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Evaluation on Radiation Treatment Planning According to use of Flattening Filter(FF) or Flattening Filter-Free(FFF) in High-Energy X-Ray Equipment

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Abstract

Background/Objectives: This study focuses on radiation therapy planning according to flattening filter or flattening filter-free in high-energy X-ray therapy. **Methods/Statistical Analysis:** VMAT (Volumetric Modulated Arc Therapy) planning was built subject to 5 patients and the CI (Conformity Index) and HI (Homogeneity Index) values were comparatively analyzed using DVH (Dose Volume Histogram). Therapy plans were made with simple fractionation for 2 patients and VMAT therapy plans according to usage of flattening filter or flattening filter-free through SBRT therapy plans were made for 3 patients. **Findings:** For the therapy plan for the first brain patient, CI values according to use of flattening filter or flattening filter-free were both shown to be 0.95, and HI values were shown to be 1.09 and 1.10. For the second lung cancer patients, CI values according to use of flattening filter or flattening filter-free were both shown to be 0.95, and HI values were both shown to be 1.09. For the third lung cancer patients, CI values according to use of flattening filter or flattening filter-free were shown to be 0.95 and 0.96, and HI values were shown to be 1.08 and 1.07. For the Fourth liver cancer patients, CI values according to use of flattening filter or flattening filter-free were shown to be 0.94 and 0.95, and HI values were shown to be 1.11 and 1.12. For the Fifth liver cancer patients, CI values according to use of flattening filter or flattening filter-free were shown to be 0.94 and 0.96, and HI values were shown to be 1.10 and 1.09. As a result of comparison, mean CI values according to use of flattening filter or flattening filter-free were shown to be 0.946 and 0.954(p= 0.135), and HI values were both shown to be 1.094(p=0.549). **Improvements:** In this study, results of radiation therapy planning according to use of flattening filter or flattening filter-free in high-energy X-ray equipment were shown to be similar and usability could be found in using flattening filter- free that can reduce therapy time by minimizing reduction of radiation output dose.

Keywords: CI (Conformity Index), DVH (Dose Volume Histogram), Flattening-Filter Free (FFF), HI (Homogeneity Index), Radiation Therapy, VMAT (Volumetric Modulated Arc Therapy)

1. Introduction

The role of radiation therapy is increasing as cancer patients are increasing[1]. The most commonly used linear accelerators in the radiation therapy field is equipment that generates high-energy X-rays and electron beams according to existence of target. For high-energy X-rays that pass transmission type targets, strong dose distribution is formed in the center line in which even dose is investigated within irradiation using a flattening filter which is a metal absorber.

In simple radiation therapy plans such as the conventional parallel opposed field technique or four field technique, delivery of dose distribution same as wide beams using Flattening Filter (FF) has been importantly used. However, Intensity Modulated Therapy (IMRT),

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Volumetric Modulated Arc Therapy (VMAT), and helical IMRT (tomotherapy) which are newly progressed therapy technologies are leading radiation therapies and are being applied in clinics. These new therapy techniques do not require direct generation of even beam on a plane in which it is applied in clinics using the characteristics of non-flattened beams[2-6].

Also, this use of flattening filter has the problem that therapy time becomes long due to reduction of X-ray output and nowadays TrueBeam STx™ (Varian, PaloAlto, USA) equipment is Flattening Filter-Free (FFF) for high-output X-ray therapy[7-9]. In this study, comparative evaluation on radiation therapy planning according to Flattening Filter (FF) or Flattening Filter-Free (FFF) in high-energy X-ray therapy in linear accelerators used for radiation therapy was conducted to evaluate the usability.

2. Materials and Methods

2.1 Radiation Therapy Planning According to use of Flattening Filter (FF) or Flattening Filter-Free (FFF)

TrueBeam STxTM (Varian, PaloAlto, USA) was used as the linear accelerator in this study in which high-energy X-rays of 6 MV and 10MV were used to set radiation therapy planning according to use of flattening filter or flattening filter-free. Videos gained from CT simulation (Philips, Netherlands) on 5 patients of brain(1), lung(2), and liver(2) were used in the study. Achieved videos were processed by inverse planning method using Eclipse RTPs (Ver.10, Varian, USA) for comparative analysis on VMAT (Volumetric Modulated Arc Therapy) radiation planning according to use of Flattening Filter (FF) or Flattening Filter-Free (FFF) [Figure 1] [Figure 2].

