DOSIMETRIC EVALUATION OF THE BENEFITS OF INTENSITY MODULATED TECHNIQUES IN CERVICAL CANCER RADIOTHERAPY

IOZSEF GAZSI[1,2], LOREDANA G. MARCU[1,3,4,*]

[1] Faculty of Physics, West University of Timisoara, Romania
[2] County Emergency Clinical Hospital, Oradea, Romania
E-mail: jozsi_2007@yahoo.com
[3] Faculty of Informatics and Science, University of Oradea, Romania
[4] UniSA Allied Health & Human Performance, University of South Australia, Adelaide, Australia
[*] *Corresponding author, E-mail*: loredana@marcunet.com

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Abstract. External beam radiotherapy for cervical cancer using 3D conformal radiotherapy (3D-CRT) is a standard procedure in Romania. A dosimetric planning comparison between 3D-CRT and intensity modulated techniques evaluating both target parameters and organs at risk could justify the implementation of the latter techniques in clinical settings. 50 cervical cancer patients were treated with 3D-CRT, and equivalent plans simulated with IMRT and VMAT for a comparative dosimetric assessment. In addition to providing better compliance and homogeneity, intensity modulated techniques provide superior protection for organs at risk, especially for bowel bag, influencing patients' quality of life.

Key words: conventional radiotherapy, intensity modulated radiotherapy, organs at risk, quality of life, dosimetry.

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1. INTRODUCTION

Globally, cervical cancer is the 3rd most common type of cancer [1]. According to the World Health Organization, in Romania, cervical cancer is the second cause of death. Annually 3380 new cases are detected and 1805 deaths of this type of cancer are reported. With these statistics, Romania is well below the European Union average in terms of survival rate at five years after the treatment. Of the total number of cervical cancers diagnosed in Europe, 7.5% come from Romania [1]. These poor outcomes are due to late diagnosis and ineffective treatments. Another important aspect leading to the high incidence of cervical cancer is the lack of systematic screening for early detection. A survey conducted in 2014 among women aged 20, showed that only a quarter underwent routine screening for cervical cancer, compared to the EU average of 66% [1]. The HPV (Human Papilloma Virus) is known to be the main cause of cervical cancer. While most infections with this virus are neutralized by the immune system, there are also resistant types that over time can lead to cancer development [1].

The most effective treatment for cervical cancer in its early stages is total hysterectomy along with pelvic lymphadenectomy. In patients at higher risk of disease relapse, postoperative pelvic radiotherapy combined with chemotherapy is advised. Postoperative radiation lowers the probability for local recurrence to 47% compared to those who receive only surgical treatment [2]. The most common radiotherapeutic approaches for cervical cancer are intracavitary brachytherapy and external beam radiation. In Romania, according to WHO statistics only 6.4 treatment devices were available per 10,000 patients in 2019 [3].

External radiotherapy can be administered *via* different techniques, such as 3D conformal radiotherapy (3D-CRT), intensity modulated radiotherapy (IMRT) or volumetric arc-modulated therapy (VMAT). Nevertheless, most radiotherapy centres in Romania still employ 3D-CRT for the management of cervical cancer.

The aim of this study was to compare the abovementioned three radiotherapy techniques and to assess the potential dosimetric advantage of one technique over the other for the same patient cohort. The cohort consisted of 50 patients diagnosed with cervical cancer and treated at our clinic with 3D-CRT radiotherapy between 2020 and 2022. Treatment plans were performed for all three techniques and dosimetric outcome compared for both tumour coverage and organs at risk.

The results of the study pinpoint towards the advantages and disadvantages of various external radiotherapy techniques for cervical cancer regarding the differential protection of organs at risk. This aspect is critical for patients who have a medical history, comorbidities or a larger tumour volume that would require larger margins, affecting the functionality of the organs at risk. Furthermore, the results could stimulate the faster implementation and use of modulated techniques in Romanian settings for the group of patients that would benefit most from such techniques.

2. MATERIALS AND METHODS

2.1. PATIENT SELECTION AND PLANNING OBJECTIVES

For this study, 50 patients treated for cervical cancer at the County Emergency Clinical Hospital, Oradea between 2020 and April 2022 were included. All patients had a histologically proven diagnosis of cervical cancer with stages between IB and IVA, as shown in Table 1.

