}_m, \mathbf{r}_c)}{\Delta D_M^2}},$$

$$r(\mathbf{r}_m, r_c) = |\mathbf{r}_c - \mathbf{r}_m|,\ \delta(r_m, r_c) = D_c(\mathbf{r}_c) - D_m(\mathbf{r}_m)$$

If $\gamma(r_m) \leq 1$, calculation pass;
If $\gamma(r_m) \geq 1$, calculation fails.

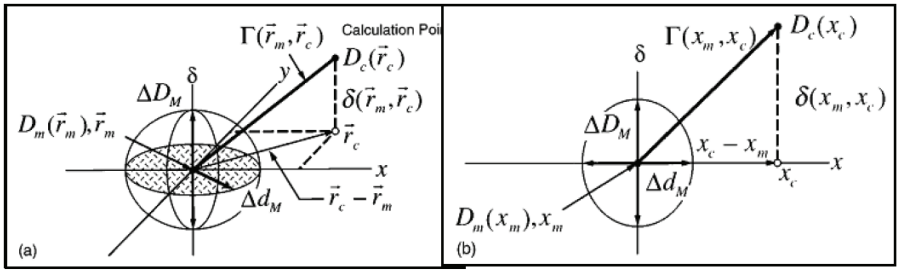

Figure 2.2 Geometric representation of dose distribution evaluation criteria using the combined ellipsoidal dose-difference and distance-to-agreement tests a) Two-dimensional representation b) One-dimensional representation [5]

2.2. Chi (χ) evaluation

The Chi index (χ) performed differently than the Gamma index, instead of looking for the evaluation points that were spatially closest to the reference point, the Chi test compared the reference dose with the evaluated dose at the same point in space coordinate, so the search data set for the Chi index is less than the Gamma index as shown in equation (2). Chi index is proportional to the dose limit condition corresponding to the dose gradient of the reference dose distribution.

The Chi index is calculated by the formula [6] [7]:

$$\chi = \frac{D_c(\vec{r} - D_r(\vec{r})}{\sqrt{\Delta D^2_{\max} + \Delta d^2_{\max}.||\vec{\Delta} D_r||^2}} \tag{3}$$

where $D_c(\vec{r})$ is the evaluated dose distribution, $D_r(\vec{r})$ is the reference dose distribution, ΔD the acceptance criterion of the corresponding dose in the Gamma index, Δd, the acceptance criterion for the distance, $\vec{\Delta} D_r||$ is the magnitude of the local gradient and the derivative D_r according to x.

If $|\chi| \leq 1$ different dose is accepted. Evaluation of each pair of measured and reference data points is performed at the same vector $\vec{r}$.

The Pylinac Log Analyzer module is programmed according to Chi index, for the software analyzing data on EPID is programmed according to Gamma index.

2.3. Gantry angle Error, Collimator angle Error

Gantry is affected by external forces such as gravity and combined with other factors causes of collimator deviation, which leads to a disturbance of isocenter. This leads to inaccuracy of the radiation beam distribution space. The

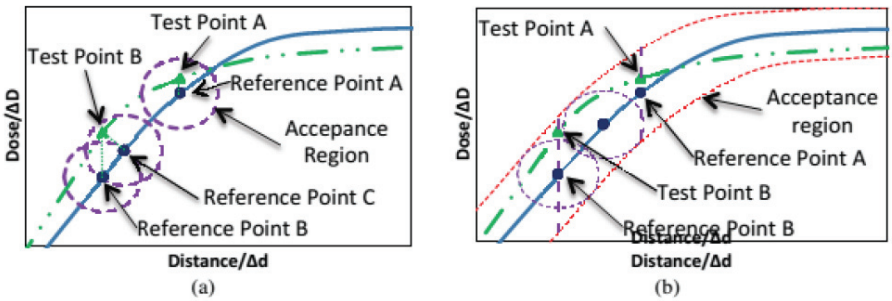

Figure 2.3 a) An illustration of a 1D γ test. b) An illustration of a 1D χ test [7]

collimator angle error and the gantry angle error occurred overtime at each treatment angle.

