Dosimetric Study Comparing 3D Conformal Radiotherapy (3D-RCT) and Volumetric Modulated Arc Therapy (Rapidarc®) in Prostate Cancer

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Abstract

RapidArc is an "IMRT Arc therapy" using a single rotation of the linac gantry to deliver a precise IMRT plan following IGRT and OBI targeting. This "volumetric arc," often labeled VMAT, for Volumetric Arc Therapy, enhances both the delivery and the targeting of prostate cancer radiation. The object if of this study was to compare VMAT prostate RT plans with three-dimensional conformal RT (3D-CRT) in terms of the clinical target volume PTV and the organs at risk OAR.

Method: In this study, the target population is a series of 8 patients with prostate adenocarcinoma to whom the radiotherapist administered a dose of 78 Gy for external radiotherapy. The specific objective that we have outlined for this study is the dosimetric comparison of two radiotherapy techniques, the RC3D (Conformal Radiotherapy in Three Dimensions) and the VMAT (volumetric modulated arc therapy) technique. Two plans of radiotherapy are defined according to the risk staging of the disease, the first including the prostate, seminal vesicles and lymph node areas, and the second including the prostate and seminal vesicles. For all patients, IR is isodose reference, i.e., 95% of the prescribed dose, VT is the total volume of the target volume which is the clinical target volume (PTV) in our case, D2%, D50% and D98% represent the doses received respectively by at least 2%, 50% and 98% of the PTV, CI is the Conformity Index and HI is the Homogeneity index. However, in order to evaluate absorbed doses to different volumes of the bladder and the rectum D15%, D25%, D35% and D50% were used, for femoral heads D25% and D40% were used and for small bowels dose received by a volume of 65(cc), 100(cc) and 180(cc) was used. Data entry was done by excel and calculated by SPSS version 21.0.

Results: For the eight patients, the calculation of the p-value of Homogeneity index (HI) for the evaluation of the two statistical series gave a p-value= 0.162 (> 0.05), which means according to the Wilcoxon test adopted for this study that the difference between the two series is not significant, however, the conformation index was ranged from 1.901 to 2.416, with a mean of 2.138 and a standard deviation of 0.324 for the RC3D technique and from 1.115 to 1.290 with a mean of 1.176 and a standard deviation of 0.171 for the VMAT technique with p-value= 0.000001 (<<<0.05), which means according to the Wilcoxon test adopted for this study that the difference between the two series is highly significant.

Conclusion: The VMAT technique has justified its superiority in terms of dosimetric conformation of the volume to be treated compared to the RC3D technique. It saves the bladder, rectum, femoral heads, and small intestines from radiation much better than the RC3D technique. Treatment is faster with the VMAT technique than with the RC3D technique.

Key Words: RapidArc, VMAT Technique.

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Introduction

Prostate cancer is considered the most common male cancer and the second leading cause of cancer death worldwide. The therapeutic strategy is well codified, using several techniques, including surgery, radiotherapy, hormone therapy and chemotherapy. In recent years, radiotherapy has become an essential therapeutic weapon, whether at the localized or metastatic stage. The objective of radiotherapy is to deliver a maximum dose to the tumor in order to increase local control and curability, and a minimum dose to the healthy organs in order to limit toxicity.

One of the common techniques for treating prostate cancer is volumetric modulated arc therapy (VMAT). As compared with 3D conformal radiation therapy, VMAT can deliver a highly conformal dose to the target, while minimizing the dose delivered to the organs at risk (OARs) [1]. Furthermore, it can produce equivalent or even better target dose coverage and normal tissue sparing than intensity-modulated radiation therapy (IMRT), while taking advantage of more efficient monitor units (MUs) and reduced treatment time [2].