For treatment planning purpose, CT scans were acquired with a thickness of 5 mm between slices starting from lumbar spine 1 to the proximal third of the femoral shaft. The position of the patients was supine with the hands above the head and all patients consumed 500 ml of water half an hour before the scan, to keep the bladder volume and position constant between the CT scan and each treatment fraction.

Table 1

Patients' clinical characteristics

Mean age (range) (years)	59 (26–87)
Stage	
IB	4 (8%)
IIA	5 (10%)
IIB	18 (36%)
IIIA	6 (12%)
IIIB	12 (24%)
IIIC	4 (8%)
IVA	1 (2%)

The contours of the target volumes and structures at risk were performed by the physician, considering the following organs at risk: bladder, rectum, bowel bag and femoral heads, outlined according to reports 62 and 83 of the International Commission on Radiation Units and Measurements (ICRU) [4]. The clinical target volume (CTV) included the cervix, pelvic nodules, and parametrial tissues. The planning target volume (PTV) included the CTV with 5 mm added margins in all directions. Both target volumes and organs at risk were outlined on all CT slices for all patients.

The dosimetric prescription for the PTV was 50 Gy in 25 fractions with 2 Gy per fraction. The minimum requirement for the PTV was for 95% of the volume to be covered by 95% of the prescribed dose. Also, the maximum dose was set not to exceed 110%, being kept preferably around 105%. The dose constraints were the same for all techniques used, bladder $V_{40} < 60\%$, rectum $V_{50} < 50\%$, bowel bag $V_{45} < 10\%$ or $V_{45} < 195$ cm^3 and femoral heads $D_{max} < 42$ Gy. In addition to dose constraints, other indicators were also analyzed for a more accurate comparison among techniques. Dosimetric limitations for organs at risk followed the QUANTEC recommendations [5]. Staging was performed according to the International Federation of Gynecology and Obstetrics classification (FIGO) [6].

2.2. PLANNING TECHNIQUES

To generate all treatment plans, 3D-CRT, IMRT and VMAT, the Monaco 5.51.10 planning system was used of the Elekta Synergy Linac with multileaf collimator (MLC) of 0.5 cm thickness.

The 3D-CRT plans were designed using the four-field "box" technique (anterior, posterior, left and right lateral) with 15 MV photon energy. The MLC leaves were conformed to 5 mm to the PTV and the field in field technique was employed to reduce the hot spots. This was also the technique employed for patient treatment.

IMRT plans were based on 8 fields with 6 MV photon energy with the leaves conformed to 5 mm to the PTV. The dMLC option of the Monaco system

was used to perform the treatment plans, which offers, in addition to step and shoot, a variable dose rate and the possibility to move the leaves dynamically.

For VMAT plans with 6 MV photons, 2 arcs were used starting from the 180° angle, one clockwise and one counterclockwise, with the collimator in 5° to reduce lamellar transmission. These were conformed to 5 mm to the PTV.

The primary planning objective was to achieve at least 95% PTV coverage with 95% of the prescribed dose for all plans, while the secondary objective was to minimize OAR doses (Table 2).

Table 2

Dose-volume constraints

Target / OAR	**Parameter**
PTV	$D_{95} \geq 95$ %
	$D_{max} < 110$ %
Bladder	$V_{40} < 60\%$
Rectum	$V_{50} < 50\%$
Bowel Bag	$V_{45} < 10\%$
	$V_{45} < 195$ cm^3
Femoral Heads	$D_{max} < 42$ Gy

2.3. TREATMENT PLAN EVALUATION TOOLS

Quantitative evaluation of plans was performed by mean and maximum values of standard dose-volume histogram (DVH). The dosimetric parameters for the PTV and OARs were compared between 3D-CRT-IMRT and IMRT-VMAT. Percentage of PTV receiving 95%, 105%, 107% and 110% of the prescribed dose (PTV_{95}, PTV_{105}, PTV_{107} and PTV_{110}) were considered. Dosimetric comparison of OARs between the techniques was presented by the mean doses and by the volume percentage to receive 10 Gy, 20 Gy, 30 Gy, 40 Gy, 45 Gy and 50 Gy (V_{10}, V_{20}, V_{30}, V_{40}, V_{45} and V_{50}).

