RESEARCH PAPER

Comparison of the dose distribution of the VMAT radiotherapy technique depending on the beam used: FFF-X10MV and FFF-X15MV

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ABSTRACT

Background: The aim of the study was to answer the question of whether flattening filter (FF) and flattening filter-free (FFF) beams can be used alternately in the volumetric modulated arc therapy (VMAT) treatment technique, regardless of the size of the irradiated volume [small (S) or large (L) planning target volume (PTV)].

Materials and methods: Two groups of patients were examined: a group with a S-PTV-laryngeal cancer and a group with a L-PTV — gynecological volume. For each patient, two treatment plans were made for beams (energies): FFF-X10MV and FF-X15MV. Then, a statistical analysis, nonparametric test, and independent groups were performed, comparing the beams' impact on the analyzed treatment plans.

Results: In the case of laryngeal irradiation (S-PTV), there are no statistically significant differences between the energy used and the assessed parameters of the plan. In the case of gynecological volume (L-PTV), only statistically significant differences were noted for the number of monitor units depending on the energy used. For a large irradiated volume (gynecological case), the use of FFF beams increases the number of monitor units by 39,4% in relation to the FF beam.

Conclusions: In the case of gynecological neoplasms, statistically significant differences were found in the number of monitor units. Therefore, in the case of irradiation of L-PTV, it is recommended that flattening-filtering beams are used due to the smaller number of monitors. In the case of S-PTV, no statistically significant differences were found between the types of beams used (FF or FFF) and the treatment plan parameters analyzed in the study.

Key words: flattening filter-free beams (FFF); flattening filter beams (FF); volumetric modulated arc therapy (VMAT); radiation planning index (RPI)

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Introduction

Radiotherapy, whether used alone or as a part of combined therapy, gives a lot of options for the implementation of treatment plans. Dynamic techniques give a lot of possibilities of modifying the dose distribution in the patient. They use the movement of a multi-leaf collimator (MLC) during irradiation to modulate the beam in order to adjust the dose distribution in the patient. The VMAT technique additionally introduces the gantry movement during irradiation, which further increases the possibilities of isodose modifications [1–9].

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The geometry of fields, their collimation, and energy are decided based on the arrangement of the target and organs at risk (OAR) [3]. The choice of radiation energy has an effect on how the dose is deposited. The deeper the target area is located, the higher the energy is used. The use of beams with a flattening filter (FF) will even out the beam profile; however, this limits the maximum dose rate. Flattening filter-free (FFF) beams are most often used for stereotactic radiosurgery. It is a type of radiotherapy used in most cases for small cancers with few fractions that contain high doses [8–11]. Despite this use of radiation, normal tissues near the target area get only small doses of radiation. Therefore, the toxicity is low.

The final step that has the greatest impact on determining the dose distribution in the patient is the MLC motion obtained by optimization in the treatment planning system (TPS) [1–9].

Dose Volume Histogram (DVH) gives information on dose-volume relationship between target area and OARs [3, 6]. Based on DVH, we can calculate the Radiation Planning Index (RPI) that allows us to compare dose distribution between plans [12]. In brief, RPI analyzes doses at targets and OARs to calculate values between 0 and 1. Extreme values are theoretical, where 0 means that OARs get a homogeneous maximal dose and 1 means that OARs get no dose [11, 12]. Therefore, a comparison of dose distributions for two different VMAT beams applied to different locations of irradiated volumes associated with the PTV dimension can be useful in making clinical practice decisions related to treatment planning [13–29].

Materials and methods

Two groups of patients were analyzed. The first group consisted of thirty patients treated for laryngeal cancer. The lymph nodes were not included in the PTV. Two treatment plans were made for each patient. Patients were treated with the VMAT technique using the same total dose (51 Gy), fractional dose (3 Gy), and based on radiation oncologist prescription. The dose was normalized on the reference point, on the 100% isodoses, unlike the normalization suggested by ICRU-83 (on median). For each energy, a new optimization plan was performed, using the same number and geometry of the beams (two fields with 0° and 90°

