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Radiobiological Assessment of the MLC Positioning Error and Its Relation to the Delivery of Dose Rate Using logfile Analysis

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RADIOTHERAPY is one of main methods of cancer treatment. The development of radiotherapy technique take place in recent years. The most used techniques intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT). Multi leaf collimator (MLC) - as a part of the secondary collimator - has a major rule in both IMRT and VMAT techniques, the accuracy of MLC positioning depends on many factors such as motors of MLC, gravity and gantry direction, leaf speed, dose rate. In modern linear accelerator a logfile is created during treatment delivery. The created logfile contains the related information of the planned and actual delivered monitor units (MU), jaw aperture, gantry angels, collimator angels, leaf speed and leaf position. This work aims to study the effect of MLC positional error on the radiobiological parameters of the radiotherapy treatment planning and how the logfile can be useful to detect the error which can affect the quality of treatment planning. There are two major radiobiological parameters used for plan evaluation: Tumor Control Probability (TCP) and Normal Tissue Complication Probability (NTCP). TCP is a parameter used in radiotherapy to calculate the percentage of tumor killing based on the effect of radiation, while NTCP describes the percentage of the damage to normal tissue due to the radiotherapy treatment. In this study the TCP and NTCP parameters were measured using MATLAB program as biological evaluation tools of radiotherapy treatment plans before and after MLC error applied from logfile analysis. 10 Head and Neck (H&N) VMAT cases were selected for this study. The results showed an increase in the TCP and NTCP values once the MLC error has been corrected in the TPS according to the data of the logfile. For all cases, the average TCP value is 82.64% for the original plan and 84.96% for the plan after MLC modification, which means that there is an increase in the TCP by ~ 3% from the original value after MLC modification; while for the NTCP, there are some variations in the results from organ at risk to another. In conclusion the logfile has important role to discover the error of positioning which may affect the radiobiological parameters of radiotherapy planning evaluation.

Keywords: Radiotherapy, Multi leaf collimator (MLC), Logfile, Tumor Control Probability (TCP), Normal Tissue Complication Probability (NTCP)

Introduction

Radiotherapy plays an important role in cancer treatment [1]. The development of radiotherapy technique starting from Three-Dimensional Conformal Radiotherapy (3DCRT) till the advanced techniques such as intensity modulation radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT), were designed to achieve the balance between two aims: to deliver the prescribed dose to the full target volume and decrease the effect of scattered dose on the organs at risk. The multi leaves collimator - which is inside the head of linear accelerator (LINAC) - has the main role to achieve these aims. In 3DCRT, the multi leaf collimator (MLC) is used to shape the target tumor, but in advanced techniques such

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as IMRT and VMAT the MLC can be used for dose distribution more conforming to the tumor by adding small segment in the field with more sparing of normal organs by using different positions and velocity of MLC during dose delivery [1,2,3]. Multi leaf collimator (MLC) is made of individual "leaves" of a high atomic numbered material - usually tungsten - that can move independently in and out of the path of a beam to shape it and vary its incident intensity and manufactured in different thicknesses according to the LINAC model. The accuracy of the techniques IMRT and VMAT delivery depends on the accuracy of MLC movement. MLC movement accuracy depends on several factors such as motors of MLC, gravity and gantry direction, leaf speed, and dose rate [1,4]. In the modern clinical series of linear accelerators, there is an option to record the mechanism of dose delivery from the LINAC in a logfile, this logfile has also been proposed to save the information of gantry rotation, delivered monitor unite, collimator rotation, MLCs position and actual speeds during delivery and planned in treatment planning system (TPS) [5]. To improve the efficiency of patient-specific quality assurance and provide insight into machine parameters not possible with phantom based measurements, logfile analysis has also been proposed [5,6,7,8]. The logfile can guide the planner if the plan had been delivered with accurate position or not for each session of treatment. On the other hand, the quality of treatment planning has been evaluated by physical parameters, thought to correlate with biological response rather than by estimates of the biological outcome itself. Developments in our understanding of advantages and limitations of existing dose-response models begin to allow the incorporation of biological concepts into a routine treatment planning process. Therefore, tumor Control Probability (TCP) and Normal Tissues Complication Probability (NTCP) are directly correlated to the delivered doses. The truly delivered dose is expected to be as close as possible to the prescribed dose (PD). Practically, to perform the irradiation, the prescribed dose is translated in Monitor Units (MU) by a specific calculation algorithm in the TPS. However, to improve the accuracy of treatment, TCP/NTCP as a radiobiological evaluation parameter can be used to assess new dose calculation algorithms and probe the need for an adjustment of the PD and the TCP/NTCP parameters to keep reproducible clinical results [9]. In this study we aimed to study the effect of MLC positional error on the radiobiological parameters of the radiotherapy treatment planning and how the logfile can be useful to detect the error which can affect the quality of treatment planning.

