STUDY TO OPTIMIZE VMAT PLAN IN TREATMENT OF HEAD AND NECK CANCER BY USING 6 MV FF AND FFF PHOTON BEAMS

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Abstract:

This study aims to compare and evaluate the dose distribution and physical characteristics of photon beams 6 MV Flattening Filter (FF) and 6 MV Flattening Filter Free (FFF) of TrueBeam STx (FFF) in Eclipse v13.6 software in head and neck cancer (H&N) treatment plans.

Computed Tomography Simulation (CT-Sim) imaging of 31 H&N cancer patients treated with photon beam 6 MV-FF and Volumetric Modulated Arc Therapy (VMAT) technique were used to re-plan the Eclipse v13.6 software with photon beams 6 MV-FFF.

The Quality of Coverage (Q), the Conformity Index (CI), the Homogeneity Index (HI) and the Dose-Volume Histograms (DVH) for the targets and the dose on organs at risk (OARs) were

used to compare and evaluate the dose distribution and physical characteristics of 6 MV-FF and FFF photon beams. All plan quality assurance (QA) was performed using the Electronic Portal Imaging Device (EPID), and the gamma index method was used to qualify the agreement of dose distribution between the calculations and the measurements. Besides, total Monitor Units (MUs) and the beam on time (BOT) were investigated.

The dose evaluation indicators obtained from plans using 6 MV-FFF photon beams give values close to the ideal values than 6 MV-FF photon beam plans. In terms of physical characteristics, the plans to use the FFF photon beam for the average number of MU are about 17.39% higher than the plans to use FF photon beams. However, the BOT of FFF photon beam (1400MU/mins) is reduced by 49.34% compared to FF photon beam (600MU/mins). For the tolerances dose to OARs, FF photon beams give tolerated dose values at some OARs using 6 MV-

FF photon beam for lower dose values than 6 MV-FFF photon beams at the spinal cord (0.76%) and right inner ear (0.24%). However, the 6 MV-FFF photon beam has a lower dose value than the 6 MV-FF photon beam in most of the remaining OARs such as 0.36% in the brainstem, 5.68% in the chiasm, 12.18% in the left len, 14.77% in the right len, 1.01% in the left inner ear, 3.07% in the left optic nerve, 2.79% in the right optic nerve, 1.15% in the left parotid gland, 0.87% in the right parotid gland and 4.44% of the body mean dose. Therefore, the results calculated by 6 MV-FFF photon beam are different and close to ideal values than 6 MV-FF photon beam.

The dose distribution indices obtained from 6 MV-FFF photon beams are better than FF photon beams in H&N cancer. Therefore, maybe the application of 6 MV-FFF beam in the routine clinical treatment of H&N cancer.

Keywords: *FF, FFF, Conformity Index, Homogeneity Index, H&N cancer, Eclipse v13.6.*

Tóm tắt:

Mục đích: So sánh, đánh giá phân bố liều và các đặc trưng vật lý của hai chùm tia photon lọc phẳng Flattening Filter (FF) và không lọc phẳng Flattening Filter Free (FFF) trên kế hoạch bệnh nhân ung thư đầu – cổ bằng việc sử dụng phần mềm Eclipse v13.6. **Đối tượng và phương pháp:** Dữ liệu hình ảnh CT – mô phỏng của 31 bệnh nhân ung vùng đầu cổ đã được điều trị bằng kỹ thuật VMAT được sử dụng để lập lại kế hoạch trên phần Eclipse v13.6 bằng hai chùm photon là FF và

