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Monte Carlo-based Volumetric Arc Radiation Therapy vs. Helical Tomotherapy in Terms of Tumor Control Probability and Normal Tissue Complication Probability for Endometrial Cancers

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What is known on this subject?

The dose range providing uncomplicated cure for gynecological cancers, especially in the presence of a gross disease, is narrow. Even though the provision of high-quality dose-response analysis for external radiotherapy of gynecologic carcinomas is not possible, analyses of tumor sites present an important correlation between the radiotherapy dose and probability of controlling macroscopic diseases. The treating doses used for lymph node metastases of gynecological cancers come with a limitation to reveal a significant relationship between dose and tumor response. A routine 60 Gy administration of radiotherapy to lymph node metastases with intensity modulated radiation therapy (IMRT) and image-guided radiation therapy leads to a significant decrease in the rate of intra-field paraaortic nodal recurrence to less than 5%. These results offer a very significant relationship between the dose of radiotherapy and the tumor control probability (TCP). At the same time, the possibility of normal tissue complications for critical organs has gained importance in the evaluation of radiotherapy in recent years. For the same reason, the evaluation of normal tissue complication probability (NTCP) based on different methods for endometrial cancers has come to light in recent studies.

What this study adds?

The great importance of Monte Carlo (MC) dose calculation algorithm in protecting critical structures is determined in recent studies. Therefore, in this study, MC-volumetric arc radiation therapy (VMAT) plan was compared with the dose volume-helical tomotherapy (HT) plan to evaluate plan effectiveness in reducing the radiation dose causing toxicity and the quality of the plan was analyzed for both approaches in terms of dosimetric results, TCP and NTCP. For the analysis, two different approaches were considered for plan quality evaluation and the equivalent uniform dose (EUD) based TCP and NTCP model, proposed by Niemierko, was taken advantage of for analysis in this study. In previous studies, dosimetric analysis was done to evaluate critical structures' dose. However in the present study MC based VMAT plan HT plan in terms of EUD based TCP and norma tissue complication probability.

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ABSTRACT

Objective: This study aimed to compare the effectiveness and to plan parameters of the Monte Carlo (MC)-based volumetric arc radiation therapy (VMAT) plan, which was devised using the equivalent uniform dose concept for endometrial cancers, to the dose volume (DV)-based helical tomotherapy (HT) plan. Additionally, both approaches were evaluated in terms of tumor control probability (TCP) and normal tissue complication probability (NTCP).

Material and Methods: The study comprised ten patients diagnosed with endometrial cancer, and treated with radixact tomotherapy unit. The target volumes (PTV) and organs at risks (OARs) were contoured through an accuracy planning system. All plans were devised to receive a total of 50.4 Gy in 28 fractions with the fractional dose to be 1.8 Gy for patient treatment. Monaco 5.51 planning system hosted all planning computed tomography images to devise MC-based VMAT plans. Both plans were analyzed in terms of TCP and NTCP.

Results: DV-HT plans (CI: 1.1) came with the more conformal plan while the difference between both approaches was <1% for HI. Based on the results of the analyses, no statistical difference between DV-HT plan of MC-VMAT for the dose values of 2%, 30%, and 40% of rectal volume ($p>0.05$) was observed. The same results were obtained for the dose values of 2% and 30% of the bladder volume ($p>0.05$). The $D_{5\%}$ of the femoral heads were 7 Gy which is < MC-VMAT plan compared to DV-HT plan. The NTCP values of all OARs were <1% in both approaches.

Conclusion: Statistically, similar results were obtained in MC-VMAT and DV-HT plans for OAR's doses when the treatment dose was given to PTV. Both approaches had no significant difference for NTCP statistically; however, the possibility of bone marrow complications to be investigated as well was concluded, so as to evaluate hematological toxicity.