The conformity index and homogeneity index were calculated according to the following formulas:

$$CI = \frac{V_{RX}^2}{TV * V_{RI}}, \quad HI = \frac{D_{5\%}}{D_{95\%}}$$

where in the calculation of the conformity index the VRX is the volume of the structure covered by the dose of interest, TV is the total volume of the structure and VRI is the total volume of the isodose of interest; for the homogeneity index the $D_{5\%}$ and $D_{95\%}$ are the minimum doses in 5% and 95% of the PTV volume that

received the prescribed dose. CI and HI values closer to 1 indicate better dose conformity and homogeneity of the plan.

2.4. STATISTICAL ANALYSIS

For the evaluation of statistical significance of dosimetric differences among treatment techniques a paired Student *t*-test was employed for *p* value calculations. The threshold for statistical significance was set at $p < 0.05$.

3. RESULTS

3.1. PTV COVERAGE

Dosimetric parameters evaluated for PTV coverage using all three techniques are presented in Table 3. With 48.95 Gy, the PTV coverage for VMAT was superior, however, IMRT and 3D-CRT both fell within the required coverage of over 95% for most plans ($p = 0.02$). For maximum doses above 105%, no statistically significant differences were observed between 3D-CRT and intensity modulated techniques ($p = 0.25$). No technique exceeded the dosimetric limitation of 107% to the PTV. Statistical evaluation of maximum doses showed that IMRT is superior to VMAT ($p < 0.001$) and 3D-CRT is superior to IMRT ($p < 0.001$), with the 3D-CRT technique obtaining the lowest maximum doses (52.5 Gy). From the conformity index analysis, it was found that IMRT is the most conformal technique both compared to 3D-CRT and VMAT ($p < 0.001$). A better dose homogeneity was achieved with IMRT as compared to 3D-CRT ($p < 0.001$). Figure 1 illustrates two examples of the comparative dose distribution for the PTV among the three delivery techniques.

Table 3

Comparative dosimetric data for PTV coverage among the three external beam radiotherapy techniques

Parameter	**3D-CRT**	**IMRT**	**VMAT**	**3D *vs* IMRT**	**IMRT *vs* VMAT**
Volume (cm^3)	830.39 ± 826.73	826.32 ± 830.02	826.31 ± 830.03	–	–
PTV_{95} (Gy)	48.35 ± 1.63	48.59 ± 0.6	48.95 ± 1.32	**0.02**	**< 0.001**
PTV_{105} (%)	0.32 ± 13.12	0.01 ± 0.03	0.06 ± 0.4	0.25	**< 0.001**
PTV_{107} (%)	0	0	0	–	**–**
PTV_{110} (%)	0	0	0	–	**–**
D_{max} (Gy)	52.5 ± 1.09	52.74 ± 1.1	53.2 ± 0.72	**< 0.001**	**< 0.001**
CI	0.53 ± 0.25	0.8 ± 0.26	0.74 ± 0.25	**< 0.001**	**< 0.001**
HI	1.07 ± 0.03	1.05 ± 0.03	1.04 ± 0.03	**< 0.001**	0.63