Materials and Methods

Patients' selection and preparation

10 VMAT plans for 10 patients were selected for a Head and Neck (H&N) site. The conventional prescribed dose was used in one phase 70, 60, 50 Gray (Gy) for H&N. the selection of H&N site is for its complexity in using MLC during treatment delivery. The planning dosimetric parameters for the selected patients used to evaluate the planning is tabulated inTable (1).

Computed Tomography (CT)

Using a *Toshiba scanner Aquilion*^{R} (TSX-201A) CT machine figure(1). This model of scanner is a multi-slice CT with a wide bore (90 cm and 16 detector row /32 slices Aquilion (TSX-201A). Also, this scanner has field of view (FOV) for the acquisition equal to 70 cm which allows to cover more anatomy. 3mm were the CT scanning cuts for all patients.

Treatment Planning System (TPS)

All patients' scans were transferred via a Digital Imaging and Communication in Medicine (DICOM) transferring protocol to the *Eclipse* Treatment planning System (TPS) Figure (2) version 13.5., *Varian* © Co. The targets of tumors and surrounding healthy tissues were

TABLE 1: the dose constraints of surrounding critical structures (the organs at risk) [10]

Organ	Constraints*
Spinal cord	Dmax < 45 Gy
Brain stem	Dmax < 54 Gy
Mandible	Dmax < 70 Gy
Parotid	Dmean < 25 Gy
Oral cavity	Dmean < 45 Gy

*The D_{max} and D_{mean} are the maximum and mean accepted scatted dose respectively for the organ.

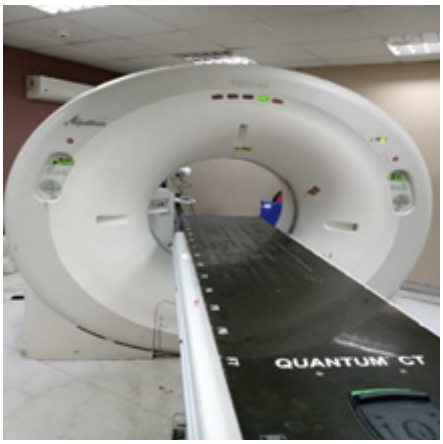

Fig. 1. CT Toshiba scanner Aquilion^{R} (TSX-201A)

