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Evaluation and comparison of dosimetric parameters in PTV for prostate cancer via step and shoot IMRT and 3DCRT

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ABSTRACT

The aim of radiation therapy treatment planning is to achieve an optimal balance between delivering a high dose to target volume and a low dose to healthy tissues. The integral dose, conformity and homogeneity indexes, hence, are the important guidance for predicting the radiation effects and choosing the optimal treatment plan. The goal of this study is to compare and investigate the aforementioned parameters in 3DCRT vs. IMRT plan. In order to evaluate dosimetric parameters, data from five patients with prostate cancer, planned by IMRT and 3DCRT were obtained. Prescribed doses for IMRT procedure and 3DCRT were 80Gy and 70 Gy, respectively. Also, the target coverage was achieved with 95% of the prescribed dose to 95% of the PTV in 3DCRT and 95% of the prescribed dose to 98% of the PTV in IMRT method. A total of thirty IMRT and 3DCRT plans were performed for evaluation of dosimetric parameters (for each patient both treatment plans, step and shoot IMRT and 3DCRT with 6, 10 and 18MV energies) were done. The integral dose was calculated as the mean- dose times the volume of the structure. The mean integral dose (ID) received by rectum for 3DCRT was almost 1.01% greater than IMRT while in bladder mean value of ID for IMRT was approximately 1.68% higher than 3DCRT. For PTV in IMRT the ID of target volume had the biggest value (1.14%) compared to that of 3DCRT. Dose conformity in PTV volume in S.A.S and 3DCRT was almost equal. The same outcome was achieved in homogeneity index. The results of this study shows that IMRT method leads to adequate target dose coverage while the prescribed dose for this modality is higher than 3DCRT. IMRT has the ability of increasing the maximum dose to tumor region and improves conformity and homogeneity indexes in target volume and also reduces dose to OAR.

Indexing terms/Keywords

Integral Dose; Homogeneity index; Conformity index; IMRT; 3DCRT.

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1. Introduction

Clinicians are still looking for the optimal planning methods of treating prostate cancer with external beam radiation therapy. The role of radical dose in radiation therapy has been established in the management of non-metastatic prostate cancer [1].

Previously, radiation treatment was matched to the height and width of the target volume, meaning that the normal structures were exposed to the beams. Advances in imaging technology have made it feasible to locate and treat the tumor more precisely. In recent years, 3 Dimensional Conformal Radiation Therapy or so called 3DCRT has commonly been used. By using CT or MRI scans tumor can be seen in three dimensions. Therefore, we can design the therapeutic fields that follow the shape of the tumor more closely. Thus, the radiation beam would provide better dose distribution in target volume while spares healthy tissues as far as possible.

The need for Intensity Modulated Radiation Therapy (IMRT) arised from the requirement to sculpt precise dose distributions which conform in three dimensions to the shape of planning target volumes (PTVs) and spares organs at risk (OARs) [2]. Nowadays, IMRT has its own place for treatment of variety of cancers. As like 3DCRT, IMRT models the radiation beams to closely fit the region where the tumor is.

IMRT can also create a concave area within the radiotherapy field to spare normal structures that would be damaged by the radiotherapy. This is very useful in regions such as prostate, for example to bring out the rectum or bladder. Hence, IMRT leads to better conformity of dose distribution to the target volume than 3DCRT. The basic principle of IMRT involves irradiation from a number of different beam directions with nonuniform energy fluences, which have been optimized to deliver a high dose to the target volume and acceptably low dose to the surrounding normal structures [3]. The treatment planning program divides each beam into a large number of beamlets and determines the optimum setting of their energy fluences or beam weights [3]. IMRT increases the volume of normal tissue exposed to some radiation but can reduce the total dose received by critical structures [4]. In addition of mentioned advantages of IMRT over 3DCRT, IMRT can enhance the fluence at margins of the target and compensate the portal boundaries [5]. Another distinct advantage offered by IMRT is that it makes it possible to deliver different doses to different target volumes in a single plan, commonly referred to a Simultaneously Integrated Boos IMRT (SIB IMRT) [5].