collimation and the head rotation in the range of 240–120° and 120–240°). In each plan, the spinal canal was spared. The maximum dose on the spinal canal was optimized according to internal guidelines. The parameter suggested is $D_{max} \leq 18$ Gy. Due to the volume of the treated area, we will refer to this group of patients as small PTV (S-PTV). The second group consisted of thirty-two patients treated with radiotherapy in the gynecological volume. This area covered the tumor and the lymph nodes. Fields of irradiation were much greater than that of the larynx. Due to the volume of the treated area, this group of patients was called large PTV (L-PTV). For each patient, two treatment plans were made using FFF-X10MV and FF-X15MV beams. The VMAT technique was used and the same field collimation (30° and 330°) and the number of beams were used (two beams with head rotation 181–179°, 179–181°). The total dose (50.4 Gy) and the fractional dose (1.8 Gy) were the same in every plan performed. In these cases, we also applied 100% isodose normalization at a reference point. The OARs in gynecology irradiation were the bladder, rectum, femoral bone heads and intestines. OAR doses were optimized according to internal guidelines. The suggested parameters are as follows:

- rectum $D_{30Gy} < V_{60\%}$;
- bladder $D_{45Gy} < V_{35\%}$;
- femoral Bone $D_{30Gy} < V_{15\%}$;
- intestines $D_{40Gy} < V_{30\%}$.

The maximum dose in OARs should not exceed 100% of the prescribed dose. The definition of S-PTV/L-PTV refers to the separation of the planned areas of this work.

The beams (energy) used in the study were FFF-X10MV and FF-X15MV. The accelerator used in this paper uses MLC HD120 (28 outer leaves 5.0 mm wide and 32 inner leaves 2.5 mm wide on one side). The study used Eclipse v. 16.1 treatment planning system using the Acuros algorithm by Varian Medical Systems. For each patient, calculations were made using a new optimization plan based on the same beam geometry. No additional restrictions or adjustments were applied (apart from sparing the OAR mentioned above). This solution allows plans to be compared accurately. It must be emphasized, however, that the quality of the beam planning can be further improved; therefore, patients will not be treated with
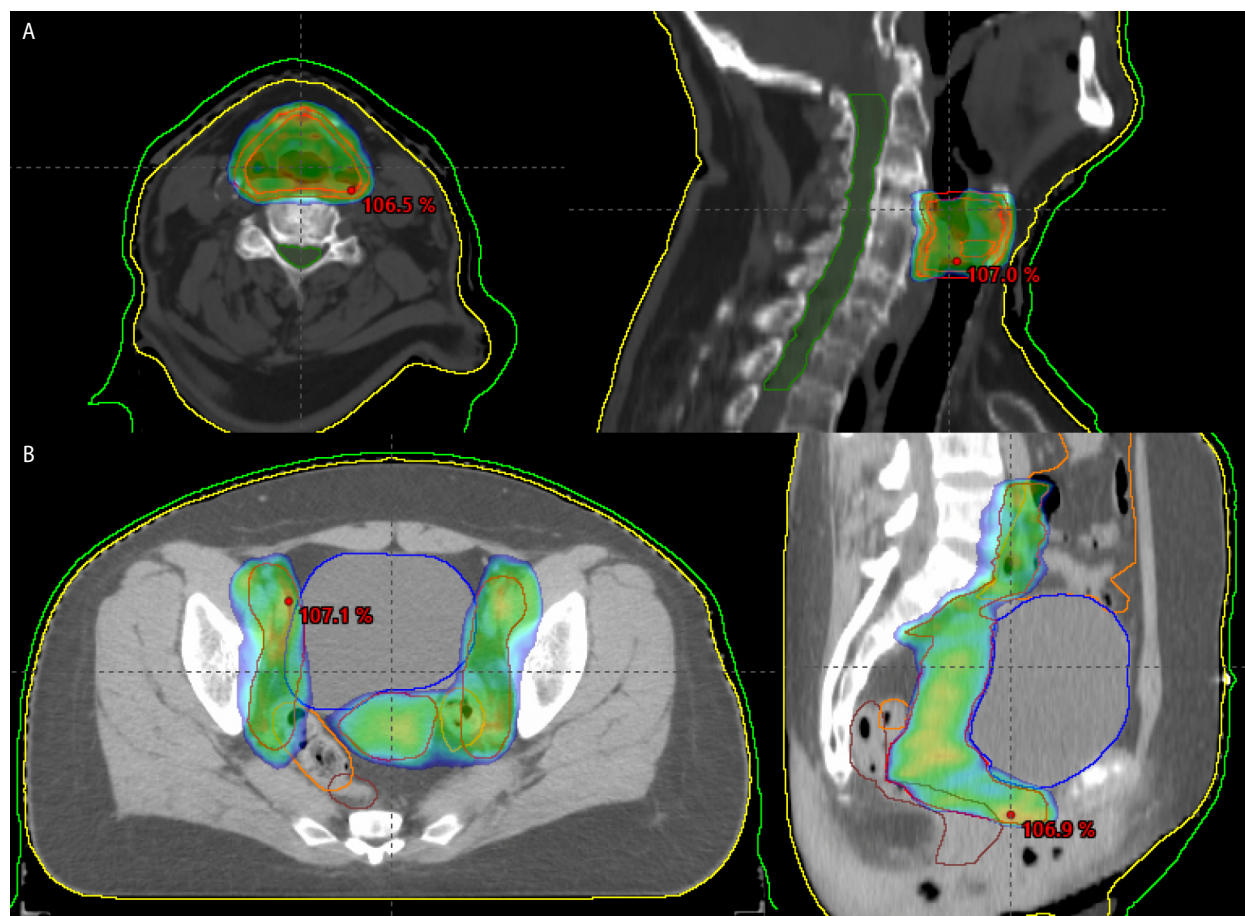
Figure 1. Dose distributions for example patients. **A.** Small planning target volume (S-PTV; larynx); **B.** Large planning target volume (L-PTV; gynecology)