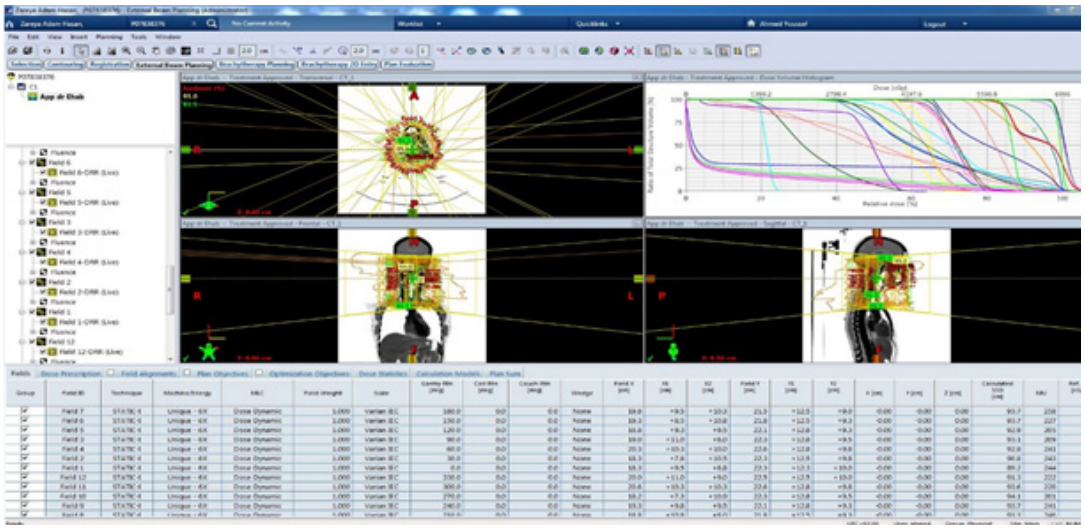

Fig. 2. treatment planning system (TPS)

drown by an oncologist using. After that, an advanced treatment plan was done for each patient. The optimization algorithm of TPS is Dose Volume Optimizer (DVO) version 13.5, this version of optimizer was used for both IMRT and VMAT plans as a default algorithm.

UNIQUE linear accelerator

The UNIQUE is a trading name of an automated controlled LINAC model of Varian company for LINAC productions (figure 3); this LINAC has 6 MV as a single high mega voltage flatted x-ray energy used for radiation therapy. It is equipped with a 120 Millennium multi leaf collimator (MLC) to make shaping for radiation beam, conforming the tumor and protect the healthy tissues surrounded the tumor. This machine can produce different dose rates ranging from 100 MU/min to 600 MU/min. The advantage of 120 Millennium MLC and maximum dose rate is to deliver IMRT and VMAT radiotherapy techniques.

LINAC logfile

During the treatment session and in the LINAC software, a logfile for each session is created selectively for all treatment parameters. By using special code written in the MLC controller software in the ARIA- which is called for a treatment session organization-, the logfile can be extracted to demonstrate the record of the movements and positions of MLCs. The logfile in the LINAC contains information of gantry angle rotation, delivered monitor unite, collimator angle

Fig. 3. UNUQUE LINAC

rotation, and shaping & positioning of MLCs, it can demonstrate the physical parameter of dose delivered during the treatment session. In general, the execrated data of logfile does not indicate the measured dose, but just indicates the actual physical parameters of treatment which necessarily affect the delivered dose.

Dynalog Viewer

The Dynalog viewer is a program in the software control unit of the LINAC machine. This software can be used to analysis the data of logfile. RMS are calculated for each logfile the result is tabulated as shown in figure (4). Equation 1 represents the MLC positioning error between the real leaf position (produced) and estimated leaf position (calculated by TPS)

$$\Delta N_{(\eta,\tau)} = N_{(\text{produced }(\eta,\tau))} - N_{(\text{estimated }(\eta,\tau)))} \quad (1)$$

Where:

$\Delta N_{(\eta,\tau))}$: is the error difference between the real leaf position and predictable leaf position (calculated by TPS) at *n*-leaf count and *t*-time

$N_{(produced\ (\eta,\ \tau))}$: existent leaf place (delivered) at *n*-leaf, *t*-time

$N_{(estimated\ (\eta,\ \tau))}$: estimated leaf position (computed in TPS)

when the beam is on, the error was only considered. The aim of this calculation is to assess each leaf position at certain time meanwhile, the aim of getting root mean square (RMS) error was to evaluate each leaf moving error per treatment. The equation of RMS error present in equation (2) [5,11].

$$RMS_{error} = \sqrt{\sum(\Delta X(n)/C} \quad (2)$$

where *C* is the number of test error leaf position.

Based on these equations, the error of MLC between calculated and actual positing can be calculated.