Integral Dose (ID) is the volume integral of the dose deposited in a patient and is equal to the mean dose times the volume irradiated to any dose [3]. The ID is also the area under the curve of a differential absolute-volume histogram [**6**]. It is often stated that the large number of beamlets and monitor units used in IMRT leads to an increase in ID [7] and that higher-energy photon beams substantially reduce the normal tissue ID (NTID) [9]. In contrast, an alternative hypothesis suggests that the total energy deposited in a patient during irradiation (ID) is relatively independent of treatment planning parameters [6]. The aim of this study is to compare the integral dose and also the dose distribution for these two techniques based on the dose volume histogram (DVH) analysis of the target and critical organs. This treatment planning study also is designed to address the two following important issues: whether step and shoot IMRT technique increases conformity index compared to 3DCRT, and whether the use of IMRT method reduces homogeneity index or not?

2. Materials and Methods

2.1. Requirements

At the onset of the study five patients with prostate cancer were selected to be planned with external beam radiation therapy for the future analysis. Planning computed tomography (CT) images with slice thickness of 3mm was attained for all patients while they were fixed in supine form. Target volumes and Organs at Risk (OAR) were contoured using M.I.R.S (version 5 Nuclemed, Boins Ayros, Argentina) which utilizes Scatter Integration algorithm to calculate the dose distribution.

The clinical linear accelerators (Elekta, Precise model, United kingdom) which produces three ranges of photon energies 6, 10, and 18MV and integrated with 80 pairs of leaves (MLCs) was utilized for step and shoot IMRT and 3DCRT. The collimator angle was defined zero for all therapeutic fields which were used for IMRT and 3DCRT, and also each of IMRT beams has 11segments.

2.2. Integral dose definition

Integral dose is the total energy absorbed by the body, and is computed based on the average organ density, averaged organ dose, and volume as defined in equation (1):

$$Integral\ Dose = \overline{D}.\overline{\rho}.V \quad (Gy.Kg)\ [11] \quad (Eq.1)$$

Where $\overline{D}$, $\overline{\rho}$ and *V* are averaged organ dose, averaged organ density and volume, respectively [11].In this study the integral dose is calculated by **equation (2)**:

$$Integral\ Dose = Average\ Dose * Volume\ (Gy.Lit)\ (Eq.2)$$

2.3. Homogeneity and conformity indexes

Dose homogeneity and dose conformity are independent specifications for evaluating plan quality. Dose homogeneity characterizes the uniformity of dose distribution within the target volume and dose conformity specifies the degree to

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which the high dose region conforms to the target volume, usually the PTV [12]. In this study, the target dose conformity and uniformity are measured and estimated according to ICRU83 which are shown in equations 1 and 2.

The conformity index (CI) is defined as following:

CI (ref) = Volume of PTV covered by the reference dose/Volume of PTV and CI = 1.0 is the ideal value. ***(Eq.3).***

HI = (D2 % – D98 %) / D50 % (*Eq.4*)

Where, D 2%, D 98% and D 50% are the doses received by 2%, 98%, 50% of the volume and HI = 0 (Zero) is ideal value

2.4. Treatment Planning

All patients were planned with both techniques: IMRT and 3DCRT. For step and shoot technique the PTV was created using 10 mm three dimensional margining around the CTV (CTV is considered as prostate plus seminal vesicles) except towards rectum that was increased 8mm. In 3DCRT the PTV was also created by addition of 10 mm margin around CTV similar to IMRT techniques and 6mm in the direction of rectum.

The prescribed doses for IMRT treatment plans and 3DCRT were considered 80 and70Gy, respectively. Dose per fraction was also considered 2Gy. Dose volume Constraints (DVCs) for IMRT are shown in Table1.

The maximum and minimum doses for PTV were measured by prescribed dose (80Gy) time to 102% and 98%, as upper and lower constraints, respectively. For 3DCRT five fields have the same weight (40cGy for each beam) and dose per fraction was considered 2Gy. Both treatments were normalized to isocenter which was placed in the center of PTV.