Keywords: Endometrial cancer, Monte Carlo, NTCP, tomotherapy, TCP, VMAT

Introduction

Endometrial cancers (ECs) are among the most common forms of gynecological cancers worldwide (1). Predicted standard surgical treatment is by total abdominal hysterectomy (TAH) and bilateral salpingo-oopherectomy (2). Identification of lymph node-positive patients is recognized through lymphadenectomy compelling adjuvant therapy. However this therapy is not required in low-risk ECs (i.e., stage-1, grade I-II, ½< myometrial invasion, and no lymph vascular invasion) (3,4,5). Based on the results of the GOG-249 study, pelvic external beam radiation therapy (EBRT) should use as the standard therapy in patients with high-intermediate and high-risk stage I-II EC (grade III, and deep invasion and/or lymph vascular space invasion, unfavorable histology, and unfavorable molecular factors) (6,7). In the long run, EBRT increases the rise of morbidity; however, the pelvic region's acute and late toxicity is reduced by taking advantage of intensity modulated radiation therapy (IMRT) (8,9,10). Additionally, a new dimension for IMRT is defined as the provision of highly conformal dose distribution within the target volume with helical tomotherapy (HT). Dose volume [(DV)-HT] planning is proven to be superior to a traditional linac-based IMRT in providing dose homogeneity and protecting the organs at risks (OARs) (11). One of the main advantages of IMRT compared to conformal radiation therapy (3D-CRT) is its ability to rapidly decrease provision in the dose between target volume (PTV) and OARs (12,13,14). Nonetheless, controlling the low-dose region in the modern IMRT is proven to be difficult. Consequently, the risk of developing secondary malignancies in normal tissues is available. To avoid the problem, volumetric arc radiation therapy (VMAT) was developed; thus, the high dose area around the normal tissues was reduced at the same time by providing a homogeneous dose distribution in PTV. Meanwhile, controlling the low-dose zone with VMAT is easier (15,16,17).

The Monaco treatment planning system (TPS) offers various optimizations for VMAT treatment (18). Unlike the DV-based TPS, Monaco TPS requires using three different biological functions for dose optimization, which are the poisson statistical cell kill model, serial, and parallel complication model (19,20). Although the poisson statistical cell kill model is mandatory for target volumes, biological and physical function may be selected for OARs. In Monaco TPS, dose optimization takes place in two stages with beam segmentation performed in the first stage, as well as dose optimization in the second stage using the Monte Carlo (MC)-based virtual source model (21,22).

Undoubtedly, the foundation of radiotherapy is to provide maximum level of protection for the OARs, while delivering the prescription dose to the PTVs. On the same ground, being aware of the exact amount of absorbed dose plays an important role in escalating the chances of the success of the treatment, while protecting patients against radiation damage. Being aware of the tumor control probability (TCP) and normal tissue complication probability (NTCP), equivalent uniform dose (EUD) is the key to optimal plan design providing information about the treatment outcomes

(23,24,25). In recent years, the concept of EUD has gained importance in biological based treatment planning, since it reveals information about the organ function, whether serial or parallel (26,27).

Considering the abovementioned concept, evaluating the effectiveness and plan parameters of MC-VMAT plan, which was created using the EUD concept, was aimed through comparing with DV-HT plan for ECs. Additionally, analyzing both approaches in terms of TCP and NTCP was aimed.

Material and Methods

Patient Selection

A total of ten patients diagnosed with ECs were selected for this retrospective study. All patients received adjuvant radiotherapy who were treated with Radixact Tomotherapy Unit in Basaksehir Cam, Sakura City Hospital Radiation Oncology Clinic between February 2021 and April 2021. All TAH, bisalpingo oophorectomy, and pelvic lymph node dissection were performed. Detailed information concerning the patients is presented in Table 1.

Simulation and Contouring

The planned computed tomography (CT) images were obtained by scanning the patients in the supine position with a slice of 3-mm thickness using a Philips Big Bore CT (Philips Healthcare, Andover, MA, USA). According to our defined protocol, all patients were asked to drink 1 L of water 45-60 minutes before the CT scan. At the same time, enemas were applied to the patients before the procedure, and the extraction was ensured with an empty rectum. All planned CT images were transferred with the Accuracy Precision of 2.0.0.1 TPS to contour the PTV and OARs. The radiation Oncology Group-0418 (RTOG) study atlas was used to control the nodal target volumes. Provided pelvic radiotherapy or common iliac, external, and internal iliac, obturator lymph nodes, parametrium, upper vaginal/paravaginal tissue, and presacral lymph nodes (in patients with cervical involvement) were observed, and they were included in the residual; in other ways, they were added in an operation lodge. A 1-cm wide vaginal volume was added laterally and caudally to the clinical target volume (CTV). A 7-mm margin was added to the periphery of the pelvic vessels, internal, external, and common iliac nodes. PTV was created by giving a 7-mm margin to the CTV. The bladder was contoured from the base to the dome. The rectum was contoured as the part between the ano-rectal line and the recto-sigmoid component. The peritoneal cavity was contoured up to 5 cm above the PTV. The femoral heads were contoured from the apex of the hip joint to the lower border of the lesser trochanter.