TCP and NTCP Calculations

The original definition of the Equivalent Uniform Dose (EUD) was derived based on a mechanistic formulation using a linear quadratic cell survival model [12]. Equation 3,4 and 5 describe the definition of EUD, TCP and NTCP receptively based on EUD model.

$$EUD = (\sum V_i D_i^a)^{\frac{1}{a}} \quad (3)$$

$$TCP = \frac{1}{1+(\frac{TCD_{50}}{EUD})^{4\gamma 50}} \quad (4)$$

$$NTCP = \frac{\cdot}{1+(\frac{TD_{50}}{EUD})^{4\gamma 50}} \quad (5)$$

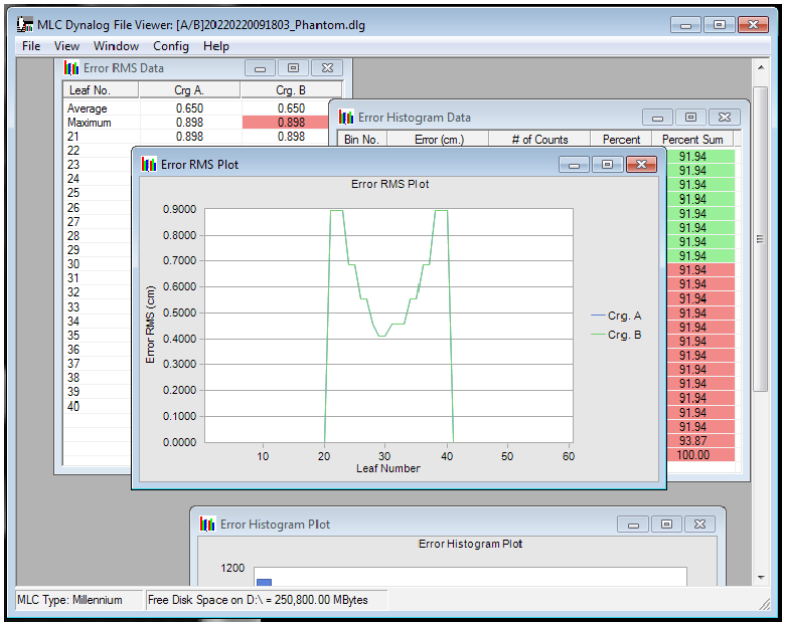

Fig. 4. The Dynalog viewer program in the LINAC control station

V_i: - is the fractional organ volume receiving a dose Di

a: - is a tissue specific parameter which describes the volume effect.

TCD_{50}: the tumor dose to control 50% of the tumors.

TD_{50} is the tolerance dose for 50% complication rate.

γ^{50} describes the slope of the dose-response curve.

The calculation of tumor control probability (TCP) and normal tissue complication probability (NTCP) in this study was based on EUD-Model. A MATLAB code used based on *Hiram et.al* Model which used a MATLAB program to calculate TCP and NTCP more details were found in refence [12]. The DVH is exported from TPS on text format and then this format is converted to comma spread values (CSV) format and imported to MATLAB and then the calculation process starts.

The (*a*) parameter, gamma 50 value TCD for PTV or TD50 for OAR's and α/β ratio used for PTV and organ at risks table (2) based on [12,13,14].

In this study the calculation of TCP and NTCP will be done for the plan before MLC modification and the plan after MLC modification which is the actual delivered plan to patient based on Logfile analysis. The calculations were done by MATLAB program.

Result and Discussion

Effect of MLC error on DVH result: -

We calculated the error of MLC from equations (1) and (2). The deviation position between MLC calculated in TPS and the actual position MLC delivered in LINAC is applied in TPS again in a copy from the original plan, so after the modification is applied, then become tow copies of plans. 1st plan is before MLC error applied and 2nd plan for after MLC error applied. That results in difference in DVH values figure (5) shows two DVH one before MLC modifications and second after MLC modification this result is in line with *Woon et al*, 2018 [2]**.**

As shown in the figure (5), the coverage of PTV is increased after MLC modification error which is applied from logfile analysis. On the other hand, the dose of OAR is also increased; this noted effect may lead to increasing the dose constrains of OAR, and at a same time, may lead to late dose effect. That due the MLC error analyzed from logfile. This effect of MLC error might be due to many affected factors such as the mechanical error of MLC itself or dose rate effect and/or the effect of gravity force **[4]**.