For 3DCRT the whole PTV was set to receive at least 95% of the prescribed dose and in IMRT the mentioned conditions were used to achieve the minimum criteria of 98% of the target volume receives 95% of the prescribed dose. Therefore, the average doses, the volume of all regions (in both methods) in three ranges of energies (6, 10 and 18 MV) were achieved to calculate and compare the integral dose in step and shoot IMRT vs. 3DCRT.

Table 1. DVCs for S.A.S IMRT

Structures	**DVC**(Gy)
PTV	Dose max = 8160 Dose min = 7840
Rectum	D60≤4560 D30≤7200 D5≤8000
Bladder	D50≤5680 D20≤6800 D5≤8000
Right Femur Head	D50≤5680
Left Femur Head	D50≤5680

3. Results

3.1. Integral dose

The volume, average dose and IDs of PTV, bladder and rectum are summarized in tables2, 3, and 4.

Table2. The volume of PTVs and OARs

	The Volume of OARs		**3DCRT**	**IMRT**
	Rectum(Lit)	**Bladder(Lit)**	**PTV(Lit)**	**PTV(Lit)**
patient 1	0.089	0.169	0.419	0.429
patient 2	0.074	0.083	0.316	0.327
patient 3	0.188	0.165	0.388	0.395
patient 4	0.128	0.111	0.233	0.247
patient 5	0.172	0.105	0.289	0.31

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Table3. The average and integral dose of PTV for IMRT and 3DCRT

Energy		IMRT		3DCRT	
		PTV		PTV	
		D avrag(Gy)	ID(Lit.Gy)	D avrag(Gy)	ID(Lit.Gy)
6MV	Patient 1	80.13	34.31	70.76	29.65
	Patient 2	78.85	25.78	71.01	22.49
	Patient 3	79.83	31.49	70.57	27.16
	Patient 4	78.24	18.01	71.41	16.83
	Patient 5	79.08	23.53	71.14	20.55
10MV	Patient 1	79.88	34.21	70.93	29.71
	Patient 2	79.98	31.55	71.07	22.51
	Patient 3	79.37	25.95	70.74	27.23
	Patient 4	78.91	18.16	71.33	16.8
	Patient 5	78.79	23.44	71.24	20.37
18MV	Patient 1	79.86	34.2	70.32	29.45
	Patient 2	79.54	26.00	70.58	22.35
	Patient 3	79.90	31.52	70.26	27.04
	Patient 4	79.61	18.23	70.61	16.63
	Patient 5	78.85	23.46	71.10	20.54

Rectum and bladder have the same volume in all patients, while the volume of PTV in 3DCRT is totally different with PTV in IMRT. Because of the identical volume in body for each case (Table2) and also regarding to the integral dose formula, it is obvious that the average dose has the radical role in amount of integral dose. Thus, plainly in the regions with equal volume (rectum and bladder) treated by each methods, the main affecting factor on integral dose is the average dose.

Table3 shows the data used for calculating integral dose of IMRT and 3DCRT.

Because of the greatest average dose and volume for PTV in IMRT the integral dose has increased, noticeably. According to table3 for PTV the integral dose in IMRT is about 1.14% higher than 3DCRT and in both of treatment modalities the integral dose decreases with increasing energies, Figure1.