Table 1. Patient characteristics

Patient characteristics	Number of patients
Myometrium invasion <50%	1
Myometrium invasion >50%	9
Grade I	1
Grade II	4
Grade III	5
Endovascular invasion	5
TAH + BSO + PLND	7
TAH + BSO + PLND + PALND	3
Peryton sampling (+)	0
Peryton sampling (-)	5
Peryton sampling (0)	5
Stage IB	6
Stage II	2
Stage IIIA	2
Adenocarcinoma	9
Carcinosarcoma	1

TAH: Total abdominal hysterectomy, BSO: Bisalphingo-oophorectomy, PLND: Pelvic lymph mode dissection, PALND: Paraaortic lymph node dissection

Treatment Planning

Taking advantage of Radixact Tomotherapy TPS, namely Accuracy Precision Version 2.0.0.1, DV-HT plans were devised (Tomotherapy Inc. Madison, WI). A total of 50.4 Gy to PTV in 28

Table 2. Summary of parameters used in all treatment plans

Energy	6 MV
Grid spacing (cm)	0.3
Algorithm	Pencil Beam and Monte Carlo
Statistical uncertainty	1% per calculation
Min. CT number	-600
Auto flash margin (cm)	0.2
Surface margin (cm)	0.6
Beamlet width (cm)	0.3
Target margin	Normal (8 mm)
Avoidance margin	Normal (8 mm)
Maximum number of arcs	2
Maximum control points	720
Minimum segment width (cm)	0.3
Fluence smoothing	Low

fractions with the 1.8 Gy fractional dose was delivered during the treatment plans. The field width was determined as 2.5 cm, pitch factor as 0.250, and the modulation factor was selected as 3-3.5 in all plans. All contoured CT images were transferred to Monaco 5.51 TPs for the purpose of generating VMAT plans. Based on the biological optimization, EUD concept was used in MC-VMAT plans. The couch angle was 0° and two arcs for a single arc with a fixed collimator rotational position at 0° for all plans. The grid spacing, beamlet width, and minimum segment width were 0.3 cm. In the first step, the pencil beam algorithm was used for rapid modeling, and the final dose optimization was done with the MC algorithm. The list of parameters used in all treatment plans is shown in Table 2. EUD-based functions for PTV and OARs were defined, and the list of functions used is presented in Table 3.

Dosimetric Analysis

Indices of conformity (CI) and heterogeneity (HI) were used in this study to evaluate the plan quality. In addition, the $D_{95\%}$, $D_{98\%}$, and $D_{2\%}$ values which are the doses received by 95%, 98%, and 2% of PTV, respectively, and the mean dose (D_{mean}) were analyzed. The volume receiving 107% of the treatment was considered to evaluate the maximum dose (D_{max}). The reference protocol for dose criteria of OARs was defined to be RTOG-0615 protocol. The D_{max} for the femoral heads, and the dose that received 5% of its volume ($V_{5\%}$) were taken into account. The dose received by 2%, 30%, and 40% of the rectum and bladder volumes ($D_{2\%}$, $D_{30\%}$, $D_{40\%}$), as well as the volume receiving 40 Gy (V_{40Gy}) and D_{mean} were evaluated as well. Data from the DV histograms of all plans were used to determine the difference between the two approaches.