Figure 1. TrueBeam STx™ (Varian, Palo Alto, Ver 1.5 USA).

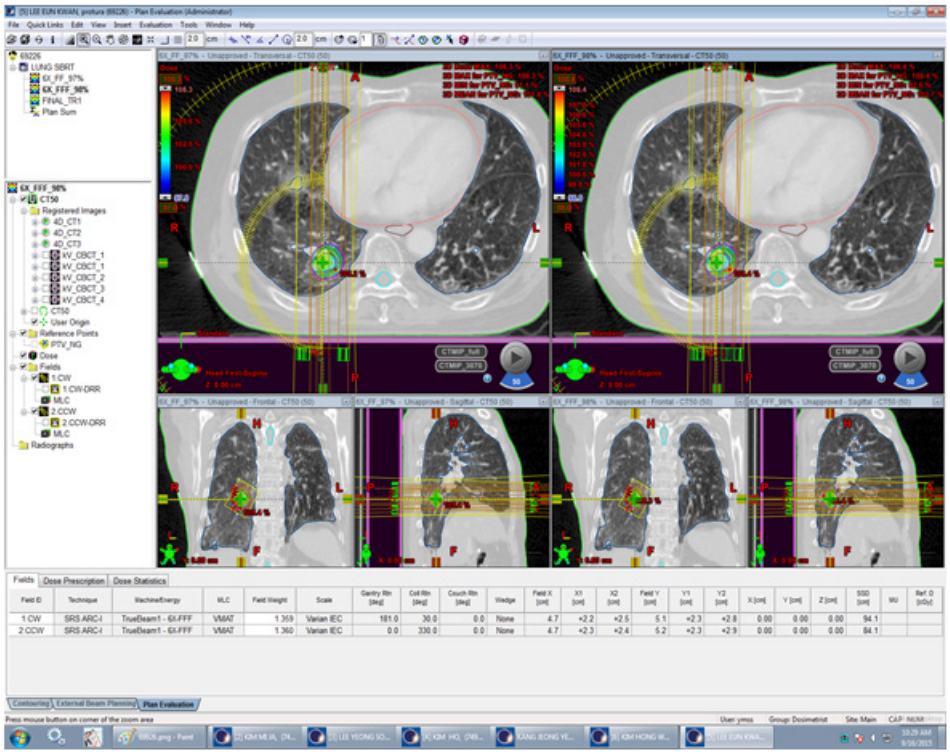

Figure 2. Radiation treatment planning was performed using the Eclipse RTPs(Ver.10, Varian, USA).

Therapy plans were made with simple fractionation for 2 patients and VMAT therapy plans according to usage of flattening filter or flattening filter-free through SBRT therapy plans were made for 3 patients[Table 1] [Figure 3].

Table 1. Patient Information for Radiation Treatment Planning

No	Site	Energy	Dose/ Fx	Mode	Fractionation
1	BRAIN	6X	46Gy/ 23Fx	FF FFF	Simple
2	LUNG	6X	50Gy/ 20Fx	FF FFF	Simple
3	LUNG	6X	60Gy/ 4Fx	FF FFF	SBRT
4	LIVER	10X	45Gy/ 3Fx	FF FFF	SBRT
5	LIVER	10X	45Gy/ 3Fx	FF FFF	SBRT

2.2 Analysis on Radiation Therapy Planning

For comparison of radiation therapy planning according to use of flattening filter or flattening filter-free, an optimization program was used to find DVH (Dose Volume Histogram), CI (Conformity Index) and HI (Homogeneity Index) values were comparatively analyzed based on this[Figure 4].

The Conformity Index (CI) as defined in ICRU 83 is

CI = Volume of PTV covered by the reference dose / Volume of PTV (1)

CI = 1.0 is ideal value

The HI is defined as the ratio of the dose to 95% of the volume of the PTV (D≥95%) to the dose to 5% (D≥5%) of the PTV.

HI = D5% / D95% (2)

CI value close to 1 means accurately prescribed dose on PTV (Planning Target Volume) and HI value close to 1 means that even dose is show in PTV.