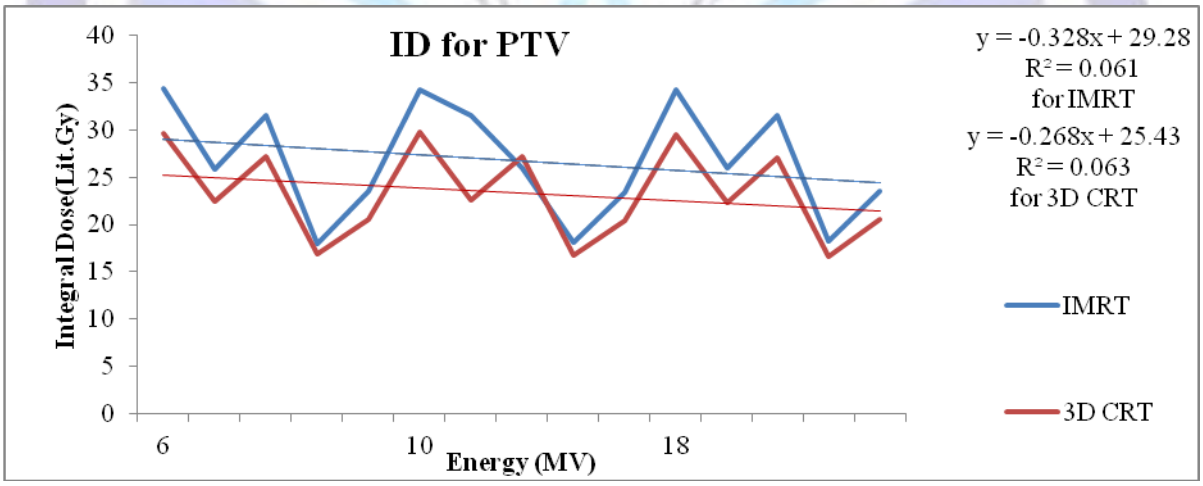

Fig1. Integral dose for PTV in both techniques

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Table 4 shows the data achieved for OARs.

Table4. The average and integral dose in OARs for IMRT and 3DCRT

		IMRT				3 DCRT			
		Bladder		Rectum		Bladder		Rectum	
Energy		D avr (Gy)	ID(Lit.Gy)	D avr (Gy)	ID(Lit.Gy)	D avr (Gy)	ID(Lit.Gy)	D avr (Gy)	ID(Lit.Gy)
6MV	patient 1	45.80	7.73	59.67	5.31	45.54	3.454	64.27	5.72
	patient 2	61.01	5.06	54.01	4.02	61.51	3.639	57.56	4.29
	patient 3	55.66	9.19	46.62	8.79	57.66	3.153	46.46	8.76
	patient 4	56.69	6.29	39.97	5.13	58.31	3.015	44.57	5.72
	patient5	58.70	6.16	49.16	8.47	61.38	6.44	52.48	9.02
10MV	patient 1	44.31	7.48	59.64	5.3	45.83	3.65	63.66	5.66
	patient 2	60.19	4.99	54.37	4.53	61.54	3.786	56.96	4.24
	patient 3	55.87	9.22	46.03	8.68	57.51	3.355	45.85	8.64
	patient 4	57.48	6.38	40.07	5.14	58.40	3.219	43.75	5.61
	patient5	58.54	6.14	49.21	8.48	61.21	6.43	52.41	9.01
18MV	patient 1	43.42	7.33	59.02	5.25	45.64	3.706	62.37	5.52
	patient 2	60.60	5.03	54.47	4.06	61.42	3.877	56.14	4.18
	patient 3	55.08	9.09	44.96	8.47	57.13	3.403	44.80	8.44
	patient 4	56.69	6.29	39.02	5.03	57.67	3.24	42.95	5.51
	patient5	58.61	6.15	48.88	8.42	60.55	6.36	52.29	9.02

In rectum, the mean value of ID for IMRT is about 1.01% lesser than 3DCRT, while in bladder the inverse trend is observed and the mean value of ID for IMRT is about 1.68% greater than 3DCRT. Irrespective to the increasing of integral dose, the average dose in bladder and rectum is reduced by IMRT technique. As the other studies show in IMRT and especially for S.A.S technique, because of increasing in the MU and time of treatment, the integral dose goes up. The data of ID and average dose are summarized in table5.

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Table5. The average data of integral dose and average dose

	Bladder				Rectum			
	IMRT		3DCRT		IMRT		3DCRT	
	D avr(Gy)	ID(LIT.Gy)	D avr(Gy)	ID(LIT.Gy)	D avr(Gy)	ID(LIT.Gy)	D avr(Gy)	ID(LIT.Gy)
The Average of 6 MV data	55.57	6.86	56.58	3.94	49.88	6.34	53.06	6.7
The Average of 10 MV data	55.28	6.82	56.89	4.08	49.86	6.42	52.52	6.63
The Average of 18 MV data	54.88	6.77	56.48	4.11	49.27	6.24	51.71	6.53
The Average of all data	55.24	6.83	56.75	4.05	49.67	6.34	52.43	6.62

The dose distribution in axial sections are shown in Figures 2a, 2b and 2c for 18MV photon beams. These axial sections clearly show the concave PTV coverage and exclusion of rectum and bladder during optimization by step and shoot IMRT.