the plans made during the study. All treatment plans were implemented on the same machine, i.e., Varian Medical Systems TrueBeam v.2.7 accelerator. In each plan, the energies were implemented with the highest possible dose rate — for flattening filter beams (FF-X15MV), it was 600 MU/min, for flattening filter free beams (FFF-X10MV), it was 2400 MU/min. Figure 1 represents an example of dose distribution acquired in plans used in this study. The adopted zero hypothesis indicates that there is no effect of beam type (FFF/FF) on dose distribution and MU for large and small irradiated volumes (which correlates with the field dimension of the radiation beam. Statistical analysis was performed using U-Manna-Whitney tests. Statistical significance was determined at the level of 0.05. In order to compare dose distribution for different types of beams in analyzed locations, RPI was used [12]. The obtained results were compared with data from the work of D. Plaza and K. Orzechowska [11].

Results

For each patient from the two study groups, two treatment plans using different energy were made. Table 1 and Table 2 show the mean values and standard deviation obtained for the sum of monitor units, minimum and mean doses in PTVs, as well as maximum doses in critical organs in the laryngeal (Tab. 1) and gynecological (Tab. 2) groups, respectively.

The average volume of the small PTV was 30.1 cm^3 (SD — 12.4 cm^3) and the large PTV, 173.1 cm^3 (SD — 17.6 cm^3).

The influence of energy used (and type of beam) on the sum of monitor units, average and minimum doses in PTV, as well as maximum and average doses for critical organs was taken into account. In the case of laryngeal irradiation (S-PTV), there are no statistically significant differences between the energy used and the assessed parameters of the plan. But in the case of

Table 1. The mean values and standard deviation of the sum of the monitor units, minimum doses in planning target volume (PTV), maximum doses in organ at risk (OAR) (spinal canal) and mean doses in PTV and OAR for small PTV (s-PTV)

	Larynx, S-PTV			
	FFF-X10MV		FF-X15MV	
	Mean	SD	Mean	SD
Dmin_PTV [Gy]	42.8	3.0	42.8	3.0
Davg_PTV [Gy]	52.2	0.4	52.0	0.4
Dmax_SpinalCanal [Gy]	17.2	3.3	18.1	3.1
Davg_SpinalCanal [Gy]	3.4	1.4	3.6	1.3
Sum MU	665.0	192.8	573.2	111.2

FF — flattening filter beams; FFF — flattening filter-free beams; SD — standard deviation; MU — monitor units

Table 2. The mean values and standard deviation of the sum of the monitor units (MU), minimum doses in planning target volume (PTV), maximum doses in organs at risk (OAR): OAR1 (bladder) and OAR2 (rectum), mean doses in PTV, OAR1 and OAR2 for large PTV (L-PTV)

	Gynecology, L-PTV			
	FFF-X10MV		FF-X15MV	
	Mean	SD	Mean	SD
Dmin_PTV [Gy]	46.2	1.6	47.2	1.2
Davg_PTV [Gy]	51.3	0.6	51.8	0.4
Dmax_OaR1 [Gy]	53.0	1.0	53.1	1.0
Davg_OaR1 [Gy]	29.8	3.1	30.0	2.3
Dmax_OaR2 [Gy]	51.9	1.6	52.1	1.6
Davg_OaR2 [Gy]	23.8	3.7	24.0	3.7
Sum MU	807.0	138.9	488.9	66.4