FFF và thuật toán AAA trên máy Trubeam STx. Với tất cả các kế hoạch, các chỉ số độ bao phủ (Quality of Coverage – Q), chỉ số độ phù hợp (Conformity Index – CI), chỉ số độ đồng nhất (Homogeneity Index – HI) và giản đồ liều khối (Dose Volume Histograms – DVH) cho thể tích điều trị và các cơ quan nguy cấp (Organs at risk – OARs) được dùng để so sánh và đánh giá. Kiểm chuẩn chất lượng kế hoạch (Quality Assurance – QA) được thực hiện bằng cách sử dụng EPID (Electronic Portal Imaging Device) và phương pháp gamma index được sử dụng để phân tích phân bố liều giữa tính toán và đo đạc. Ngoài ra, số MU (Monitor Unit) và thời gian phát tia cũng được sử dụng nghiên cứu. **Kết quả:** Các chỉ số đánh giá về liều thu được từ các kế hoạch điều trị sử dụng chùm tia photon FFF cho giá trị gần với giá trị lý tưởng hơn so với các kế hoạch sử dụng chùm tia photon FF. Về đặc trưng vật lý, các kế hoạch sử dụng chùm tia photon 6 MV-FFF cho số MU trung bình cao hơn các kế hoạch sử dụng chùm photon 6 MV-FF khoảng 17,39%. Tuy nhiên, thời gian phát tia của chùm photon 6 MV-FFF (1400MU/phút) thì lại giảm hơn 49,34% so với chùm photon 6 MV-FF (600MU/phút). Đối với liều dung nạp vào cơ quan nguy cấp, chùm tia photon 6 MV-FF cho giá trị liều dung nạp tại một số cơ quan nguy cấp thấp hơn so chùm tia 6 MV-FFF ở tủy sống (0,76%) và tuyến tai trong phải (0,24%). Tuy nhiên, chùm tia photon 6 MV-FFF lại cho giá trị liều thấp hơn chùm tia photon 6 MV-FF tại hầu hết các cơ quan nguy cấp còn lại như 0,36% ở thân não, 5,68% ở giao thoa thị, 12.18% ở thủy tinh thể trái, 14,77% ở thủy tinh thể phải, 1,01% ở tai trong trái, 3,07% ở tuyến thần kinh thị trái, 2,79% ở tuyến thần kinh thị phải, 1,15% ở tuyến nước bọt trái, 0,87% ở tuyến nước bọt phải và 4,44% liều trung bình dung nạp vào cơ thể. Vì vậy, các kết quả tính bởi chùm tia photon 6 MV-FFF có khác biệt và gần với giá trị lý tưởng hơn so với chùm tia photon 6 MV-FF. **Kết luận:** Các chỉ số phân bố liều thu được từ chùm tia photon 6 MV-FFF tốt hơn so với chùm tia photon 6 MV-FF trong ung thư đầu cổ. Vì thế việc áp dụng chùm tia 6 MV-FFF trong điều trị lâm sàng ung thư đầu – cổ thường quy là rất triển vọng.

Từ khóa: *FF, FFF, chỉ số độ phù hợp CI, chí số động đồng nhất HI, ung thư đầu – cổ, Eclipse v13.6.*

I. INTRODUCTION

Today, linear accelerators (Linac) used in advanced radiotherapy have been integrated with dose calculation algorithms in addition to existing algorithms such as Analytical Anisotropic Algorithm (AAA), Acuros XB (AXB), Pencil Beam (PCB) in Varian's Eclipse software, or beams photon FF and FFF. All aimed at improving the quality and accuracy of the treatment process for patients [1]. The trend of high dose radiation therapy is being widely used [2][3] as well as studying ultra-high dose rate such as FLASH radiotherapy [4][5][6].

Since September 2017, The Department of Radiation Oncology and Radiosurgery – 108 Military Central Hospital is equipped with TrueBeam STx accelerator system and Eclipse v13.6 planning software. H&N cancer patients were prescribed radiotherapy on the TrueBeam STx linac accelerator, using the VMAT technique with the AAA dose calculation algorithm – a convolution superposition algorithm used to calculate radiation dose distribution in a treatment planning system computer. The treatment plans are dosed using FF photon beams. FFF photon beams are commonly used in stereotactic radiosurgery (SRS) and stereotactic body radiation therapy (SBRT) to provide high doses and reduce the number of a fraction [7]. Currently, there is no research on the use of

FFF photon beams in the routine of radiotherapy. This study was conducted to show the advantages and disadvantages of two FF and FFF photon beams characteristics in dose distribution on treatment plans. The indicators of dose distribution, physical characteristics, and tolerance dose to healthy organs. plan with two algorithms on the same CT image sequence used for the evaluation and comparison.