Table 3. The cost functions and isoconstraints that define the OARs and target

	MC-VMAT plan	
Structure	Cost function	Isoconstraints
PTV	Target penalty	PD: 5040 cGy
	Quadratic overdose	MD: 5400 cGy RMS: 2 cGy
Bladder	Parallel	RD: 3500 cGy MOD: 40% PLE: 3.5
	Serial	EUD: 3500 cGy PLE: 15
Rectum	Parallel	RD: 2800 cGy MOD: 20% PLE: 3.5
	Serial	EUD: 2800 PLE: 15
Femoral heads	Quadratic overdose	MD: 2000 cGy RMS: 2 cGy
Bowel	Quadratic overdose	MD: 4000 cGy RMS: 50 cGy

MD: Maximum dose, EUD: Equivalent uniform dose, RD: Reference dose, PLE: Power low exponent, MOD: Mean organ damage, RMS: Root mean square, MC: Monte Carlo, OARs: Organs at risks, VMAT: Volumetric arc radiation therapy, PTV: Target volumes

Biological Model

As Niemerko suggests, EUD-based TCP and NTCP were taken advantage of in radiobiological model response evaluation. To evaluate biological effectiveness, target dose distribution was performed based on a generalized EUD. The EUD was calculated according to the equation given below (28):

$$gEUD = (\sum_i v_i D_i^a)^{1/a} \quad \text{.....(1),}$$

where D_i is the dose, v_i, the fractional organ volume that received the dose, and a is the tissue-specific parameter that describes the DV effect (4).

In this study, a = -10 was defined as the target volume. Additionally, biologically equivalent dose (EQD), which is the physical dose of 2 Gy, was considered for the purpose of comparison. EQD was defined as

$$EQD = D \times \frac{\frac{\alpha}{\beta} + \frac{D}{n_f}}{\frac{\alpha}{\beta} + 2} \quad \text{.....(2),}$$

where n_f is the fraction number, and α/β is linear quadratic parameter which is tissue-specific for organs (29). TCP, which is the probability of tumor cells controlling the radiation dose, was considered as well. TCP was calculated based on the equation

$$TCP = \frac{1}{1+(\frac{TCD_{50}}{EUD})^{\gamma_{50}}} \quad \text{.....(3),}$$

where TCD_{50} is the dose to control 50% of the tumor when the radiation is delivered to the tumor homogeneously. Based on the linear quadratic model, NTCP was defined as a function of the delivered dose and normal tissue volume which was irradiated. NTCP was calculated as

$$NTCP = \frac{1}{1+(\frac{TD_{50}}{EUD})^{\gamma_{50}}} \quad \text{.....(4),}$$

where TD_{50} is the tolerance dose for a 50% complication rate at a specific time interval, and γ_{50} is a dimensionless parameter which defines the slope of the dose response curve (30). All coefficient used for EUD, EQD, TCP, and NTCP calculation are listed in Table 4.

Table 4. Parameters used to calculate EQD-based EUD and EUD-TCP and NTCP

Structure	100% Dpf	n_f	A	α/β (Gy)	γ_{50}	TCD_{50} (Gy)	TD_{50} (Gy)	Dpf (Gy)
Tumor	1.8	28	-10	1.2	2.2	28.34	-	2
Rectum	1.8	28	8.33	3.9	3.63	-	80	2
Bladder	1.8	28	2	8	2.66	-	80	2
Femur heads	1.8	28	4	0.85	4	-	65	2

EQD: Biologically equivalent dose, EUD: Equivalent uniform dose, TCP: Tumor control probability, NTCP: Normal tissue complication probability, n_f: Number of fractions, TCD_{50}: The tumor dose to control 50% of the tumor, TD: Tolerance dose, Dpf: Dose per fraction

Statistical Analysis

The dosimetric comparison occurred in two parts: Firstly, the radiation dose for PTV and ORAs were analyzed based on the aforementioned criteria. In the second part, both the approaches were evaluated through EQD, EUD, TCP, and NTCP comparisons. The statistical differences of each parameter obtained through all plans were examined by SPSS statistical software (SPSS, Statistics v22, Chicago, IL, USA). For statistical analysis, the test of the significance between two plan parameters was first applied to check whether the variables assume normality. Provided that the differences were distributed normally, paired-samples t-test were applied, or else, two related-samples test was applied. A p value <0.05 was considered statistically significant for both tests.