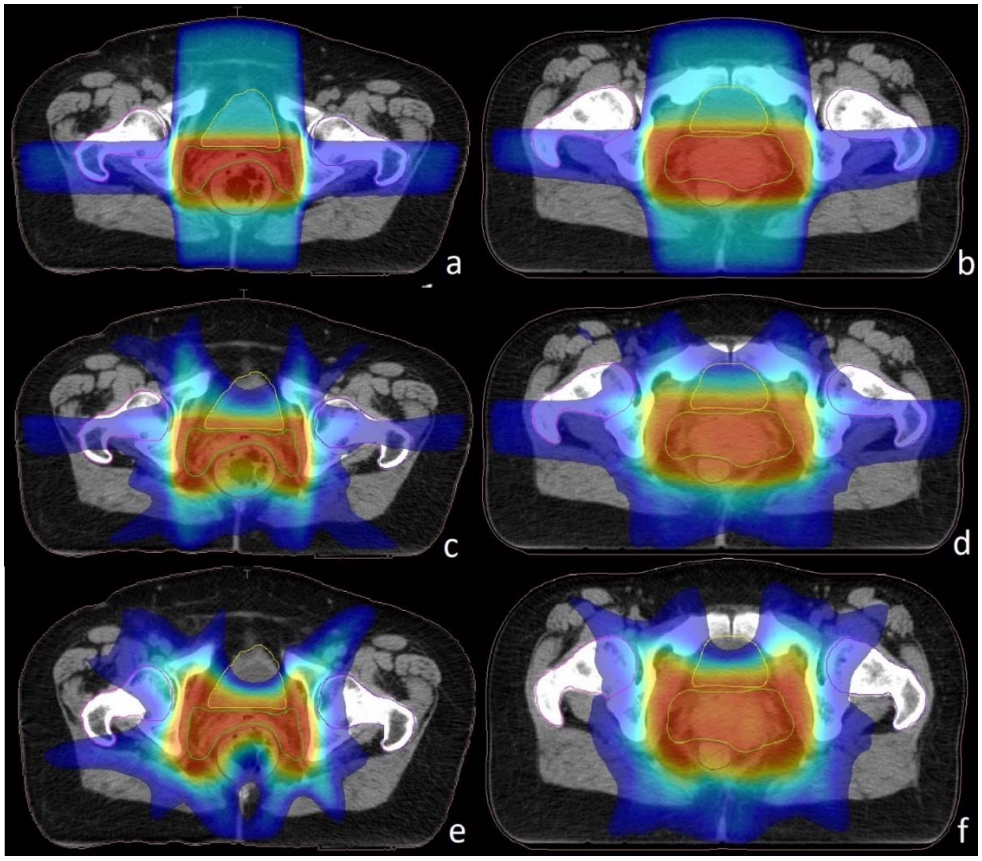

Fig. 1 – Examples of comparative dose distribution with the three treatment delivery techniques for two patients. Patient 1: 3D-CRT (a), IMRT (c) and VMAT (e) and patient 2: 3D-CRT (b), IMRT (d) and VMAT (f). The four-field "box" technique offers dose distribution with limited normal tissue sparing (a,b). Differences in dose distribution are visible between 3D-CRT and intensity modulated techniques especially for the rectum and bladder, organs that receive significantly less dose with the latter methods.

3.2. DOSES TO THE ORGANS AT RISK

Dosimetric parameters corresponding to organs at risk (bladder, rectum, bowel bag and femoral heads) are presented in Table 4. Intensity modulated plans considerably reduced the dose to OARs compared to 3D-CRT, apart from the femoral heads, where 3D-CRT resulted in the lowest values for the maximum dose ($p < 0.001$).

The comparison of 3D-CRT with IMRT for the bladder showed that IMRT is superior to the 3D-CRT technique for the protection of this organ with better dosimetry in terms of average dose and volumetric parameters $V_{20,30,45,50}$ ($p < 0.001$). The differences between IMRT and VMAT are significant for mean dose and $V_{20,30,40}$

where VMAT proved superior, whereas for V_{10} and V_{45} no significant differences were observed. For V_{50} IMRT proved superior to VMAT (0.33% *vs* 3.15%) ($p < 0.001$).

Table 4

Comparative dosimetric data for OARs among the three external beam radiotherapy techniques