II. MATERIALS AND METHODS

2.1 CT - Simulation dataset

We conducted retrospective studies based on phase I CT-Sim data of 31 H&N cancer patients who were treated with VMAT technology at the Department of Radiation Oncology and Radiosurgery – 108 Military Central Hospital from September 2017 to December 2019. In 31 patients, there were 23 males and 8 females, ages from 29 to 80. The volume of PTV is from 16.7 cm^3 to 236.3 cm^3. The thickness of each CT slice is 2.5 mm. The position of patients is head first-supine, permanent with a 5-point mask Q-fix to positioning and immobilization and simulated by CT GE Optima 580 machine.

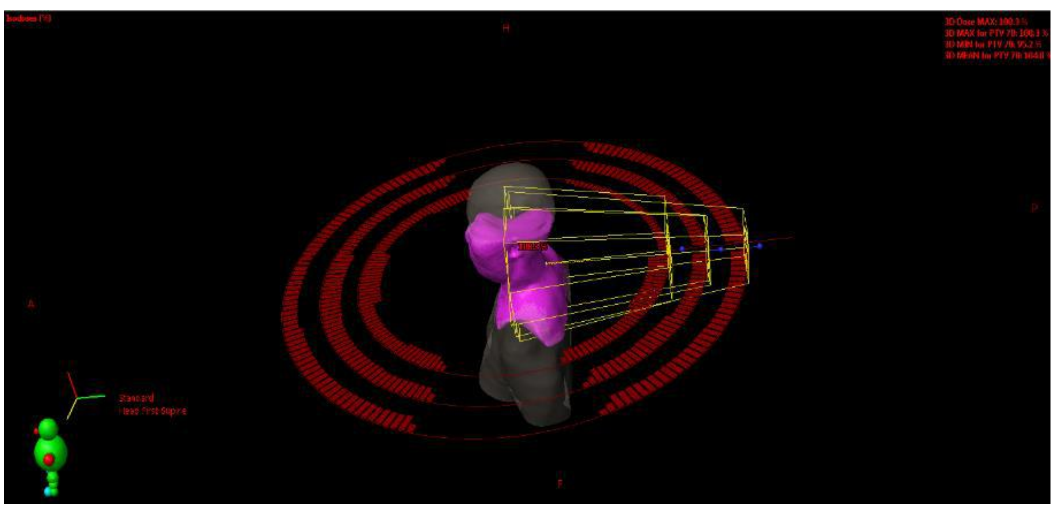

Figure 1: Three arcs of VMAT plan for H&N cancer patients.

Treatment planning for H&N cancer patients using three flat same arcs CW: 179^o – 181^o and CCW: 181^o – 179^o with avoidance sectors from 80^o – 110^o and 250^o – 280^o to limit the dose to the two joints action on both shoulders with AAA algorithm to calculate dose. The photon beam has an energy level of 6 MV with FF photon beam characteristic with a dose rate of 600 MU/mins. The dose prescription was at PTV with 69.96 Gy in 33 fractions.

To compare the advantages and disadvantages between FF and FFF photon beams. We conducted re-plan the plans by using the 6 MV-FFF photon beam (1400MU/mins) and then used the evaluation indicators of dose including: Coverage – Q [8], Conformity index – CI [9][10], the homogeneity index – HI [8][11] and physical characteristics are the number of MUs and the beam on time used. Table 1 present the formula for calculating the indicators.

Table 1: The formula of planning evaluation indicators.