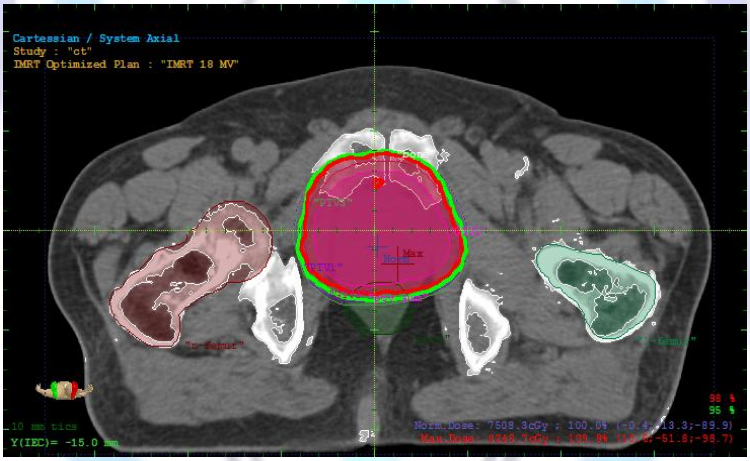

Fig 2a. Axial section dose distribution in IMRT

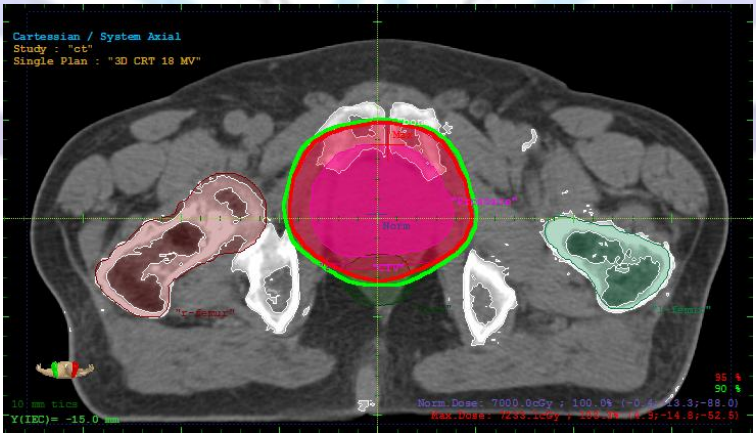

Fig 2b. Axial section dose distribution in 3DCRT

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The Dose Volume Histograms (DVH) achieved for bladder in both techniques are shown in Figures3a and 3b.