PTV target volume DVH statics based on MLC error

Table (3) shows the static of the target volume before and after MLC Modification the average maximum dose of PTV before MLC modification

TABLE2. parameters used for TCP and NTCP calculation in this study

	a parameter	TCD / TD50 (Gy)	gamma 50	**α/β ratio**
PTV	____	51.77	2.28	10
Brainstem	7	65	3	2.1
Spinal cord	7.4	65	4	2
Esophagus	19	68	4	3
Optic nerve	25	65	3	3
Chiasm	25	65	6	3

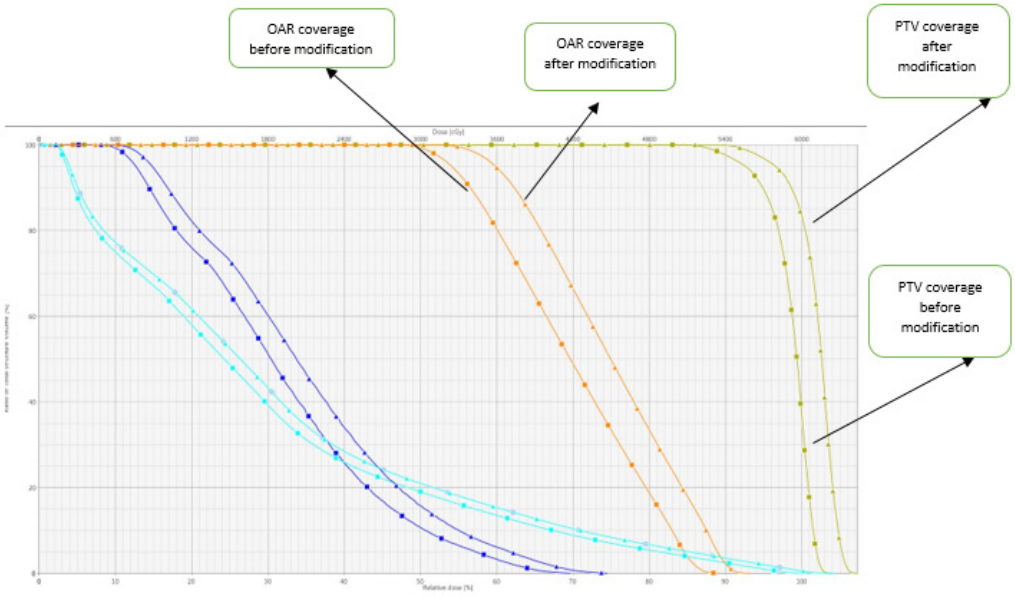

Fig.5. Example of two DVH one before modifications and second after MLC modification

is 75.58 Gy and after MLC modification is 76.834 Gy. The average mean dose are 70.42 Gy and 71 Gy for before and after MLC modification respectively. The increasing of mean dose indicates increasing in plan coverage to target volume.

Organs at risk DVH statics base on MLC error

Normal organs surrounding the target volume also effect from MLC positions error Table (4) shows the average of max, min and mean dose for 6 selected normal organs spinal cord, parotid, chiasm, brainstem, optic nerve and esophagus. The result shows increasing in the received dose to normal organs after MLC modification comparing to before modification which indicate the importance of MLC accuracy during treatment delivery.

Dose rate effect of on MLC error

Figure 6 shows the error histogram that was plotted between the error percentage (y-axis) and dose rate (x-axis) to summarize the detected deviations of leaf positions that was reported during treatment of selected cases. It was shown that the MLC performance vary depending on the dose rate. MLC deviations in the range of 0.005 to 1.5mm was higher for dose rate 600 MU/min and lower at 100MU/min and ranged from 300 to 400 MU/min are equal. From these results, it obtains the dependency of MLC error of dose rate. The result shows: As the dose rate increasing, the percentage of error are increasing; this result is in line with *Kim et al*, 2021 and *Kojima* et al, 2017 [1,18].