OAR	Parameter	3D-CRT	IMRT	VMAT	3D *vs* IMRT	IMRT *vs* VMAT
Bladder	Volume (cm^3)	149.96 ± 310.8	149.98 ± 311.28	149.98 ± 311.28	–	–
	D_{Mean} (Gy)	40.66 ± 5.93	37.66 ± 5.62	35.31 ± 5.54	**< 0.001**	**< 0.001**
	V_{10} (%)	100 ± 0.04	100 ± 0	100 ± 0.12	0.32	0.14
	V_{20} (%)	99.95 ± 1.62	97.94 ± 7.06	91.39 ± 16.49	**< 0.001**	**< 0.001**
	V_{30} (%)	99.24 ± 13	78.89 ± 21.36	64.57 ± 23.25	**< 0.001**	**< 0.001**
	V_{40} (%)	46.1 ± 30.72	44.28 ± 27.94	40.48 ± 19.32	0.41	**0.03**
	V_{45} (%)	33.69 ± 26.17	26.7 ± 22.19	26.56 ± 18.06	**< 0.001**	0.93
	V_{50} (%)	16.81 ± 25.73	0.33 ± 1.29	3.15 ± 11.3	**< 0.001**	**< 0.001**
Rectum	Volume (cm^3)	72.68 ± 176.49	72.7 ± 176.47	72.68 ± 176.74	–	–
	D_{Mean} (Gy)	39.42 ± 15.76	37.86 ± 14.45	34.68 ± 11.45	0.08	**< 0.001**
	V_{10} (%)	95.87 ± 32.45	94.59 ± 33.65	93.97 ± 36.71	0.42	0.71
	V_{20} (%)	93.23 ± 38.46	92.27 ± 40.9	88.09 ± 38.51	0.63	**0.04**
	V_{30} (%)	88.25 ± 43.31	85.36 ± 42.45	69.03 ± 27.53	0.30	**< 0.001**
	V_{40} (%)	52.56 ± 39.61	52.22 ± 33.1	40.87 ± 27.3	0.91	**< 0.001**
	V_{45} (%)	38 ± 38.95	29.38 ± 22.63	23.94 ± 22.51	**0.004**	**0.01**
	V_{50} (%)	17.38 ± 29.51	0.24 ± 1.17	1.74 ± 8.23	**< 0.001**	**< 0.001**
Bowel bag	Volume (cm^3)	1036.52 ± 5171.49	1034.81 ± 5172.57	1025.81 ± 5181.57	–	–
	D_{Mean} (Gy)	23.71 ± 9.91	23.18 ± 6.18	23.81 ± 9.85	0.46	0.37
	V_{10} (%)	77.91 ± 26.01	88.54 ± 20.84	91.69 ± 22.84	**< 0.001**	**0.02**
	V_{20} (%)	63.01 ± 26.32	58.29 ± 26.9	60.66 ± 29.7	0.07	0.43
	V_{30} (%)	40.15 ± 30.66	24.56 ± 31.43	26.94 ± 44.8	**< 0.001**	0.36
	V_{40} (%)	9.48 ± 22.99	7.26 ± 32.82	8.01 ± 19.11	0.09	0.54
	V_{45} (%)	6.07 ± 16.1	2.29 ± 6.6	2.76 ± 6.32	**< 0.001**	0.25
	V_{45} (cm^3)	60.77 ± 288.52	28.7 ± 234.99	27.86 ± 155.78	**0.01**	0.92
	V_{50} (%)	2.92 ± 14.84	0.02 ± 0.28	0.03 ± 0.14	**< 0.001**	0.22
Left femoral head	Volume (cm^3)	121.25 ± 122.04	123.28 ± 120.87	122.68 ± 121.47	–	–
	V_{30} (%)	2.15 ± 27.56	6.38 ± 10.39	8.78 ± 14.6	**< 0.001**	**0.01**
	V_{40} (%)	0.01 ± 0.52	0.01 ± 0.05	0.01 ± 0.07	0.86	0.39
	D_{max} (Gy)	35.37 ± 7.66	39.6 ± 7.98	40.3 ± 8.96	**< 0.001**	0.07
Right femoral head	Volume (cm^3)	122.7 ± 100.25	122.66 ± 100.79	122.66 ± 100.79	–	–
	V_{30} (%)	3.78 ± 75.86	6.64 ± 15.01	9.04 ± 12.95	0.19	**0.02**
	V_{40} (%)	0.01 ± 0.59	0.01 ± 0.05	0.02 ± 0.09	0.98	0.09
	D_{max} (Gy)	34.86 ± 8.82	39.78 ± 11.2	40.29 ± 9.67	**< 0.001**	0.26

For the rectum, comparing the 3D-CRT technique with IMRT, statistically significant differences were observed for V_{45} ($p = 0.004$) and V_{50} ($p < 0.001$) in favor of IMRT. Comparing the IMRT technique with VMAT almost all values are significantly in favor of VMAT ($p < 0.04$), excepting for V_{50} where IMRT achieved better dosimetric sparing (0.24% *vs* 1.74%).

The bowel bag, following the dosimetric evaluation of the 3D-CRT and IMRT techniques, proved more protected with IMRT as shown by $V_{30,45,50}$ ($p < 0.01$), excepting for V_{10} (3D-CRT = 77.91% *vs* IMRT = 88.54%, $p < 0.001$). Comparing IMRT with VMAT, the only parameter presenting statistically significant difference ($p = 0.02$) in favor of IMRT was V_{10} (88.54% *vs* 91.69%). No other dosimetric parameters presented statistically significant differences for the bowel bag.