The specific objective that we have outlined for this study is the dosimetric comparison of two radiotherapy techniques, RC3D (Conventional Radiotherapy in Three Dimensions) and VMAT (Rotational Intensity Modulated Radiotherapy). The present work focuses on: - The comparison of the homogeneity of the dose delivered to the Clinical target volume and organs at risk between the two techniques used.- Comparison of the dose conformation to the clinical target volumes- the sparing rate of organs at risk (bladder, rectum, femoral heads, and small Bowl)[3]. The result of the study shows the superiority of the VMAT technique over the RC3D technique in terms of the conformation of the dose to the target volume and the sparing of organs at risk, without bringing any beneficial contribution on the homogeneity of the dose.

Method

In this study, the target population is a series of 8 patients with intermediate risk prostate adenocarcinoma as criteria of selection to whom the radiotherapist administered a dose of 78 Gy for external radiotherapy. Using VMAT (Volumetric Modulated Arc Therapy) or RC3D (Conformal Radiation Therapy in Three Dimensions), Two plans of radiotherapy for both techniques are defined according to the risk staging of the disease: - A plan including the prostate, seminal vesicles and lymph node areas- A plan including the prostate and seminal vesicles. - We have used Clinac iX accelerator, dosimetric scanner GE with 16rods and Eclipse Treatmenet Planification System (TPS) version 15.5.

Simulation and Dosimetric Scanner

In order to image patients' anatomy and to know the position and the shape of the tumor and the OAR, a three-dimensional imaging was performed with scans separated by 3mm. For keep the bowels away from the treatment area and also to keep the rectal wall as far posterior as possible, patients were instructed to have a full bladder and an empty rectum. A topogram is taken to identify the patient's pelvic limits in the supine position with appropriate restraints (knee brace, foot brace and head brace) to make the patient's position comfortable and reproducible throughout the treatment process.

Volume Definition & Contouring

In the case of prostate cancer, the target organs are prostate and seminal vesicles± pelvic lymph node drainage areas (indication still debated). However, the organs at risk are bladder, rectum, femoral heads and the small Bowll. Different volumes were defined on the dosimetric scanner, the GTV was the volume corresponds to the visible macroscopic tumor, the CTV was the volume corresponds to the tumor and its visible or non-visible microscopic extensions (seminal vesicle; extracapsular extension) and the PTV was the volume corresponds to the CTV to which automatic margins are added for possible patient and/or prostate movements and repositioning errors [4] [5].

For the all-patients treatments, in the first 3D technique we used the classical conformal method for the two dose levels 46Gy, and 78Gy and the plans were treated as follows. In the first plan, dose to PTV1 was 46 Gy and was delivered using Four beams, (one anterior, one posterior, and two lateral), with the following weights 0.67 for the anterior and posterior fields and 0.33 for the lateral fields (Fig-1) [6]. In addition, given the depth of the volume to be treated, high energy X-ray photons are used, i.e., photons with a maximum energy of 16

MV, and also for better conform to the PTV a static MLC was used. In the second plan, dose to PTV2 was 78 Gy, and It was delivered, with six fields (Left lateral (90°), Right lateral (270°)), and four oblique angles of 35°, 255°, 125°, 305° respectively (Fig-2). However, in VMAT technique (Fig-3), the optimization is done according to a reverse planning, with at least 2 constraints. The first imply a minimum dose, i.e., 95% of the PTV must receive at least 95% of the dose, thus 95% of the volume must receive at least 43.7 Gy in the case of PTV 1 (46Gy case), and the second imply a maximum dose, i.e., PTV1 must not receive a dose greater than 107% of the prescribed dose (49.22 Gy).