Results

Dosimetric Comparison for Target Volume

To evaluate the superiority of each approach in terms of PTV coverage, the MC-VMAT plan and DV-HT plan were compared based on the abovementioned criteria. Based on the results, no statistical difference between DV-HT plan and MC-VMAT plan was observed in terms of $D_{98\%}$, $D_{95\%}$, $V_{107\%}$ ($p>0.05$) along with the percentage difference between both approaches for the parameters was obtained lesser than 1.5%. On the one side, the $D_{2\%}$ value was 1.12% higher in MC-VMAT plan compared to DV-HT plan, which was statistically significant ($p<0.05$). On the other side, both treatment approaches showed similar results in delivering prescription dose to the target as well as providing a target volume coverage based on the statistical analysis. CI and HI values were considered to assess the plan quality. Even though a more conformal dose distribution was achieved by the DV-HT plan than expected (CI: 1.1), the difference between HI values was <1%. The planning data of target volume are listed in Table 5.

Dosimetric Comparison for OARs

The required dose of OARs was gained through a comparison between the MC-VMAT plan and the DV-HT plan. The two approaches revealed no statistical difference in the dose values of $D_{2\%}$, $D_{30\%}$, and $D_{40\%}$ which received 2%, 30%, and 40% of the rectal volume and the V_{40Gy} value, which was the volume receiving 40 Gy ($p>0.05$). In the DV-HT plan, the D_{mean} of the rectum was approximately 4 Gy lower. For the bladder, the difference between both plans was <1% for D_2 and V_{40Gy} values. On the other hand, D_{mean} and $D_{40\%}$ were 3 Gy and 4 Gy higher, respectively, in the MC-VMAT plan compared to DV-HT plan. For the femoral heads, the $D_{5\%}$ value in the MC-VMAT plan was 7 Gy lower than the DV-HT plan, and the MC-VMAT plan was more effective in reducing the femoral heads dose. In addition, D_{max} was approximately 6 Gy and 3 Gy less for the right and left femoral heads, respectively, in the MC-VMAT plan, and the difference between the approaches was statistically significant ($p>0.05$). The critical organ doses obtained from both plans along with their comparisons are presented in Table 5. Additionally, half dose distributions of the MC-VMAT plan and DV-HT plan were shown in Figure 1.

Biologic Model Evaluation

With the aiming gaining an awareness of the response of target volume and normal tissues to radiation, EUD-based TCP and NTCP calculations were performed. The mean EQD and EUD in MC-VMAT plan were 1.73 Gy and 48.6 Gy, respectively, while these values were 1.76 Gy and 49.3 Gy in the DV-HT plan. No statistically significant difference between the EUD values for both approaches ($p>0.05$) was observed. EUD-based TCP was calculated for PTV according to Niemierko model. Although TCP values in the MC-VMAT plan were <1% compared to the DV-HT plan, this result caused a statistically significant difference ($p<0.05$). In addition, NTCP calculation was performed for the rectum, bladder, and femoral heads. NTCP values were <1% in both approaches and no statistical difference was observed between the values ($p>0.05$). EUD, EQD, TCP, and NTCP values calculated for both approaches are shown in Table 6.

Table 5. Summary of evaluated dosimetric values for target and organs at risk

		MC-VMAT plan	DV-HT plan	p (<0.05)
PTV 50.4	$D_{2\%}$ (Gy)	53.19±0.25	52.59±0.37	0.016
	$D_{98\%}$ (Gy)	48.10±0.31	48.77±0.31	0.050
	$D_{95\%}$ (Gy)	49.27±0.15	49.72±0.19	0.050
	D_{mean} (Gy)	51.27±0.16	51.07±0.29	0.022
	$V_{107\%}$ (%)	0.23±0.25	0.10±0.07	0.083
	CI	0.52±0.28	1.11±0.08	0.000
	HI	1.07±0.00	1.09±0.01	0.050
Rectum	D_{mean} (Gy)	28.07±8.346	24.98±6.39	0.037
	$D_{2\%}$ (Gy)	51.46±1.48	51.62±1.65	0.444
	$D_{30\%}$ (Gy)	36.06±12.11	35.09±11.21	0.203
	$D_{40\%}$ (Gy)	31.63±11.52	28.59±10.61	0.114
	$V_{40\ Gy}$ (%)	29.10±17.22	26.68±14.03	0.445
Bladder	D_{mean} (Gy)	34.40±8.76	31.55±8.94	0.022
	$D_{2\%}$ (Gy)	52.23±0.66	51.97±0.77	0.139
	$D_{30\%}$ (Gy)	41.74±9.35	40.47±10.06	0.047
	$D_{40\%}$ (Gy)	38.25±0.11	34.94±12.00	0.017
	$V_{40\ Gy}$ (%)	43.48±27.29	41.55±26.16	0.169
Right femur	$D_{5\%}$ (Gy)	20.54±5.11	27.76±6.53	0.005
	D_{max} (Gy)	30.97±8.74	36.10±8.98	0.799
Left femur	$D_{5\%}$ (Gy)	21.15±4.28	28.02±5.98	0.007
	D_{max} (Gy)	33.94±7.82	36.61±7.29	0.095