Angle error = (Actual Value) - (Expected Value)

2.4. Beam hold error, MLC position Error

The MLC control system and the accelerator are schematically depicted in Figure 2.4. The MLC controller controls how the leaves of MLC move linearly between the control points, the control points used to determine the individual leaf's trajectory. Through communication, the controller records the state of the accelerator beam on or beam off, dose fraction, expected leaf positions and actual leaf positions.

During beam on, the MLC-controlled computer checks all the leaves position of the MLC after 20 ms [2], and compares those positions with the position according to the treatment plan and records in the trajectory log file. If any leaf position is deviated from its position according to the plan beyond the preset limit by 0.05 to 0.2 cm [8], the radiation will not be distributed until all leaves are removed transfer within limits. When a deviation occurs a Beam hold-off command appears.

When the beam is in the beam on mode, at that time the value record in the log file is 0. When the beam stops transmitting to move from segment to segment or off beam, at that time the value record in log file is 2 [2].By comparing these indicators between the trajectory log file and the treatment planning system to evaluate the integrity of the system.

The MLC position error or RMSD is the sum of the errors of the treatment squared, divided by the sample size and then square rooted. This provides a good measure of the accuracy of the treatment.

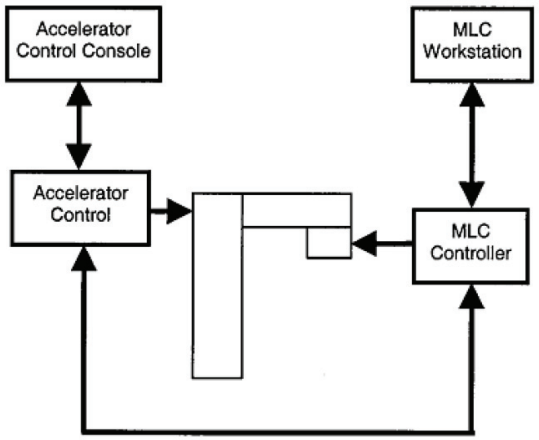

Figure 2.4 A schematic diagram describes a MLC controller system and Accelerator [9]

$$RMSD = \sqrt{\frac{\sum_{n=1}^{N}(X_{\exp,n} - X_{\mathrm{act},n})^2}{N}} \tag{4}$$

where N is the sample size, $X_{\exp}$ is the treatment planning value, X_{act} is the actual value.

III. Result and discussion

3.1. Gantry angle error and Collimator angle error

Table 3.1 shows that the mechanical errors for Gantry angle error and Collimator angle error of the accelerator are within the permissible error limits, and much smaller than the permitted error standards for IMRT technique as reported by TG-142 is $\pm 1^0$ [10]. It shows the current accelerator has high mechanical accuracy.

3.2. MLC position error

Table 3.2 shows that each leaf position error of the MLC in IMRT technique with a sliding window (or moving window) is approximately 0.02278 mm while the permissible tolerance as reported by TG-142 is small more than 3.5 mm [10]. The average RMSD position error occurs approximately within 0.05 mm that is up to 70 times smaller than the standard. The 95th percentile error is less than 0.07 mm.

Table 3.1: Gantry angle error and Collimator angle error between actual value and treatment planning value of 30 cases. Unit (°).

	Gantry RMSD (°)		Collimator RMSD (°)	
STT	**1**	**2**	**1**	**2**
1	0.01614	0.00877	0.00037	0.00281
2	0.00758	0.01200	0.00143	0.00343
3	0.00729	0.00713	0.00587	0.00043
4	0.01908	0.00704	0.00250	0.00043
5	0.00934	0.00331	0.00315	0.00538
6	0.01114	0.00827	0.00262	0.00127
7	0.01131	0.00868	0.00059	0.00364
8	0.01610	0.00500	0.00055	0.00307
9	0.00672	0.01834	0.00348	0.00034
10	0.01319	0.01982	0.00252	0.00034
11	0.01040	0.02203	0.00237	0.00032
12	0.01058	0.01908	0.00448	0.00032
13	0.01319	0.00966	0.00021	0.00033
14	0.00704	0.00762	0.00139	0.00229
15	0.01245	0.01613	0.00054	0.00244
Average RMSD	0.01148		0.00196	
STD	0.00487		0.00162	

The system is highly accurate because the Truebeam accelerator system is not affected by the delay time of the MLC system compared to previous models (50 ms) [11]. The firm took the initiative in designing the later MLC control system. This result is close to published results [11] with average RMSD and 95th percentile error for IMRT technique of 0.027 mm and 0.052 mm while the results of the paper are 0.02278 mm and 0.07 mm respectively.