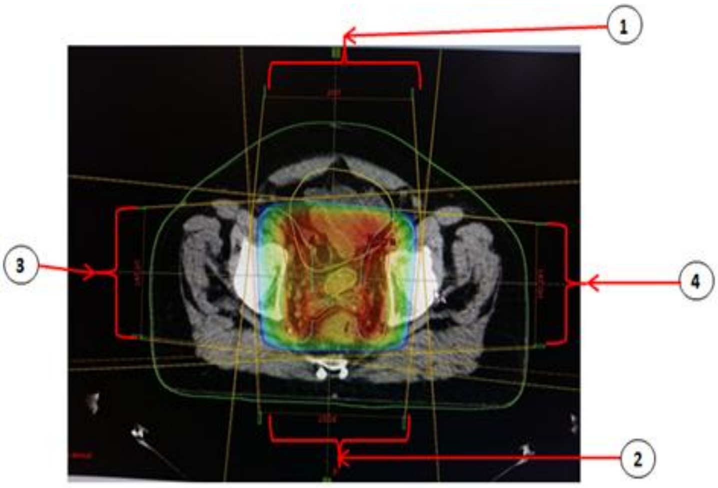

Fig. 1. Scanner section with 4 fields and 95% isodose box

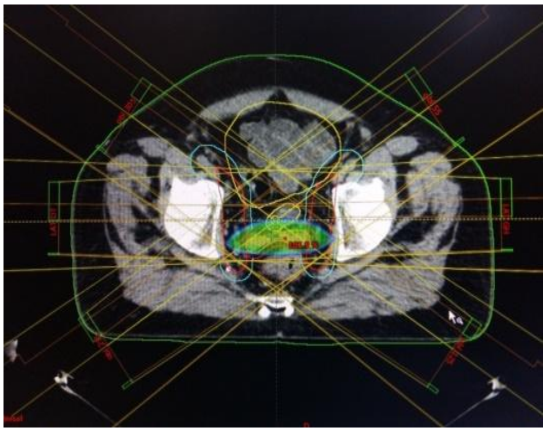

Fig. 2. Scanner section with 6 fields

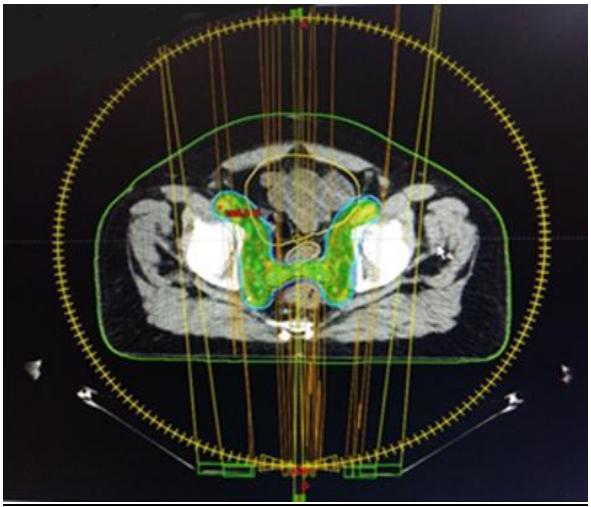

Fig. 3. Scanner section with Arctherapy

Evaluation of the Treatment Plan

Dose-volume histograms (DVH) (Fig-4), for the PTV and organs at risk (rectum, bladder, femoral heads, and intestine) are calculated by Eclipse. The dose constraints to the PTV and organs at risk are as follows. The PTV must receive between 95 and 107% of the prescribed dose [7], and for the OAR, other parameters are chosen to evaluate the protection of organs at risk according to the RTOG trial (see RTOG Appendix). However, in order to evaluate the coverage of the PTV, we use the following parameters imposed by ICRU83 rapport: D2% (%), D5% (%), D95% (%), D98% (%), VIR (volume covered by the reference isodose), VPTV (total volume of the PTV), the compliance index (CI) and the homogeneity index (HI). These two later parameters are expressed by the equations (1) and (2) [8,9].