Following the evaluation of 3D-CRT *vs.* IMRT for the femoral heads, significant differences were shown for the left femoral head at V_{30} and at the maximum dose (35.37 Gy *vs* 39.6 Gy, $p < 0.001$), and for the right femoral head for the maximum dose (34.86 Gy *vs* 39.78 Gy, $p < 0.001$), both in favor of 3D-CRT. Comparing IMRT techniques with VMAT significant differences were revealed for the left femoral head ($p = 0.01$) and for the right femoral head ($p = 0.02$) only for V_{30}, both in favor of IMRT.

3.3. ACUTE TOXICITIES

Acute toxicities were reported for the 50 studied cases, all being treated with the 3D-CRT technique. The most commonly reported post irradiation toxicities were gastrointestinal and genitourinary, in correlation with other reports [7, 8]. Acute toxicities occurring during treatment or three months post-therapy were reported by each patient and they are summarized in Table 5. No grade 3 or higher toxicity was observed. The CTCAE (Common Terminology Criteria for Adverse Events) definitions were used to grade toxicities [9].

Table 5

Acute toxicities

Acute toxicities	Number of patients	% patients
Grade 1		
Diarrhea	14	28
Cystitis	9	18
Grade 2		
Diarrhea	13	26
Cystitis	10	20
Patients with no acute toxicities	13	26

4. DISCUSSION

The aim of this study was to dosimetrically compare the parameters of the target volume and the doses received by the organs at risk for the three most common external irradiation techniques using the information obtained from 50 cervical cancer patients. Dosimetric limitations for organs at risk followed the QUANTEC recommendations [5]. Patients in the early stages of the disease have a

much better prognosis than those in more advanced stages and their quality of life can be preserved even after treatment. The incidence of cervical cancer in Romania is very high compared to the rest of Europe or globally, where HPV vaccination is more commonly adopted. Thus, of the diagnosed cases, almost 54% result in death.

According to literature reports coupled with the results of our study, IMRT was shown to be a better treatment approach when compared to 3D-CRT owing to superior normal tissue protection, high dosimetric uniformity, and higher treatment conformity [10–16]. Although a number of studies reported that the VMAT technique is superior to IMRT for target volume coverage, in our study IMRT was observed to provide a lower maximum dose and higher conformity (D_{max} = 53.2 Gy *vs* 52.74 Gy, CI = 0.74 *vs* 0.8).

Compared to the current study, all the analyzed reports obtained similar coverage for the three techniques; however, only Marjanovic *et al.* [10] reported a nearly 100% coverage as shown in Table 6. Similar values were obtained for the conformity index and the homogeneity index for the simulated intensity modulated plans [12].

Although the 3D-CRT technique offers an adequate dosimetry to the tumor volume, it proved inferior to the intensity modulated techniques regarding the protection of organs at risk. This fact is also due to the smaller number of fields used (4 field for 3D-CRT *vs* 8 for IMRT) that influences the dose distribution both in the target volume and in the neighboring organs. Regarding the dosimetric efficiency of a large number of fields Yang *et al.* [15] reported that the most common number of fields used for IMRT was 9, and that adding more fields did not significantly improve the dosimetry of the treatment plan. Guy *et al.* [12] demonstrated the advantages of VMAT over IMRT by using a single arc and much fewer delivered monitor units throughout treatment. This observation was also supported by Cozzi *et al.* [11].

Regarding normal tissue toxicity, in our study VMAT demonstrated better organ protection for the bladder, rectum and bowel bag, whereas IMRT performed better on the femoral heads. Marjanovic *et al.* [10] obtained higher values for V_{40} for the bladder for all three techniques, whereas Cozzi *et al.* [11] and Lv *et al.* [13] achieved similar values for IMRT and 3D-CRT for this OAR. The average dose obtained in our study for the rectum was comparable to that reported by Guy *et al.* [12] and Guo *et al.* [14] for the three techniques, while 3D-CRT and IMRT provided higher values in the reports by Marjanovic *et al.* [10] and Cozzi *et al.* [11].

Many clinical reports have shown significant differences between 3D-CRT and IMRT regarding bowel bag toxicity. Isohashi *et al.* [16] concluded that patients with grade II gastrointestinal toxicity received higher doses at V_{15}–V_{45} gut level than those with grade I or no toxicity. This conclusion can also be deduced from our study, as for the 13 patients who had grade II gastrointestinal toxicity, we found higher dose values delivered to the bowel bag in terms of V_{20}–V_{50} for most parameters, as compared to the corresponding mean values for the rest of the cohort. Our study reported lower mean values for V_{40} and V_{45} compared to the literature [10–16], excepting Guo *et al.* [14] who obtained similar data for V_{40} when employing VMAT planning.