3.3. Carriage error, Beam Hold error

The difference between the two Carriages is approximately equal and less than the permissible tolerance of 0.35 cm as reported by TG-142, which contributes partly to the error of MLC due to the Carriage is heavy (weighing 36 kg on each side) so influenced by gravity [10] which contributes to treatment error. This is one of the random error. In each treatment, there is a shift between segments then there is a movement of the MLC. Due to the fact that the leaves have a physical travel distance depending on the leaf velocity of MLC and dose rate then the signal is transmitted to inform the treatment machine to transmit beam on. Because of this, the asynchronous results between the radiation beam on and beam hold were recorded in trajectory log file and compared with the treatment plan as shown in Table 3.4.

Table 3.2: The leaves position error of MLC between actual value and treatment planning value of 30 cases.

	Average RMSD (mm)		Max RMSD (mm)		95th percentile error (mm)	
STT	**1**	**2**	**1**	**2**	**1**	**2**
1	0.02333	0.02111	0.06	0.05	0.06	0.06
2	0.02444	0.02111	0.05	0.05	0.08	0.06
3	0.01889	0.02111	0.05	0.05	0.06	0.06
4	0.02000	0.01667	0.05	0.05	0.06	0.05
5	0.01889	0.02222	0.05	0.05	0.06	0.07
6	0.02222	0.02444	0.06	0.05	0.06	0.07
7	0.02000	0.02444	0.05	0.05	0.06	0.07
8	0.01889	0.02222	0.05	0.05	0.05	0.06
9	0.02889	0.02556	0.06	0.06	0.08	0.07
10	0.02778	0.02000	0.06	0.04	0.08	0.05
11	0.02222	0.02222	0.05	0.05	0.06	0.07
12	0.02889	0.02667	0.06	0.06	0.08	0.08
13	0.02111	0.03333	0.05	0.06	0.06	0.08
14	0.02667	0.02444	0.06	0.05	0.08	0.06
15	0.02000	0.01556	0.04	0.05	0.05	0.06
Average	0.02278		0.05		0.07	
STD	0.00390					

The difference MU between the planning system and the actual number of MU recorded is negligible, the error is approximately 0.004 MU. Because during the time of using the machine, the system will have a system error, the machine needs to be calibrated periodically with the ±5% (2-4MU) standard [10].

3.4. QA result based on Gamma map analysis built on log file and EPID which integrated with accelerator.

QA result based on Gamma map analysis built on the log file and EPID which integrated with accelerator has approximately equal acceptance. For the log file, the result of 30 cases was 100%, while for the results obtained from EPID it was 99.4% less than 0.6% with the same criterion of DD / DTA is 3% /3mm for IMRT technique.

The QA result is based on the higher log file because there is no design of any external device so there is no setup error. Lower QA results based on EPID due to some reasons: mechanical error to lift the detector board, the detector board with physical resolution and downtime are also responsible for the lack of information in the detection of the beam that affects the results of the comparison. Besides, the unwanted scattering effect when the beam stops

Table 3.3: The position error of two Carriages is designed to carry and move leaves of MLC.