$$IH = (D_{2\%} - D_{98\%}) / D_{50\%} \quad (1)$$

$$IC = V_{IR}/VT \quad (2)$$

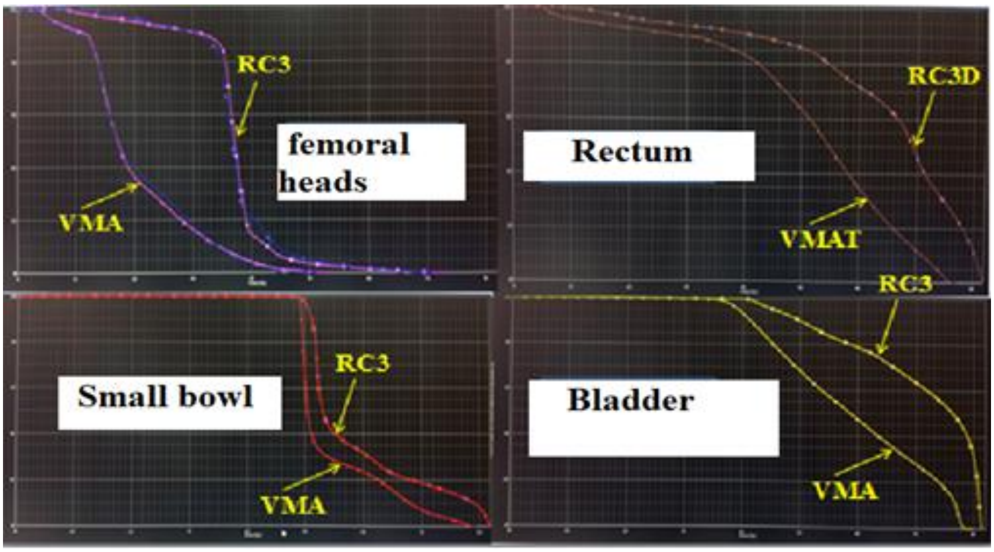

Fig. 4. HDV'S of organs at risk by the two techniques RC3D and VMAT.

Results

Clinical Target Volume (PTV) Coverage

For the eight patients the Table-1 and the Table 2 summarize a dosimetric parameters of PTV for all patients for both techniques RC3D and VMAT, the homogeneity index was between 0.061 and 0.082 with a mean of 0.068 and a standard deviation of 0.007 for the RC3D technique and between 0.065 and 0.088 with a mean of 0.073 and a standard deviation of 0.008 for the VMAT technique. The calculation of the p-value also called p-value for the evaluation of the two statistical series gave a p-value= 0.162 (>0.05) which means according to the Wilcoxon test adopted for this study that the difference between the two series is not significant. However, for the eight patients, the conformation index ranged from 1.901 to 2.416 with a mean of 2.138 and a standard deviation of 0.324 for the RC3D technique and from 1.115 to 1.290 with a mean of 1.176 and a standard deviation of 0.171 for the VMAT technique. The calculation of the p-value also called p-value for the evaluation of the two statistical series gave a p-value= 0.000001 (<<<<<0.05) which means according to the Wilcoxon test adopted for this study that the difference between the two series is highly significant.

Table 1. Dosimetric parameters of PTV for all patients for both techniques RC3D and VMAT

	Patients	P1	P2	P3	P4	P5	P6	P7	P8
	VT (cc)	**187,1**	**125,6**	**148,1**	**166,2**	**145,11**	**172,98**	**138,47**	**153,85**
RC3D	**D2%**	81,98	82,16	77,32	79,52	81,13	78,38	80,83	79,91
	D50%	81,12	79,91	75,78	77,58	80,89	77,38	79,63	78,95
	D98%	76,49	75,61	72,19	74,74	75,33	73,08	75,61	75,12
	V95% (cc)	402,4	344,14	363,58	322,43	320,69	342,50	294,94	290,78
VMAT	**D2%**	78,74	81,78	82,81	78,9	80,19	79,1	80,14	81,25
	D50%	77,42	79,83	79,92	76,63	78,9	77,87	78,87	79,44
	D98%	73,22	76,34	76,75	73,55	74,14	74,03	74,96	74,26
	V95% (cc)	218,91	211,01	231,50	204,43	206,06	226,60	186,93	198,47

Table 2. Index of conformity and homogeneity for all patiens for both techniques RC3D and VMAT