Also, these results mean, as dose rate lower, as effect on DVH statics is lower. The static from

TABLE 3.The static of the target volume before and after MLC Modification

	Statics Before MLC Modification			Statics After MLC Modification		
Patient Number	Max Dose (Gy)	Min Dose (Gy)	Mean Dose (Gy)	Max Dose (Gy)	Min Dose (Gy)	Mean Dose (Gy)
1	74.98	62.48	71.00	76.37	63.35	72.38
2	75.50	54.54	70.04	76.23	55.51	64.19
3	76.10	44.06	69.85	78.12	44.52	72.10
4	75.60	58.24	70.64	76.72	61.20	71.40
5	76.16	56.45	69.16	77.28	56.59	69.93
6	76.23	54.40	71.23	78.05	54.46	72.80
7	76.28	62.19	71.28	77.21	63.35	72.17
8	75.88	54.7	71.12	77.13	54.8	72.2
9	75.68	58.28	70.77	76.88	58.93	71.66
10	72.39	60.35	69.18	74.44	63.01	71.22
Average	75.58	56.569	70.42	76.843	63.052	71.005
ST.DEV	1.047564	4.818101	0.737752	0.948013	5.490394	2.282902

TABLE **4. The static of the organs at risk before and after MLC Modification**

	Statics Before MLC Modification			**Statics After MLC Modification**		
Normal Structure	**Max Dose (Gy)**	**Min Dose (Gy)**	**Mean Dose (Gy)**	**Max Dose (Gy)**	**Min Dose (Gy)**	**Mean Dose (Gy)**
Spinal cord	42.95	7.4	25.10	45.1	8	26.3
Parotid	58.4	10.7	37.7	59.9	11.4	38.5
Chiasm	3	1.74	2.6	3.3	1.88	2.9
Brain stem	35.2	7	12.5	36.7	7.5	13.7
Optic nerve	11.7	7.3	7.9	12.4	7.8	8.5
Esophagus	59.23	12.7	30.78	60.5	14.6	33.38

dose rate from 100 MU/min to 400 MU/min are nearly the changing is mostly observed in more than 400 MU/min.

TCP and NTCP calculations results: -

A MATLAB code [12] based on the calculation of TCP and NTCP, has been used for 10 H&N cases. Tow plans were created for each case; one is the original plan before MLC modification and the other plan done after MLC modification. Figure (7) and Table (5) shows the result of TCP for target tumor. The result shows increasing in the TCP result after modification compared with TCP before modification. The average values of TCP are 82.64% and 84.96% before and after MLC modification respectively. The *p*-value = 0.0004 and stander deviation 0.076 and 0.072 for before and after MLC modification which indicates that there is a statistically significant between TCP result before and after MLC modification error. This result is in line with *Nurajni* et al, 2019 and *Jakobi* et al, 2015 **[15,16]**

On the other hand, for NTCP result shows increasing in NTCP values after modification Table (6) shows the NTCP values for brainstem, optic nerve, esophagus, and parotid before and after MLC modifications. This result is in line with *Jakbi* et al, 2015 and *Anbumani* et al, 2014**[16,17].** Table (7) shows the average of EUD values before and after MLC modification, the values increased for after MLC modification compared to before modification

The reason of the increasing in DVH statics, EUD, TCP and NTCP result - due to the MLC position does not reach at the same position in plan - during delivery might be because of