Variables	**Formula**	**Ideal value**	**References**
Q	——	A = 1	RTOG – 1993 [8]
CI	$CI_{ICRU-62} = \frac{100}{PTV}$	A = 1	ICRU – 62 [9]
	$CI_{Paddick} = \frac{TVxTV}{PTV\ x \quad 100}$	A = 1	Paddick [10]
HI	HI = ——	A = 0	Wu – Qiuhen [11]
	$HI = \frac{D_5 - D_{95}}{}$	1<A≤1.1	RTOG – 1993 [8]

**Dmax* = maximum dose, *Dmin* = minimum dose, *DP* = dose prescription, *Dx* = the percentage of the prescribed dose covering x% planning target volume, PTV = planning target volume, PTV100 = the volume PTV received 100% dose prescription, TV = target volume.*

Based on the Dose Volume Histogram (DVH), we compared and evaluated the value of tolerated dose at OARs between two photon beam FF and FFF. The dose of tolerance at OARs of all plans were evaluted by using the recommendation by The Radiation Therapy Oncology Group - RTOG 0623 [12], RTOG 0912 [13], RTOG 0225 [14].

Pretreatment quality assurance (QA) was performed using the Electronic Portal Imaging Device (EPID) for all VMAT plans.

2.2. Results

The average value of Quality of coverage – Q, Conformity Index – CI, Homogeneity Index – HI, MUs, Beam on time BOT and dose of tolerance at OARs of 31 plans H&N cancer patients (6 MV-FF) and 31 plans H&N cancer patients (6 MV-FFF) is show in Table 2,3,4,5.

Table 2: Average values of CI index and Q of VMAT plans H&N cancer.

Indicators	**CI**				**Q (%)**	
	ICRU-62		**Paddick**			
Beam characteristics	6 MV-FF	6 MV-FFF	6 MV-FF	6 MV-FFF	6 MV-FF	6 MV-FFF
Values	0.974 – 1.217	0.976 – 1.175	0.741 – 0.926	0.768 – 0.925	31.90 – 97.60	30.00 – 97.30
Mean	1.079 ± 0.047	1.055 ± 0.035	0.840 ± 0.037	0.857 ± 0.028	83.66 ± 14.63	83.73 ± 15.01
p	*0.0032*		*0.0052*		*0.8236*	

Table 3: Average values of HI index of VMAT plans H&N cancer.

Indicators	**HI**			
	RTOG		**Wu**	
Beam characteristics	6 MV-FF	6 MV-FFF	6 MV-FF	6 MV-FFF
Values	1.063 – 1.132	1.072 – 1.126	0.046 – 0.082	0.047 – 0.091
Mean	1.097 ± 0.011	1.098 ± 0.012	0.067 ± 0.006	0.068 ± 0.008
p	*0.5500*		*0.4811*	

Table 4: Average values of MUs and BOT of VMAT plans H&N cancer.

Indicators	**Physical characteristics**			
	MUs		**Beam on time – BOT (min)**	
Beam characteristics	6 MV-FF	6 MV-FFF	6 MV-FF	6 MV-FFF
Values	486.80 – 868.40	625.20 – 1070.70	0.811 – 1.447	0.447 – 0.765
Mean	638.12 ± 57.08	749.12 ± 85.14	1.064 ± 0.095	0.535 ± 0.061
p	*0.0000*		*0.0000*	

Table 5: Average values of tolerant doses at OARs of of plans H&N cancer.