	Patients	P1	P2	P3	P4	P5	P6	P7	P8	P-value
IH	**RC3D**	0,068	0,082	0,068	0,062	0,072	0,068	0,066	0,061	**> 0,05**
	VMAT	0,071	0,068	0,076	0,070	0,077	0,065	0,066	0,088	**(0,162)**
IC	**RC3D**	2,15	2,74	2,45	1,94	2,21	1,98	2,13	1,89	**< 0.05**
	VMAT	1,17	1,68	1,56	1,23	1,42	1,31	1,35	1,29	**0,000001**

Bladder

For the eight patients the Table-3 summarize an absorbed dose data for different volumes of bladder according to the R.T.O.G, the respective volumes of 15%, 25%, 35% and 50% of the bladder must not exceed the values of 80 Gy, 75 Gy, 70 Gy and 65 GY respectively. In fact, the dose received by a 15% volume of the bladder was validated for only one patient among the eight with the RC3D technique, whereas with the VMAT technique, the 15% volume of each patient received a dose within the standard. The tolerable dose for a volume of 25% of the bladder is respected by only one patient with the RC3D technique whereas it is with the VMAT technique. The tolerable dose per 35% bladder volume was met by only two of the eight patients with the RC3D technique, whereas it was met by all patients with the VMAT technique. The tolerable dose per 50% of the bladder volume is not respected in any of the patients with the RC3D technique, whereas it is respected in all patients with the VMAT technique. In addition, the values of the p-value indicators of comparison of the 4 series of measurements are all lower than the threshold of significance (<< 0.05), which means that the measurements made by the RC3D technique are strongly different from those made by the VMAT technique.

Table 3. Absorbed dose data for different volumes of bladder for 8 patients with a prescribed dose of 78 GY

Volume	technique	Patient1	Patient2	Patient3	Patient4	Patient5	Patient6	Patient7	Patient8
$D_{15\%}$	Contrainte	80	80	80	80	80	80	80	80
	RC3D	80,92	79,67	79	77,11	76,32	78,18	79,05	75,91
	VMAT	75,85	76,81	67,16	70,89	72,23	73,94	76,00	72,67
$D_{25\%}$	Contrainte	75,00	75,00	75,00	75,00	75,00	75,00	75,00	75,00
	RC3D	80,45	78,95	74,40	76,9	75,3	77,2	74,87	75,01
	VMAT	71,63	70,17	54,56	69,43	68,15	64,12	69,01	66,39
$D_{35\%}$	Contrainte	70,00	70,00	70,00	70,00	70,00	70,00	70,00	70,00
	RC3D	79,62	77,50	66,70	78,11	76,67	67,92	78,97	74,77
	VMAT	66,06	61,54	49,13	65,22	64,22	62,63	63,22	63,08
$D_{50\%}$	Contrainte	65,00	65,00	65,00	65,00	65,00	65,00	65,00	65,00
	RC3D	76,41	71,68	77,14	77,14	70,33	75,89	74,39	72,22
	VMAT	58,66	55,57	41,61	59,22	56,13	53,12	48,53	49,05

Rectum

For the eight patients the Table-4 summarize an absorbed dose data for different volumes of Rectum according to the R.T.O.G, the respective volumes of 15%, 25%, 35% and 50% of the rectum must not exceed the values of 75 Gy, 70Gy, 65 Gy and 60 GY respectively. The tolerable doses for the 15%, 25%, 35% and 50% volumes of the rectum are not respected in any of the patients with the RC3D technique whereas with the VMAT technique all these constraints are respected. The p-values for these two sets of measurements are well below the significance threshold (p-value < 0.05), so the two techniques RC3D and VMAT provide very different results.