Table 6

Comparative dosimetric values reported in the literature among the three external beam radiotherapy techniques

Study	Target / OAR	Parameter	3D-CRT	IMRT	VMAT
Marjanovic *et al.* [10] 95 patients (of which 50 patients with 3D-CRT and the rest with IMRT)	PTV	PTV_{95} (%)	99.9	99.27	N/A
		PTV_{105} (%)	0.04	2.63	
		CI	0.58	0.64	
		HI	1.04	1.06	
	Bladder	D_{Mean} (Gy)	50.73	41.18	
		V_{10} (%)	100	100	
		V_{20} (%)	100	99.96	
		V_{30} (%)	99.3	98.76	
		V_{40} (%)	78.23	68.56	
		V_{45} (%)	40.53	14.06	
	Rectum	D_{Mean} (Gy)	43.22	41.97	
		V_{10} (%)	99.81	99.55	
		V_{20} (%)	99.43	99.13	
		V_{30} (%)	98.51	98.62	
		V_{40} (%)	87.39	76.78	
		V_{45} (%)	51.14	20.3	
	Bowel bag	D_{Mean} (Gy)	28.43	30.58	
		V_{10} (%)	85.21	91.25	
		V_{20} (%)	64.62	76.71	
		V_{30} (%)	53.06	59.57	
		V_{40} (%)	32.51	31.04	
		V_{45} (%)	14.66	4.41	
Cozzi *et al.* [11] 8 patients	PTV	PTV_{95} (%)	N/A	97.3 ± 1.5	97.2 ± 1.8
		PTV_{105} (%)		2.9 ± 3.2	0.3 ± 0.4
		CI		1.41 ± 0.15	1.3 ± 0.06
	Bladder	D_{Mean} (Gy)		41.2 ± 2.2	36.8 ± 3.7
		V_{40} (%)		62.2 ± 11.1	47.6 ± 12.0
	Rectum	D_{Mean} (Gy)		42.5 ± 6.2	36.3 ± 5.6
		V_{40} (%)		78.7 ± 25.3	51.5 ± 20.7
	Bowel bag	D_{Mean} (Gy)		20.8 ± 5.9	18.0 ± 5.3
		V_{40} (%)		18.7 ± 8.6	12.3 ± 8.2
	Left femoral head	V_{40} (%)		13.7 ± 15.6	6.0 ± 5.0
	Right femoral head	V_{40} (%)		11.0 ± 10.2	3.5 ± 3.1
Guy *et al.* [12] 10 patients	PTV	D_{Max} (Gy)	47.56 ± 0.33	48.23 ± 0.56	48.44 ± 0.59
		CI	1.79 ± 0.24	1.07 ± 0.039	1.03 ± 0.050
	Bladder	D_{Mean} (Gy)	41.82 ± 5.43	37.74 ± 5.16	35.68 ± 3.52
		V_{40} (%)	39.78 ± 5.84	26.23 ± 10.1	26.39 ± 10.8
	Rectum	D_{Mean} (Gy)	39.39 ± 3.36	36.96 ± 4.42	36.31 ± 4.6
		V_{40} (%)	38.25 ± 9.13	33.75 ± 13.05	32.4 ± 14.16
	Bowel bag	D_{Mean} (Gy)	26.23 ± 9.54	20.79 ± 5.04	19.73 ± 5.47