MC: Monte Carlo, VMAT: Volumetric arc radiation therapy, DV: Dose volume, HT: Helical tomotherapy, CI: Indices of conformity, CI: Heterogeneity

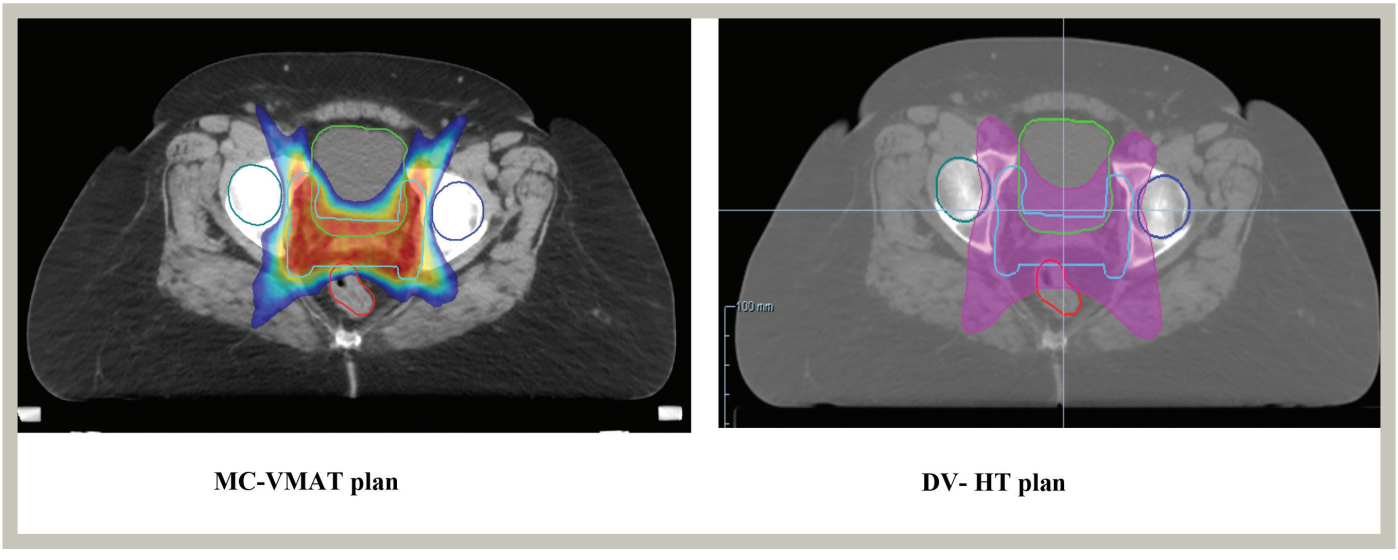

Figure 1. The half dose distribution in both approaches for the selected case

MC: Monte Carlo, VMAT: Volumetric arc radiation therapy, DV: Dose volume, HT: Helical tomotherapy

Table 6. Calculated EQD, EUD, TCP, and NTCP for both treatment planning

	MC-VMAT plan	DV-HT plan	p (<0.05)
$EQD_{(PTV)}$ (Gy)	1.735	1.760	0.008
$EUD_{(PTV)}$ (Gy)	48.60	49.30	0.277
TCP (%)	76.62	77.19	0.008
$NTCP_{(Rectum)}$ (%)	0.065	0.047	0.107
$NTCP_{(Bladder)}$ (%)	0.073	0.053	0.070
$NTCP_{(Right\ Femur\ Head)}$ (%)	0.003	0.014	0.646

EQD: Biologically equivalent dose, EUD: Equivalent uniform dose, TCP: Tumor control probability, NTCP: Normal tissue complication probability, TCD: The tumor dose to control, DV: Dose volume, HT: Helical tomotherapy