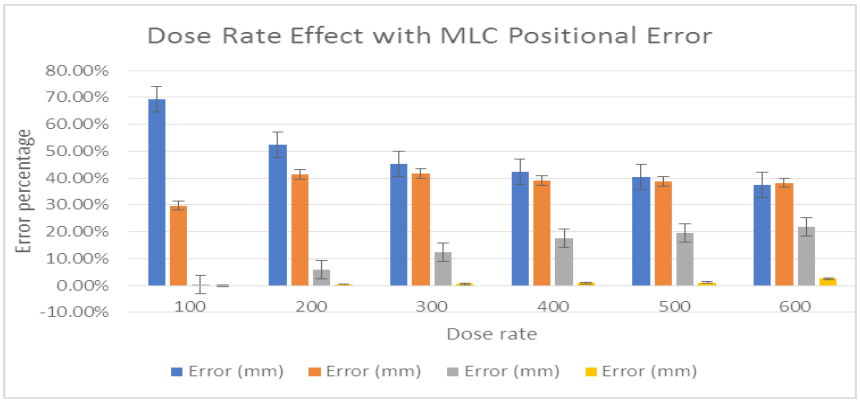

Fig. 6. Effect of dose rate on MLC error

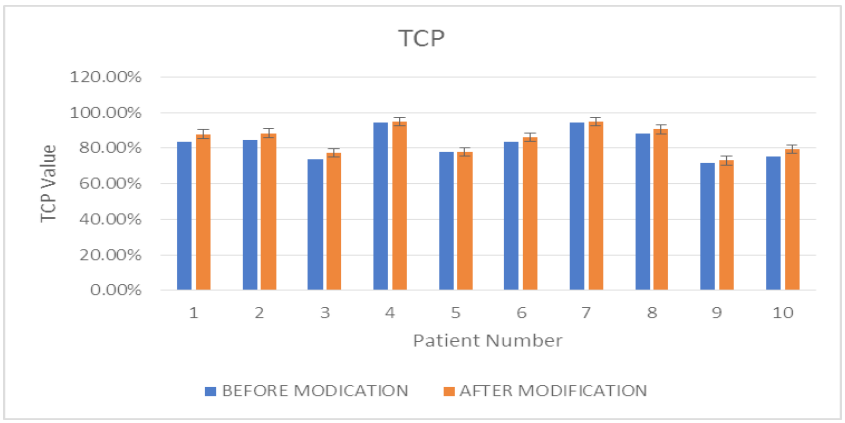

Fig. 7. TCP result before and after MLC modification

TABLE 5. the statics of TCP and EUD results before and after MLC modification

TCP BEFORE MLC MODICATION	TCP AFTER MLC MODIFICATION	EUD BEFORE MLC MODICATION	EUD AFTER MLC MODIFICATION
83.70%	87.86%	70.157 Gy	73.2585 Gy
84.60%	88.30%	69.658Gy	70.4157 Gy
73.50%	77.26%	61.897 Gy	65.6315 Gy
94.10%	94.76%	71.359 Gy	72.6595 Gy
77.74%	77.78%	65.584 GY	66.984 GY
83.38%	85.99%	66.6991 Gy	68.0249 Gy
94.14%	94.84%	71.1203 Gy	72.1815 Gy
88.37%	90.48%	70.695 Gy	71.211 Gy
71.58%	72.95%	70.6751 Gy	72.0871 Gy
75.28%	79.38%	70.1948 Gy	71.2336 Gy
82.64%	84.96%	68.928 Gy	69.6488 Gy
Average	Average	Average	Average
82.64 %	84.96 %	75.755 Gy	77.3321 Gy
STDEV.	STDEV.	STDEV.	STDEV.
0.076	0.072	3.3	2.9

TABLE 6. average of NTCP before and after MLC modification

	Before MLC modification	After MLC modification	Difference
Brainstem	0.14%	0.17%	-0.03%
Spinal cord	0.001%	0.009%	-0.05%
Chiasm	0.01%	0.05%	-0.04%
Optic nerve	0.34%	0.81%	-0.047%
Esophagus	3.84%	6.3%	-2.46%
Parotids	12.84%	27.17%	-14.33%

TABLE 7. average of EUD before and after MLC modification

	EUD Before MLC modification (Gy)	**EUD After MLC Modification (Gy)**
Brainstem	15.93	20.68
Spinal cord	24	25.38
Chiasm	31.2	33.4
Optic nerve	29.1	30.8
Esophagus	49.5	51.94
Parotids	34.5	50.6

the high dose rate, so it's recommended to treat the complex plans in low dose rate for further research.

Conclusion

This study has shown the sensitivity of logfiles to detect the impact of MLC errors in dose delivery for complex 10 VMAT plans. There is a strong positive linear relationship between MLC position error in complicated plans and dose rate in all OARs and PTVs for TCP, NTCP and DVH statics. However, in low and moderate dose rate the effect of MLC error is stable and not observed, so it's recommended that treat to the complication plans in low dose rate. For further research.