3. Results and Discussion

3.1 Comparison of Radiation Therapy Planning According to use of Flattening Filter or Flattening Filter-Free

For the therapy plan for the first brain patient, X-ray of 6 MV energy was divided by 23 fraction of 46 Gy. CI value was 0.95 when using a flattening-filter and was 0.95 without a flattening-filter as well. HI value was 1.09 when using a flattening-filter and was 1.10 without a flattening-filter which showed similar results. For the second lung cancer patients, X-ray of 6 MV energy was divided by 23 fraction of 50 Gy. CI value was 0.95 when using a flattening-filter and was 0.95 without a flattening-filter as well. HI value was 1.09 when using a flattening-filter and was 1.09 without a flattening-filter which showed the same results. For the third lung cancer patients, X-ray of 6 MV energy was divided by 4 fraction of 60 Gy. CI

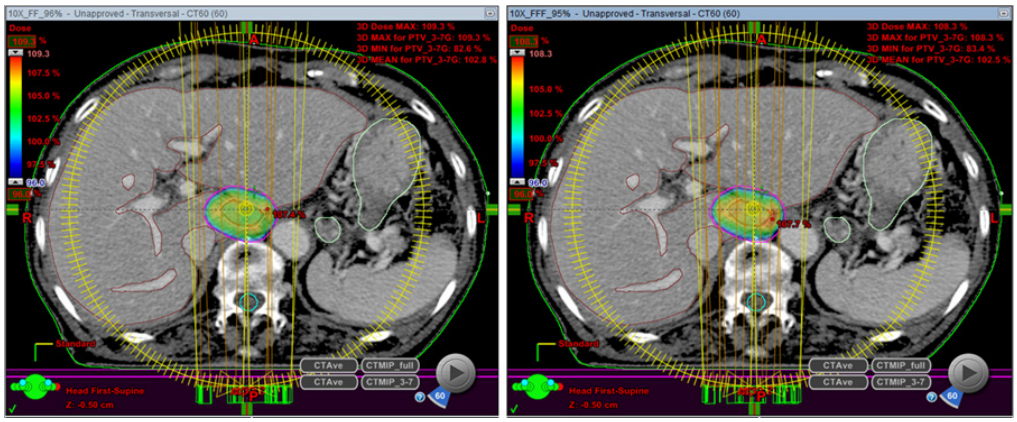

Figure 3. VMAT radiotherapy planning in according to use of flattening filter or flattening filter-free of liver cancer (Left is using a flattening filter and right is flattening filter-free).

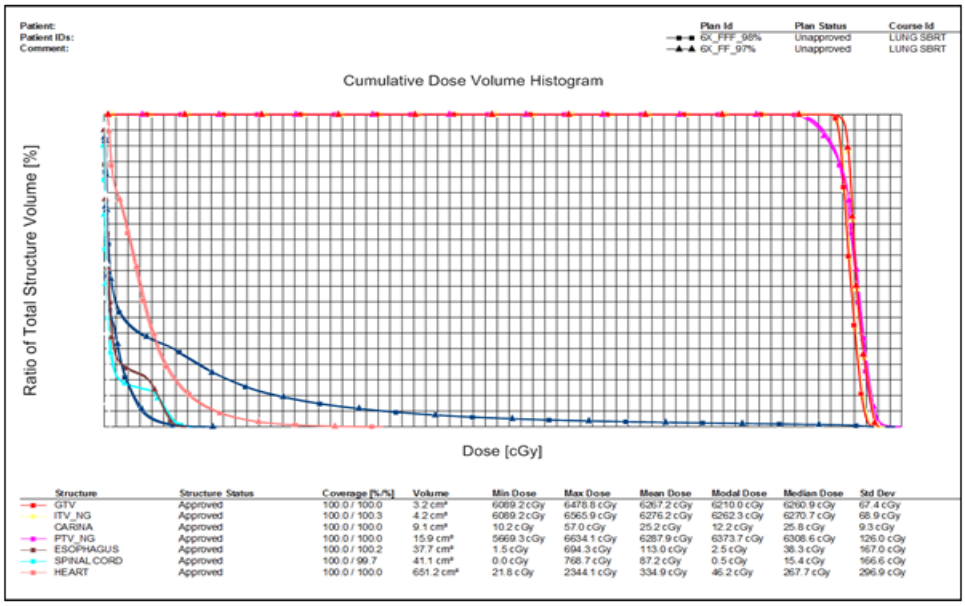

Figure 4. Comparing the radiation treatment plan using the DHV.