OARs	Beam characteristics	Values	Mean	*p*
Spinal Cord (D_{max}: Gy)	6 MV-FF	37.24 – 42.81	40.95 ± 1.04	*0.1783*
	6 MV-FFF	37.71 – 44.54	41.26 ± 1.48	
Brainstem (D_{max}: Gy)	6 MV-FF	48.95 – 59.27	52.96 ± 2.07	*0.3877*
	6 MV-FFF	49.24 – 60.19	52.77 ± 1.66	
Chiasm (D_{max}: Gy)	6 MV-FF	6.75 – 58.73	19.35 ± 9.91	*0.0076*
	6 MV-FFF	5.18 – 58.06	18.31 ± 10.17	
Left Lens (D_{max}: Gy)	6 MV-FF	4.07 – 8.67	6.53 ± 0.95	*0.0000*
	6 MV-FFF	3.04 – 7.98	5.79 ± 1.20	
Right Lens (D_{max}: Gy)	6 MV-FF	3.91 – 8.68	6.37 ± 1.00	*0.0000*
	6 MV-FFF	2.77 – 7.67	5.55 ± 1.05	
Left Inner Ear (D_{mean}: Gy)	6 MV-FF	39.72 – 49.30	44.23 ± 1.07	*0.1127*
	6 MV-FFF	37.27 – 46.95	43.79 ± 1.24	
Right Inner Ear (D_{mean}: Gy)	6 MV-FF	30.01 – 48.53	41.95 ± 3.21	*0.7257*
	6 MV-FFF	30.52 – 48.26	42.05 ± 3.27	
Left Optic Nerve (D_{max}: Gy)	6 MV-FF	6.28 – 59.76	30.88 ± 13.00	*0.1377*
	6 MV-FFF	5.23 – 58.39	29.96 ± 13.39	
Right Optic Nerve (D_{max}: Gy)	6 MV-FF	6.52 – 59.63	29.12 ± 12.64	*0.1328*
	6 MV-FFF	5.43 – 58.79	28.33 ± 13.95	
Left Parotid Gland (D_{mean}: Gy)	6 MV-FF	22.77 – 25.97	24.69 ± 0.56	*0.0592*
	6 MV-FFF	22.95 – 25.99	24.41 ± 0.58	
	6 MV-FF	22.37 – 27.34	24.47 ± 0.79	*0.0845*

Right Parotid Gland (D$_{mean}$: Gy)	6 MV-FFF	21.33 – 27.19	24.26 ± 0.84	
Body Mean Dose (D$_{mean}$: Gy)	6 MV-FF	6.66 – 15.35	11.06 ± 2.10	*0.0320*
	6 MV-FFF	6.42 – 14.40	10.59 ± 2.02	

Table 2,3,4 show the evaluation indicators of dose and the average physical characteristics of H&N cancer VMAT plans. Most of the dose evaluation indicators, the 6 MV-FFF photon beam results close to the ideal value than the FF photon beam. With MU numbers, the plans use 6 MV-FF photon beams, the average number of MU generated per plan is 638.12 ± 57.08 while for 6 MV-FFF photon beams it is 749.12 ± 85.14. We see that the MU number in the 6 MV-FFF photon beam plans is much bigger than the 6 MV-FF photon beam plans and is about 17.39% larger. The average beam on time for the plan of using 6 MV-FF photon beam to calculate the dose is 1,064 ± 0.095 minutes while for 6 MV-FFF photon beam is 0.535 ± 0.061 minutes. It was found that the beam on time of 6 MV-FFF photon beam plans was significantly reduced compared to plans using 6 MV-FF photon beams, down to 49.34% despite the MU numbers in the plans using 6 MV-FFF photon beam emitting 17.39% more because the dose rate of 6 MV-FFF photon beam is 1400 MU/mins bigger 2.33 times than that of 6 MV-FF photon beams. The CI, MU, and the beam on time with $p < 0.005$ should be statistically significant and the HI and Q index, the value $p > 0.05$ should not be statistically significant. Such a result may be due to the properties of the beam. With the FFF photon beam, the removal of a flattened filter reduces the dose in the half-life region, the dose outside the field of projection, and increases the surface dose.

Table 5 shows that the radiotherapy VMAT plans were made according to the evaluation criteria according to RTOG 0623 [12], RTOG 0912 [13] and RTOG 0225 [14]. The value of tolerance at some OARs when using 6 MV-FF photon beams gave lower dose values than 6 MV-FFF photon beams such as spinal cord (0.76%) and right inner ear (0.24%). However, the 6 MV-FFF photon beam has a lower dose value than the 6 MV-FF photon beam in most of the remaining OARs such as 0.36% in the brain stem, 5.68% in the chiasm, 12.18% in the left lens, 14.77% in the right lens, 1.01% in the left inner ear, 3.07% in the left optic nerve, 2.79% in the right optic nerve, 1.15% in the left parotid gland, 0.87% in the right parotid gland and 4.44% of the body mean dose. Therefore, the results calculated by 6 MV-FFF photon beam are different and close to ideal values than 6 MV-FF photon beam (Table 5). In OARs such as chiasm, left lens, right lens, and body mean dose have $p < 0.05$ should be statistically significant. As for the other OARs have $p > 0.05$ should not be statistically significant.