FF — flattening filter beams; FFF — flattening filter-free beams; SD — standard deviation; MU — monitor units

the gynecological area (L-PTV), statistically significant differences were noted for the number of monitor units depending on the type of beam used. The use of FFF beams increases the number of monitor units by 39.4% in relation to the FF beam (Fig. 2). Statistically significant differences were also obtained in the mean and the minimum dose in PTV (p-value < 0.05), but the differences are less than 1%.

The RPI of the completed treatment plans was assessed. There are no statistically significant differences between the calculated coefficient and the energy used. Additionally, for small and large PTV, the values for each energy are very similar. Its value is 0.87 (for FFF) *vs*. 0.86 (for FF) for S-PTV and 0.61 for L-PTV, regardless of the beam. This means that the choice of the FFF or FF beam, regardless of the PTV dimension, does not affect the dose distribution.

Discussion

The aim of the study was to analyze the effect of the application of different kinds of beams: FFF and FF on the dose distribution, depending on the volume of the treated area, which is related to the size of the PTV. For L-PTV, the use of FF-X15MV energy resulted in as much as 39.4% fewer monitor units. In addition, the treatment plans had a higher Minimum and Average Dose in the area of PTV, and these differences were statistically significant. This allows suggesting the use of flattening-filtering beams for large fields.

In the article of "Effects of flattening filter (FF) and flattening filter-free (FFF) beams on small-field and large-field dose distribution using the VMAT treatment plan" [11], the FF-X6MV and FFF-X6MV beams were analyzed. Therefore, the results obtained for the FFF-X10MV and FF-X15MV beams were
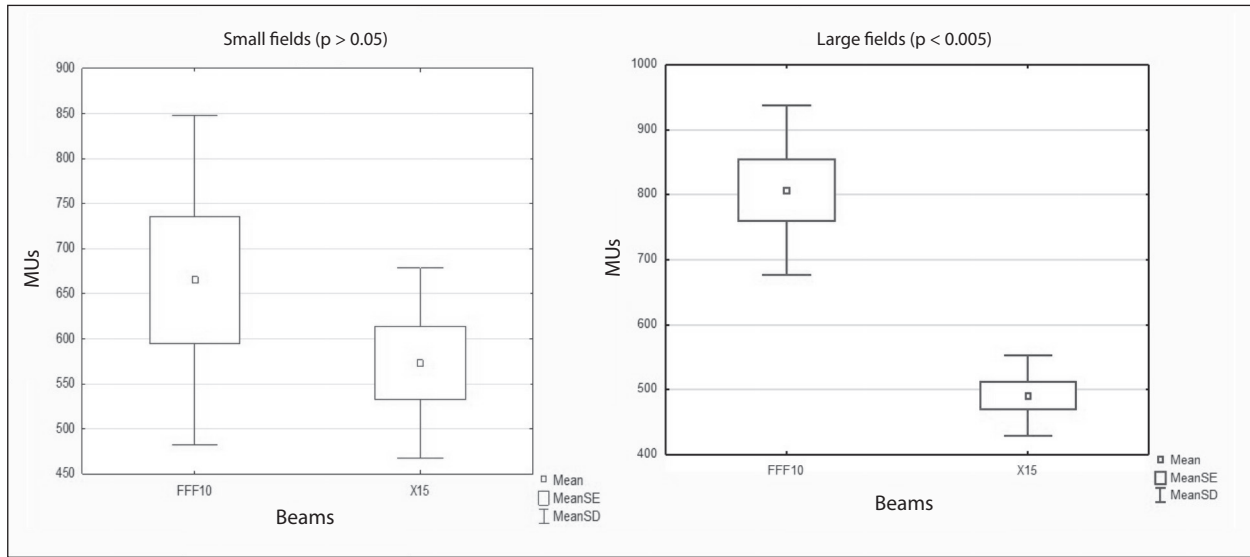
Figure 2. Difference in the number of monitor units for a plan with small planning target volume (S-PTV) and large planning target volume (L-PTV) depending on the type of beams used. FFF — flatenning filter free; SE — standard error; SD — standard deviation

compared with the FFF and FF 6MV beams. A total of four treatment plans were made for each of the two locations and their parameters were then compared. 248 treatment plans were calculated and analyzed.