value was 0.95 when using a flattening-filter and was 0.96 without a flattening-filter as well. HI value was 1.08 when using a flattening-filter and was 1.07 without a flattening-filter which showed similar results. For the Fourth liver cancer patients, X-ray of 10 MV energy was divided by 3 fraction of 45 Gy. CI value was 0.94 when using a flattening-filter and was 0.95 without a flattening-filter as well. HI value was 1.11 when using a flattening-filter and was 1.12 without a flattening-filter which showed similar results. For the Fifth liver cancer patients, X-ray of 10 MV energy was divided by 3 fraction of 45 Gy. CI value was 0.94 when using a flattening filter and was 0.96 without a flattening-filter as well. HI value was 1.10 when using a flattening-filter and was 1.09 without a flattening-filter which showed similar results[Table 2][Table 3].

Table 2. CI values are compared according to use of Flattening Filter (FF) or Flattening Filter-Free (FFF)

Pt. No	Site	Mode	V_{TV}	V_{PTV}	CI
1	BRAIN	FF	517.37	541.89	0.95
		FFF	514.95	541.89	0.95
2	LUNG	FF	300.4	314.63	0.95
		FFF	300.08	314.63	0.95
3	LUNG	FF	15.21	15.95	0.95
		FFF	15.39	15.95	0.96
4	LIVER	FF	27.41	29.09	0.94
		FFF	27.76	29.09	0.95
5	LIVER	FF	39.9	42.3	0.94
		FFF	40.5	42.3	0.96

Table 3. HI values are compared according to use of Flattening Filter (FF) or Flattening Filter-Free (FFF)

Pt. No	Site	Mode	$D_{5\%}$	$D_{95\%}$	HI
1	BRAIN	FF	5019	4613	1.09
		FFF	5040	4600	1.10
2	LUNG	FF	5445	5011	1.09
		FFF	5447	5010	1.09
3	LUNG	FF	6471	6011	1.08
		FFF	6453	6035	1.07
4	LIVER	FF	4985	4487	1.11
		FFF	5032	4510	1.12
5	LIVER	FF	4921	4490	1.10
		FFF	4932	4516	1.09

4. Conclusion

As a result of comparison, mean CI values according to use of flattening filter or flattening filter-free were shown to be 0.946 and 0.954($p = 0.135$), and HI values were both shown to be 1.094($p = 0.549$) [Table 4].

Through the research results of this study, results of radiation therapy planning according to use of flattening filter or flattening filter-free in high-energy X-ray equipment were shown to be similar and usability could be found in using flattening-filter free that can reduce therapy time by minimizing reduction of radiation output dose.

Table 4. Compared to the average values of the CI and HI

	Mode	N	Mean	Std Dev	Min	Max	p-value
CI	FF	5	0.946	0.0055	0.94	0.95	0.135
	FFF	5	0.954	0.0055	0.95	0.96	
HI	FF	5	1.094	0.0114	1.08	1.11	0.549
	FFF	5	1.094	0.0182	1.07	1.12	

5. Discussion

Difference of physical dose according to use of flattening filters is being measured or analyzed by Monte Carlo simulation by various researchers[10-13]. The main issues are general beam characteristics (flatness, symmetry, penumbrae), spectrum, beam energy and depth doses, backscatter, electron contamination, out of field dose, neutron production, and shielding requirements[14-18]. The difference of radiation therapy plans according to usage of overall flattening filters in actual therapies was to be analyzed.

In this study, CI values and HI values according to usage of flattening filters were comparatively evaluated using DVH during radiation therapy plans in VMAT therapy.

Through the research results, it was known that there was no difference of dose distribution of radiation therapy plans according to usage of flattening filters, but it is considered that the results may be useful for therapy plans that do not require generation of even beams such as beamlet in small field therapy plans or intensity modulated radiation therapies.

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