III. DISCUSSIONS

For FF and FFF photon beams, there have been several studies on the treatment plans of authors in different areas of the body such as that of Maged Mohammed et al 2016 [15], this study resulted in the removal of a flattened filter that reduces the dose in the half-life area, scattering at the treatment head, the out-of-field dose and increasing the dose rate and surface dose. The dose rate of beams without flat filters is about 2.46 times higher than beams with flat filters, reducing treatment time. Another study by Wuzhe Zhang et al. 2014 [16] evaluated the dose distribution when using a beam without a flat filter (FFF) with IMRT radiotherapy technique for cancer treatment in the early stages of esophagitis, this study resulted in a treatment plan using IMRT technique with two types of FF and FFF photon beams achieving full dose distribution results for the treatment volume. The FFF photon beam is more effective at reducing the lower dose in the lungs and reducing the average lung dose by 20% compared to FF photon beam. The results of the above studies show that the applicability of FFF photon beams to routine clinical treatment is very large.

However, in the process of studying and calculating the data collected at the Department of Radiation Oncology and Radiosurgery – 108 Military Central Hospital, Both FF and FFF photon beam characteristics have advantages and own disadvantages.

The most obvious difference between the two beam characteristics is the maximum dose rate FFF photon beams due to the removal of a flat filter, the maximum dose rate for 6 MV-FFF photon beams is 1400 MU/mins compared to only 600 MU/mins for 6 MV-FF photon beams, increasing to 2.33 times [17]. Therefore, although the MU of the 6 MV-FFF photon beams plans is higher, the beam on time is reduced by nearly half compared to the 6 MV-FF photon beam plans.

Thereby, improving the effectiveness of treatment for patients, helping patients more comfortable in treatment.

Treatment results are evaluated on two criteria: tumor destruction and protection of OARs. Based on Table 5, we see that there are some tolerable values for brainstem, chiasm, left inner ear gland, right inner ear gland, left optic nerve gland, right visual nerve gland, left parotid glands and right parotid glands are higher than the rating given by RTOG 0225 [14][18]. The reason is that these are the plans made follow the CT phase I with a large volume of treatment, close or invading OARs. At the Department of Radiation Oncology and Radiosurgery – 108 Military Central Hospital, for H&N radiotherapy VMAT plans, the treatment regimen consists of 33 fractions in two phases, with the initial phase I being 20 fractions. The physician will give sufficient priority to the therapeutic volume and accept high doses into the OARs. For phase II, when the therapeutic volume meets the radiation dose, the volume will be reduced, then priority will be given to reducing the dose into the OARs as long as the total two-phase dose still meets the given evaluation criteria. Therefore, it will meet the requirement of just enough dose to the volume of PTV treatment while ensuring the dose to OARs.

This study has only been researched with VMAT plans for H&N cancer on Eclipse V13.6 software. We will continue to work with radiologist, conduct further research and clinical evaluation on issues of concern when using FFF photon beams and their use in routine radiotherapy treatment. Thereby, making recommendations on the use of FFF photon beams in practical application with ordinary radiation.

IV. CONCLUSIONS

For H&N patients' VMAT plans, indicators of dose distribution and OARs show that the FFF photon beam is close to the ideal value. At the same time, due to the large dose rate, the advantage of treatment time should be considered using FFF photon beams. Therefore, the application of FFF photon beams in clinical treatment for routine radiotherapy has great promise. This is consistent with the studies of Maged Mohammed [15] and Wuzhe Zhang et al.[16]. However, the above conclusions are for reference only, the use of which beam properties depends on many factors such as facility equipment, the possible effects when using the FFF photon beam haven't researched yet.

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