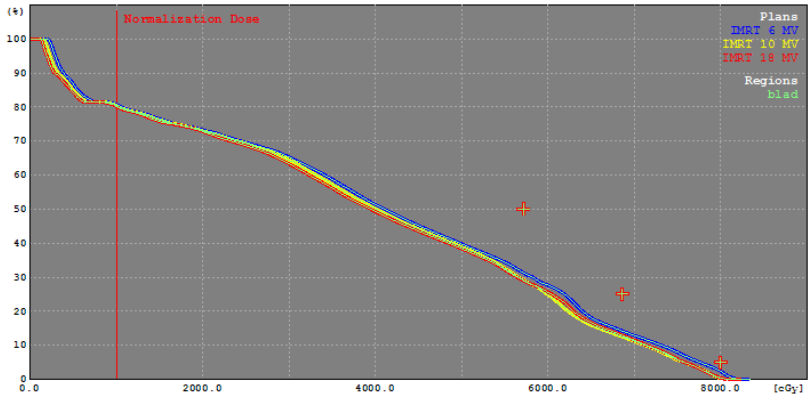

Fig 3a. DVHs of bladder in IMRT

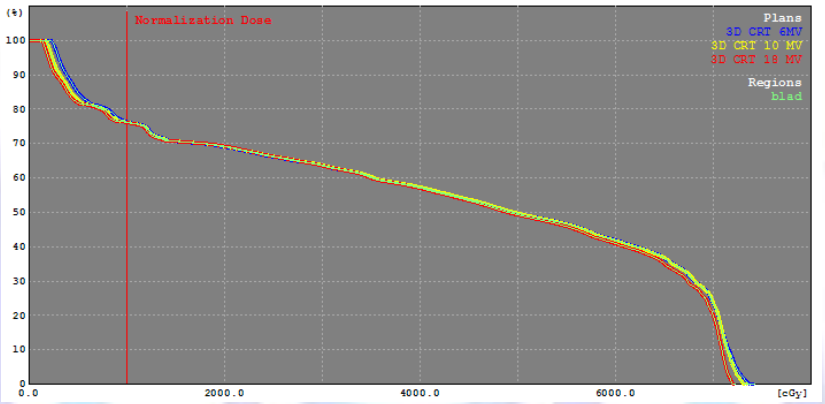

Fig 3b. DVHs of bladder in 3DCRT

3.2. Homogeneity index conformity index(H.I and C.I)

The planning objectives are met in the selected patients with three techniques. 3DCRT plans frequently showed hotspots near the rectum and bladder wall but within the acceptable limit. The normalized target coverage of both IMRT methods and 3DCRT and their PTV are presented in Table 6.

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Table 6. Comparison of data achieved in two methods of treatment

Type of treatment		Energy	D50(cGy)	D98(cGy)	D2(cGy)	H.I	volume of PTV (Lit)	The volume which is received the desired Dose(Lit)	C.I
SAS	Patient1	6MV	8085	7161	8485	0.16376	0.429	39.39078	0.9182
		10MV	8044	7029	8441	0.175535	0.429	38.92317	0.9073
		18MV	8046	7000	8455	0.180835	0.429	38.83308	0.9052
	Patient2	6MV	7970	6661	8367	0.214053	0.327	27.42876	0.8388
		10MV	8014	6735	8382	0.205515	0.327	27.85059	0.8517
		18MV	8044	6750	8411	0.206489	0.327	28.24953	0.8639
	Patient3	6MV	8000	7000	8411	0.176375	0.395	36.1346	0.9148
		10MV	8029	7014	8323	0.163034	0.395	35.69615	0.9037
		18MV	8029	7000	8367	0.170258	0.395	35.708	0.904
	Patient4	6MV	7897	6808	8470	0.21046	0.247	20.25894	0.8202
		10MV	7926	6897	8558	0.209563	0.247	21.25682	0.8606
		18MV	8044	6794	8573	0.221159	0.247	21.6372	0.876
	Patient5	6MV	8029	6632	8500	0.232657	0.31	25.0573	0.8083
		10MV	7985	6633	8470	0.230056	0.31	24.8434	0.8014
		18MV	7985	6558	8485	0.241327	0.31	25.4293	0.8203
3DCRT	Patient1	6MV	7054	6776	7517	0.105047	0.419	41.73659	0.9961
		10MV	7067	6789	7491	0.099335	0.419	41.77011	0.9969
		18MV	7035	6774	7364	0.083866	0.419	41.56061	0.9919
	Patient2	6MV	7082	6682	7388	0.099689	0.317	31.44323	0.9919
		10MV	7094	6787	7364	0.081336	0.317	31.48761	0.9933
		18MV	7035	6670	7282	0.086994	0.317	31.34179	0.9887
	Patient3	6MV	7047	6705	7388	0.096921	0.385	38.1304	0.9904
		10MV	7058	6741	7388	0.091669	0.385	38.1304	0.9904
		18MV	7023	6682	7270	0.083725	0.385	38.1535	0.991
	Patient4	6MV	7133	6591	7615	0.143558	0.236	23.02652	0.9757
		10MV	7133	6604	7544	0.131782	0.236	22.89436	0.9701
		18MV	7058	6582	7441	0.121706	0.236	22.6914	0.9615
	Patient5	6MV	7070	6776	7346	0.080622	0.298	29.6659	0.9955
		10MV	7070	6800	7317	0.073126	0.298	29.76722	0.9989
		18MV	7023	6741	7230	0.069628	0.298	29.63908	0.9946