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التقييم الراديوبيولوجي لخطأ تحديد موقع الاوراق الديناميكية المتعددة وعلاقته بتسليم معدل الجرعة باستخدام تحليل ملف سجل العلاج

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العلاج الاشعاعى واحد من الطرق الرئيسية فى علاج الاورام السرطانية. تقنيات العلاج الاشعاعى تطورت بشكل كبير فى السنوات الاخيرة فاصبحت التقنيات الاكثر شيوعا واسخداما فى العلاج الاشعاعى الان هى العلاج الاشعاعى متغير الشدة IMRT والعلاج القوسى الحجمى VMAT ؛ وحيث ان مجمع الاوراق الديناميكية المتعددة MLC هو جزء من المعجلات الخطية الطبية وهى الاكثر استخداما فى هذة التقنيات كما انه يلعب دور اساسيا فى عملية العلاج بهذة التقنيات المتقدمة، لذا فان دقة حركة وتوقف هذه الاوراق الديناميكية ذات أهمية كبيرة جدا فى جودة العلاج الاشعاعى، ودقة حركة وثبات هذه الاوراق الديناميكية المتعددة تعتمد على عدة عوامل منها محركات الاوراق نفسها وتأثير الجاذبية الأرضية واتجاه حركة رأس المعجل الخطى وسرعة حركة الاوراق الديناميكة ذاتها بالإضافة الى تأثير تغير المعدل الزمنى للجرعة المنطلقة منها.

فى المعجلات الخطية الحديثة تم ابتكار ملف سجل إلكترونى داخل المعجل الخطى ليصبح سجل شامل لكل التغييرات التى قد تطرأ على أجزاء مجمع الوريقات أثناء إطلاق الجرعة العلاجية ، ومن ثم يتم ادراجه اثناء جلسة العلاج الاشعاعى حيث انه يحتوى على معلومات خاصة بالخطة العلاجية المرسلة من نظام التخطيط العلاجى الى وحدة العلاج والخطة التى تم العلاج بها فعليا من هذه المعلومات موضع الاوراق الديناميكية المرسلة من الخطة العلاجية والتى تم بالفعل ايصالها بواسطة المعجل الخطى.

يهدف هذا العمل الى دراسة مدى تأثير اخطاء الأوضاع العلاجية بالاوراق الديناميكية المتعددة على عملية العلاج الاشعاعى من خلال دراسة العوامل الراديوبيولوجية للخطة العلاجية قبل وبعد تعديل الاوراق الديناميكة باستخدام ملف سجل العلاج الاشعاعى.

هناك اثنين من العومل الراديوبيولوجية المستخدمة لتقييم خطة العلاج وهما عامل احتمالية التحكم بالورم (TCP) وعامل احتمالية مضاعفات الانسجة الطبيعية (NTCP) فهما يقومان بقياس مدى قدرة الخطة العلاجية على قتل الخلايا السرطانية ومدى احتمالية حدوث ضرر للخلايا السليمة المحيطة بالورم السرطانى.

تم حساب هذان العاملان باستخدام برمجة ال MATLAB كأدوات تقييم راديوبيولوجى لخطط العلاج الاشعاعى قبل وبعد تعديل الاوراق الديناميكية لعدد 10 حالات علاج قوسى فى منطقة الرأس والرقبة. أظهرت النتائج زيادة في قيم TCP وNTCP بمجرد تصحيح خطأ MLC في TPS وفقا لبيانات ملف السجل، فبالنسبة لعامل TCP لجميع الحالات، بلغ متوسط قيمته82.64% للخطة الأصلية و٨٤,٩٦٪ للخطة بعد تعديل MLC، مما يعني أن هناك زيادة في TCP بنسبة ٣٪ تقريبًا عن القيمة الأصلية بعد تعديل MLC؛ بينما بالنسبة لـ NTCP، فقد وجد ان هناك بعض التنوع لهذا العامل بناءا على الأعضاء الحيوية السليمة المجاورة للورم.

وكنتيجة لما سبق يمكن إستنتاج أن ملف السجل العلاجى له دورًا فعالا يمكن الإعتماد عيها لإكتشاف أخطاء حركة مجمع الوريقات والذي بدوره قد يؤثر على المعلمات الإشعاعية لتقييم تخطيط العلاج الإشعاعي.