Table 4. Absorbed dose data for different volumes of Rectum for all patients with a prescribed dose of 78 GY

Volume	technique	P1	P2	P3	P4	P5	P6	P7	P8
$D_{15\%}$	Contrainte	75	75	75	75	75	75	75	75
	RC3D	79,36	81,10	79,10	78,33	80,19	79,07	82,98	81,56
	VMAT	68,51	71,46	70,77	68,52	71,43	69,19	67,09	69,27
$D_{25\%}$	Contrainte	70	70	70	70	70	70	70	70
	RC3D	76,62	80,32	76,60	77,11	79,34	78,62	80,56	79,95
	VMAT	63,86	64,62	62,86	63,95	64,11	65,29	62,78	63,16
$D_{35\%}$	Contrainte	65	65	65	65	65	65	65	65
	RC3D	73,00	79,28	72,40	72,55	74,69	73,29	76,19	75,27
	VMAT	60,00	56,36	56,05	58,66	59,14	57,13	60,47	61,22
$D_{50\%}$	Contrainte	60	60	60	60	60	60	60	60
	RC3D	69,27	77,01	64,50	68,77	65,97	64,11	71,09	68,33
	VMAT	54,86	55,20	48,92	53,17	52,13	53,98	56,62	51,76

Femoral Heads

For the eight patients the Table-5 to 10 summarize the percentage of differents dose absorbed for both femoral head according to the R.T.O.G, the volume of 25% of the femoral head (left and right) should not exceed a dose of 45 GY and 40% of the volume should not exceed a dose of 40 GY. The tolerable doses by femoral head volumes are respected by both techniques (VMAT AND RC3D) for all patients. The p-values of the two sets of measurements are below the significance threshold (p-value < 0.05), so the test is significant and therefore the two techniques RC3D AND VMAT provide different results.

Table 5. Right femoral heads data

Volume	Technique	P1	P2	P3	P4	P5	P6	P7	P8
$D_{25\%}$	Contrainte	45	45	45	45	45	45	45	45
	RC3D	38,30	36,08	36,10	37,54	39,09	38,77	36,86	34,11
	VMAT	26,77	21,82	20,83	25,72	27,54	23,97	28,82	24,55
$D_{40\%}$	Contrainte	40	40	40	40	40	40	40	40
	RC3D	37,15	35,20	35,20	36,66	38,98	37,79	36,02	33,62
	VMAT	19,87	18,80	16,99	21,71	24,12	20,59	25,33	22,81

Table 6. D25% of the volume of the right femoral head

Technique	n	Moyenne	Contrainte	Ecart-type	Min	Max	*P*
RC3D	8	**37,11**	**45**	1,67	**34,11**	**39,09**	**< 0.05**
VMAT	8	**25,00**	**45**	2,76	**20,83**	**28,82**	**()**

Table 7. D40% of the volume of the right femoral head

Technique	n	Moyenne	Contrainte	Ecart-type	Min	Max	*P*
RC3D	8	**36,33**	**40**	1,69	**33,62**	**38,98**	**< 0.05**
VMAT	8	**21,28**	**40**	2,78	**2,78**	**25,33**	**()**

Table 8. Left femoral heads data

Volume	Technique	P1	P2	P3	P4	P5	P6	P7	P8
$D_{25\%}$	Contrainte	45	45	45	45	45	45	45	45
	RC3D	38,62	35,72	36,10	39,01	36,96	35,19	34,56	33,79
	VMAT	25,41	26,23	23,33	24,12	25,87	27,01	23,11	22,67
$D_{40\%}$	Contrainte	40	40	40	40	40	40	40	40
	RC3D	37,63	34,76	25,20	37,67	34,45	34,87	33,82	32,34
	VMAT	18,92	19,86	19,81	20,16	19,97	18,57	20,00	19,67

Table 9. D25% of the volume of the Left femoral head

Technique	n	Moyenne	Contrainte	Ecart-type	Min	Max	*P*
RC3D	8	**36,24**	**45**	1,85	**33,79**	**39,01**	**< 0.05**
VMAT	8	**24,72**	**45**	1,62	**22,67**	**27,01**	**()**