Lv *et al.* [13] 16 patients	PTV	D_{Max} (Gy)	52.86 ± 12.27	57.4 ± 7.39	N/A
		CI	0.54 ± 0.05	0.89 ± 0.03	
		HI	1.14 ± 0.05	1.02 ± 0.02	
	Bladder	D_{Mean} (Gy)	44.61 ± 29.47	38.63 ± 4.81	
		V_{10} (%)	100	100	
		V_{20} (%)	100	99.08 ± 0.43	
		V_{30} (%)	91.91 ± 6.34	79.43 ± 3.11	
		V_{40} (%)	73.53 ± 13.68	44.94 ± 1.94	
		V_{45} (%)	65.48 ± 15.82	30.78 ± 3.87	
	Rectum	D_{Mean} (Gy)	43.07 ± 8.90	38.79 ± 14.01	
		V_{10} (%)	100	99.9 ± 0.2	
		V_{20} (%)	100	99.65 ± 0.79	
		V_{30} (%)	97.48 ± 3.29	86.64 ± 10.02	
		V_{40} (%)	66.42 ± 3.55	41.6 ± 8.98	
		V_{45} (%)	55.81 ± 6.02	29.89 ± 6.77	
	Bowel bag	D_{Mean} (Gy)	30.44 ± 31.91	25.14 ± 16.06	
		V_{10} (%)	89.99 ± 6.04	91.24 ± 5.04	
		V_{20} (%)	80.53 ± 6.14	64.69 ± 9.32	
		V_{30} (%)	50.22 ± 13.91	32.40 ± 4.01	
		V_{40} (%)	21.48 ± 7.21	10.87 ± 1.84	
		V_{45} (%)	17.72 ± 6.03	5.80 ± 1.56	
	Left bone marrow	D_{mean} (Gy)	31.17 ± 18.62	23.08 ± 7.72	
		V_{30} (%)	62.5 ± 6.62	26.75 ± 3.83	
		V_{40} (%)	23.88 ± 4.89	4.60 ± 2.63	
	Right bone marrow	D_{mean} (Gy)	32.19 ± 15.6	23.47 ± 8.83	
		V_{30} (%)	62.76 ± 3.89	26.76 ± 5.10	
		V_{40} (%)	26.96 ± 6.07	6.38 ± 2.02	
Guo *et al.* [14] 84 patients (of which 42 with IMRT)	PTV	D_{Max} (Gy)	N/A	47.96 ± 0.93	47.6 ± 0.44
		CI		0.84 ± 0.03	0.88 ± 0.04
		HI		1.103 ± 0.03	1.084 ± 0.01
	Bladder	V_{10} (%)		99.57 ± 1.35	100
		V_{20} (%)		98.64 ± 4.06	99.01 ± 1.61
		V_{30} (%)		75.17 ± 6.92	71.62 ± 13.64
		V_{40} (%)		49.41 ± 7.13	37.62 ± 7.24
	Rectum	V_{10} (%)		98.49 ± 1.98	98.23 ± 2.6
		V_{20} (%)		96.25 ± 4.63	95.52 ± 5.36
		V_{30} (%)		91.33 ± 4.63	82.12 ± 6.38
		V_{40} (%)		49.97 ± 7.09	47.39 ± 5.77
	Bowel bag	V_{10} (%)		89.05 ± 6.89	86.52 ± 4.66
		V_{20} (%)		66.55 ± 10.7	58.08 ± 11.74
		V_{30} (%)		22.6 ± 8.97	20.64 ± 8.26
		V_{40} (%)		7.96 ± 6.1	7.32 ± 4.6

A limitation of our study is the lack of late toxicity reporting and correlation with dosimetric parameters, as patients were treated with 3D-CRT, and the

intensity modulated treatment plans were simulated for comparative purpose only. The group of patients included in our study is composed of a small, yet larger number of cases than in most literature reports mentioned above and can be considered a representative cohort. Hence, the conclusions obtained through the dosimetric comparison of the three techniques has statistical power and the results are in line with those obtained by other international studies.

Therefore, while treatment outcome evaluation cannot be determined in a comparative manner from our data, based on the results of randomized clinical trials, we can expect better treatment tolerance and reduced toxicities with IMRT than with conformal 3D techniques. We can anticipate decreased toxicities with IMRT, particularly for gastrointestinal toxicities, as demonstrated by Gandhi *et al.* [17] and Yu *et al.* [18] with no impact on overall survival including advanced staged malignancies.

5. CONCLUSIONS

Special techniques with intensity modulation have a great advantage over the traditional 3D-CRT technique in cervical cancer. In addition to providing better compliance and homogeneity, they offer much superior protection for organs at risk and beyond.

In Romania, the 3D-CRT technique is still the dominant radiotherapy approach for cervical cancer, particularly in public hospitals. While offering adequate tumor control, overall treatment outcome could be optimized with the employment of intensity modulation. These aspects are very important for patients who for various reasons cannot be treated with internal radiotherapy, therefore special techniques with better protection of the organs at risk offer clinicians the opportunity to prescribe an elevated dose to increase the probability of tumor control.

The present study can serve as a justification for the implementation in the country's clinics of intensity modulated radiotherapy techniques for cervical cancer patients.

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