	Carriage A RMSD (cm)		Carriage B RMSD (cm)	
STT	**1**	**2**	**1**	**2**
1	0.00105	0.00211	0.00091	0.00268
2	0.00192	0.00160	0.00175	0.00169
3	0.00159	0.00165	0.00141	0.00150
4	0.00073	0.00077	0.00055	0.00057
5	0.00135	0.00167	0.00118	0.00151
6	0.00188	0.00108	0.00174	0.00109
7	0.00196	0.00268	0.00181	0.00260
8	0.00087	0.00182	0.00077	0.00174
9	0.00305	0.00159	0.00297	0.00164
10	0.00235	0.00210	0.00216	0.00221
11	0.00169	0.00076	0.00263	0.00081
12	0.00230	0.00126	0.00210	0.00132
13	0.00152	0.00303	0.00153	0.00286
14	0.00222	0.00128	0.00205	0.00127
15	0.00131	0.00082	0.00118	0.00070
Average	0.00167		0.00163	
STD	0.00064		0.00068	

Table 3.4: The asynchronous between beam on and beam hold, different MU in each treatment planning case

	MU RMSD		Max Beam Hold Difference	
STT	**1**	**2**	**1**	**2**
1	0.00339	0.00245	3	4
2	0.00306	0.00391	3	3
3	0.00481	0.00416	3	3
4	0.00481	0.00303	1	1
5	0.00330	0.00440	2	5
6	0.00381	0.00216	3	3
7	0.00356	0.00423	3	4
8	0.00265	0.00381	2	4
9	0.00386	0.00555	3	3
10	0.00456	0.00483	3	3
11	0.0025	0.00492	5	3
12	0.00390	0.00607	3	3
13	0.00431	0.00422	2	4
14	0.00464	0.00539	5	3
15	0.00590	0.00467	3	3
Average	0.00409		3.1	
STD	0.00101			

transmitting contributes to the error in the measurement

Table 3.5: Percentage acceptance of Gamma maps recorded from Trajectory log files and EPID.

	Trajectory Log File		**EPID**	
STT	**1**	**2**	1	2
1	100	100	99.744	99.467
2	100	100	98.644	98.978
3	100	100	98.956	99.678
4	100	100	99.989	99.567
5	100	100	99.689	99.300
6	100	100	97.800	99.856
7	100	100	99.578	99.422
8	100	100	99.522	99.667
9	100	100	99.667	99.622
10	100	100	99.700	99.256
11	100	100	99.500	99.611
12	100	100	99.289	99.111
13	100	100	99.533	99.489
14	100	100	99.533	99.500
15	100	100	98.567	99.778
Average	100		99.400	
STD	0		0.446	

IV. Conclusion

Based on the log file is possible to analyze many data parameters of the treatment techniques. The paper focuses on analyzing the errors related to the Gantry angle, the Collimator angle, leaves position error of MLC, the asynchronism between beam on and stop beam, evaluating whether QA results pass or fail through Gamma map for IMRT technique on Varian's Truebeam accelerator system. Errors occur within the permissible tolerance to perform beam intensity modulation.

Log file accurately records the actual position of the MLC; the high resolution of the log file is useful for error detection. Using the loge file for fast and simple QA, there's no need for a phantom setup to record the beam distribution reduces the workload required. Analysis of gamma map on real beam distribution, the log file of direct reading of beam distribution parameters at a frequency of 20 times/second so it is very sensitive to small changes.

As with other QA tools, it is important to ensure that measurements are recorded correctly. The information contained in the log file should be checked.

In addition, the log file is part of the accelerator system, which cannot detect patient setup errors. Alternatively, a proven log file can be combined with other traditional measurements to realize pre-treatment quality assurance for patients. Theoretically, the leaf motive can be replaced before any clinically significant error arises, using the loge file to check to avoid errors arising in the treatment process.

The Trajectory log file is most useful to use and utilize their unique properties in analyzing a treatment failure, to try and find out why the treatment went wrong. Allows the clinician to oversee treatment as a process and to find out causes when the treatment fails, at that time how the machine is performing.

The use log file to pre-treatment QA can accurately transmission assurance, manage entirety data from TPS to the delivery machine and deliver accurately radiation for patient.

Furthermore, the log file can be performed and analyzed after the first treatment to ensure no treatment parameters have been modified, as well as device replacement error between QA and first treatment.

In addition, the hospitals that want to implement IMRT treatment techniques that do not have a treatment plan QA device, or damaged planned QA device cannot working that is in the process of repair can use the log file for analyzing and evaluating treatment plan before treating for the patient.

In the future, it may be possible to rely on log file's parameters to evaluate changes compared to the planning system parameters resulting in how dose changes affect the normal organ and how dose changes substitute do for tumor.

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