Statistical analysis was performed for both S-PTV and L-PTV. The bundles used were divided into two groups:

- first group comparing: FFF-X6MV *vs.* FFF-X10MV;
- second group comparing: FF-X6MV *vs.* FF-X15MV.

This division made it possible to compare two bundles for which independent calculations in the treatment planning system were applied to each other. The U-Mann Whitney test was used for statistical analysis [24]. The influence of the energy used (and beam type) on the sum of monitor units, average and minimum doses in PTV, maximum and average doses for the Spinal Canal were taken into account. In the case of S-PTV, there are no statistically significant differences between the energy consumed and the assessed parameters of the plan. That is presented in Table 3.

In the case of L-PTV, only statistically significant differences were noted for the number of monitor units depending on the energy used. This is shown by the results of the statistical tests in Table 4.

Table 3. Results of the U-Mann Whitney test for the small planning target volume (S-PTV) between the assessed parameters of the treatment plans

	FFF-X6MV *vs.* FFF-X10MV	FF-X6MV *vs.* FF-X15MV
SumMU	0.3593	0.7062
PTV_Dmin	0.2458	0.6152
PTV_Davg	0.7845	0.7845
SpinalCanal_Dmax	0.8476	0.9705
SpinalCanal_Davg	0.9411	0.8941

FF — flattening filter beams; FFF — flattening filter-free beams; MU — monitor units

Table 4. U Mann Whitney test results for large planning target volume (L-PTV) between assessed parameters of treatment plans

	FFF-X6MV *vs.* FFF-X10MV	FF-X6MV *vs.* FF-X15MV
Sum MU	**0.0433**	**0.0462**
PTV_Dmin	0.4496	0.5280
PTV_Davg	0.2651	0.4496
OaR1_Dmax	0.5106	0.5063
OaR1_Davg	0.8985	0.5063
OaR2_Dmax	0.4643	0.4809
OaR2_Davg	0.8247	0.8038
RPI	0.9145	0.5774

FF — flattening filter beams; FFF — flattening filter-free beams; MU — monitor units; RPI — radiation planning index

For L-PTV, the use of FFF beams increases the number of monitor units by 39.4% compared to the FF beam. In this case, the type of radiation beam used affects the number of monitor units.

Many dosimetry studies have been conducted to analyze photon beams [25–29]. The use of high-energy (> 10MeV) photon beams for treatment and its legitimacy in the case of modern radiotherapy using the dynamic VMAT technique focuses on an interesting aspect that has not been thoroughly investigated, and it is generally assumed that low energies are sufficient to implement radiotherapy with dynamic VMAT methods. The aim of the study was to analyze the impact of using different types of beams: FFF and FF on the dose distribution depending on the volume of the irradiated area, which is related to the size of the beam field. Due to the large differences in target volumes (173.1 *vs.* 30.1 cm^3), two locations were selected: laryngeal and gynecological.

In standard radiotherapy, the most commonly used energy today is FF-X6MV because dynamic techniques, including VMAT, can accumulate enough doses to target and use lower energies.12 For L-PTV, we recommend using higher energy as it reduces treatment time. Apart from this parameter, regardless of the type of beam used, the dose distributions are comparable for both large and small irradiation fields. This is confirmed by the calculated RPI values of treatment plans (Tab. 4).

It was decided to expand the previously published study and additional energies, which allowed us to compare the validity of using FFF-X6MV *vs.* FFF-X10MV and FF-X6MV *vs.* FF-X15MV, depending on the size of the treated volumes. Expanding on an earlier publication [11] allows for confirmation of previously drawn conclusions: for S-PTV, i.e., laryngeal tumors, no statistically significant differences were found between the kind of beams (FF or FFF) used and the parameters analyzed in the study. In the case of the analysis of L-PTV, i.e., gynecology neoplasms with lymph nodes, during the analysis, statistically significant differences were shown in the number of monitor units and doses in PTV.

Conclusions

The obtained results comparing the dependence of the dose distribution on energy (beams) indicate that: it is recommended to use flattening-filtering beams for large treated volumes due to the smaller number of monitor units at comparable trough doses in PTV and maximal doses in OaRs. In case of a small treated volume, we can use both beams: with a flatness filter or without a flatness filter, doesn't influence dose distribution and monitor units.

Conflict of interest

None declared.

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