Table 10. D40% of the volume of the Left femoral head

Technique	n	Moyenne	Contrainte	Ecart-type	Min	Max	*P*
RC3D	8	**35,09**	**40**	1,81	**32,34**	**37,67**	**< 0.05**
VMAT	8	**19,62**	**40**	0,57	**18,57**	**20,16**	**()**

Small Bowl

For the eight patients the Table11 summarize the percentage of different dose absorbed for Small Bowl according to the R.T.O.G, the doses received by the respective volumes of V65, V100 and V180 of the small intestines must not exceed the dose values of 45 Gy, 40 GY and 35Gy respectively. All the doses received by the 65 (cc), 100 (cc) and 180 (cc) volumes of the small intestines are outside the tolerance values for the eight patients with the RC3D technique whereas with the VMAT technique two values out of eight are tolerable for the 65(cc) series and one value out of eight for each of the other two series are outside the constraints. The mean dose values always exceed the constraints with the RC3D technique, whereas with the VMAT technique they are very close to the tolerance limit.

Table 11. Small bowl data with p-value

Volume	Technique	P1	P2	P3	P4	P5	P6	P7	P8	P Value
V_1 = 65 (cc)	Contrainte	45 Gy	45 Gy	45 Gy	45 Gy	45 Gy	45 Gy	45 Gy	45 Gy	
	RC3D	**55,00**	**48,96**	**52,49**	**54,67**	**48,96**	**52,49**	**50,13**	**52,09**	**0<0.05**
	VMAT	**48,89**	34,14	44,16	**45,06**	39,14	44,94	42,78	44,99	
V_2 = 100 (cc)	Contrainte	40 Gy	40 Gy	40 Gy	40 Gy	40 Gy	40 Gy	40 Gy	40 Gy	
	RC3D	**53,97**	**48,51**	**52,33**	**54,17**	**47,29**	**50,11**	**48,59**	**49,08**	**0<0.05**
	VMAT	**46,82**	32,17	39,35	39,9	37,55	38,89	39,15	39,98	
V_3 = 180 (cc)	Contrainte	35 Gy	35 Gy	35 Gy	35 Gy	35 Gy	35 Gy	35 Gy	35 Gy	
	RC3D	**52,97**	**48,00**	**52,00**	**53,77**	**46,9**	**48,67**	**46,98**	**47,37**	**0<0.05**
	VMAT	**41,74**	29,02	33,68	32,90	33,34	32,97	34,99	34,87	

Discussions

With a prescribed dose of 78 Gy, the bladder volumes receive non-standard doses with the RC3D technique, so it is impossible to validate a curative treatment plan made with this technique, even with ideal patient preparation, whereas this is possible with the VMAT technique. for rectal volumes receiving non-standard doses with the RC3D technique, it is therefore impossible to validate a curative treatment plan made with this technique, even with an ideal preparation of the patient, whereas this is possible with the VMAT technique. We note that a good preparation of the rectum, protects it better to irradiations. Also, the 25% and 40% volumes of the femoral heads receive doses within the norms with the RC3D technique and the VMAT technique, but the VMAT technique spares the femoral tissues better. Finally, it is impossible to validate the 65 (cc), 100 (cc) and 180 (cc) small bowel volumes with the RC3D technique, whereas with the VMAT technique validation is only possible with very good patient preparation, the VMAT technique is the only solution to spare the small bowel of a patient to whom 78 Gy is prescribed.

Conclusion

The VMAT technique has justified its superiority in terms of dosimetric conformation of the volume to be treated compared to the RC3D technique. VMAT and RC3D have the same dose homogeneity within the target volumes. The VMAT technique spares the bladder, rectum, femoral heads and small intestines to a much greater extent than the RC3D technique. In terms of cost, the VMAT technique has the disadvantage of being too expensive compared to the RC3D technique, and is not covered by the organizations providing the care. The VMAT technique is faster than the RC3D technique, but the preparation time of the dosimetry is very long which is an additional burden for the physicist. In summary, the VMAT technique is better than the RC3D technique for the treatment of prostate tumors with a dose of 78 Gy.

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