Discussion

The dose range providing an uncomplicated cure for gynecological cancers, especially in the presence of a gross disease, is narrow. Even though the provision of high-quality dose response analysis for external radiotherapy of gynecologic carcinomas is not possible, analyses of tumor sites present an important correlation between the radiotherapy dose and probability of controlling macroscopic diseases. The treating doses used for lymph node metastases of gynecological cancers come with a limitation to reveal a significant relationship between dose and tumor response. A routine 60 Gy administration of radiotherapy to lymph node metastases with IMRT and image-guided radiation therapy leads to a significant decrease in the rate of intra-field paraaortic nodal recurrence <5%. These results offer a very significant relationship between the dose of radiotherapy and the TCP. At the same time, the possibility of normal tissue complications for critical organs has gained importance in the evaluation of radiotherapy in recent years. For the same reason, the evaluation of NTCP based on different methods for ECs has come to light in recent studies.

Jodda et al. (31) compared NTCP values of bone marrow in ECs for different radiotherapy techniques and planning strategies. Data from 50 patients over three different treatment plans were analyzed. While evaluating the dose criteria for PTV, the rectum, bladder, bone marrow, bowel, and femoral heads, NTCP was compared for bone marrow only using the Lyman-Kuther-Burman-NTCP (LKB-TCP) model with the Bazan method (31).

Brent S. Rose et al. (25) tested whether the pelvic bone marrow radiation dose causes hematological toxicity in cervical patients, and the NTCP model was tried to be developed. In this study, the relationship between hematological subsets and V_{10Gy} and V_{20Gy} along with the volume of a bone marrow receiving 10 Gy and 20 Gy, respectively, during chemoradiotherapy were analyzed. Based on the obtained results, hematological toxicity increased depending on the radiation dose received by the pelvic bone marrow volume (25).

Duman et al. (32) evaluated different treatment modalities, including 3D-CRT, field in field, and seven-field IMRT for patients with endometrial and cervical cancer. In their study, dosimetric comparisons were made for critical organs, and NTCP values were calculated for OARs. Additionally, they used LKB-NTCP models for the small intestine, rectum, and bladder; NTCP was <1% for the rectum and bladder (32).

On the other hand, two different approaches were considered for plan quality evaluation and the EUD-based TCP and NTCP model proposed by Niemierko was taken advantage of for analysis in this study. The great importance of MC dose calculation algorithm in protecting critical structures is determined in recent studies. Therefore, in this study, MC-VMAT plan was compared to the DV-HT plan to evaluate plan effectiveness in reducing the radiation dose causing toxicity, and the quality of the plan was analyzed for both approaches in terms of dosimetric results for TCP and NTCP. NTCP values of OARs were <1% in both approaches, and there was no statistically significant difference between MC-VMAT and the DV-HT plan. However, this study does not consider bone marrow volume in the optimization process while hematological toxicity values were not included in the plan comparison.

Conclusion

This study compared the MC-VMAT plan to the DV-HT plan for EC. The plan parameters were analyzed in terms of TCP and NTCP. In the Monaco 5.51 TPS, VMAT plans were made using the MC algorithm and biologically based EUD concept. Similar TCP and NTCP values were obtained with MC-VMAT plan as well as DV-HT plan. As a result of the analysis, both approaches achieved success in protecting OARs while

delivering the prescription dose to PTV. On the other hand, the DV-HT plan was superior to the MC-VMAT plan in obtaining a more conformal dose distribution, and the MC-VMAT plan was superior to the DV-HT plan in reducing the D_{max} and $D_{5\%}$ doses for the femoral heads. However, for a more detailed analysis, both approaches should be evaluated in terms of hematological toxicity.

Ethics

Ethics Committee Approval: Ethics Committee Approval is not required for dosimetric studies.

Informed Consent: Informed Consent form is not needed for dosimetric studies.

Peer-review: Internally peer-reviewed.

Authorship Contributions

Concept: S.C., Design: İ.H., A.Y.B., D.K., Data Collection or Processing: S.C., Ö.A., Analysis or Interpretation: S.C., İ.H., D.K., Literature Search: S.C., Ö.A., İ.H., Writing: S.C.

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