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There is a steady improvement in C.I for PTV volume from 0.99891 in 3DCRT planned by 10MV photon beams to 0.8014 in S.A.S IMRT planned by 10MV photon beams (patient5). The H.I is improved from 0.241327 in IMRT for 18MV photon beams to the lesser value of 0.069628 in the 3DCRT for 18MV photon beams (patient5).

4. Discussion

Commonly, both IMRT and 3DCRT techniques lead to the same outcomes regarding PTV coverage. Both plans were assessed by using the following criteria:

95% of the prescribed dose should be delivered to 95% of PTV for 3DCRT and also 95% of the prescribed dose should be delivered to 98% of target volume for IMRT Fig2a, 2b. Integral dose or total cumulative dose to normal untreated tissues is higher in IMRT as compared to conventional treatments [13,14]. Compared to conformal prostate radiotherapy IMRT provided better normal tissue sparing and consequently further reduction of rectal toxicity and late effects. The inverse-planned IMRT further reduce hotspots, because of beam modulation during optimization compared to 3DCRT [15].

The monitor unit for IMRT was 6-8 times more than 3DCRT [5]. This shows that the integral dose would also be higher. This result is consistent with Pirzkall et al who concluded that the integral dose for IMRT is higher than conventional treatment [14]. According to the achieved data, integral dose in rectum for IMRT is almost equal to 3DCRT (table 4 and 5). In PTV and bladder the integral dose increased for IMRT in comparison to 3DCRT. The increasing of ID in PTV due to greater volume and average dose is absolutely logical, but in bladder while the average dose in IMRT method had the lesser value (table5) in comparison to 3DCRT, the integral dose has jumped up because of the increasing of monitor unit and irradiation time.

In general, high integral dose can be attributed to secondary malignancies for patients with a low risk for systemic relapse after treatment.

In addition, S.A.S IMRT and 3DCRT provided similar results regarding to the percentage of PTV volume which received the definitive isodose (95% of the prescribed dose), as identified in table 7.

Table7. The percentage of PTV volume that covered by certain isodose

	Step and shoot IMRT			3DCRT		
Energy	**6MV**	**10MV**	**18MV**	**6MV**	**10MV**	**18MV**
The percentage of PTV volume which received the desired dose	**94.25**	**94.32**	**94.69**	**94.73**	**94.6**	**93.14**

Depth analysis of dosimteric data revealed significant differences in amount of target coverage (Table 6). By use of the same therapeutic fields for each technique and according to the ICRU 83 guideline about the accredit amount of C.I and H.I, the obtained values are acceptable. Thus, this arrangement of beams improved homogeneity and conformity indexes, also reduced the volume of OARs such as the rectum and bladder receiving a high dose.

IMRT for prostate cancer is explored for its ability to conform the dose distribution to the concavity of target volume. With increasing sophistication in radiation treatment plans, homogeneity indexes showed improvement with inverse-planned IMRT as reported by Fisher [16]. Compared to 3DCRT, IMRT proved better normal tissue sparing. The potential advantages of IMRT technique over conventional 3D and non-3D techniques are (1) the ability to achieve dose uniformity throughout the PTV (2) the potential to reduce the dose to OARs. These abilities are expected to translate into improved cosmetic results and reduced toxicity.

Despite 3DCRT, S.A.S radiotherapy provides better target coverage (Table 8), but 3DCRT has averagely acceptable mean value in H.I (0.1884) vs. step and shoot technique (0.1515), in three ranges of energies. For the C.I by regarding the goal of ICRU 83(C.I= 1 is ideal) the 3DCRT shows better results over S.A.S IMRT except in 18MV (Table 7) but irrespective to the discrepancy in prescribed dose (10Gy) IMRT has shown better results, averagely. The IMRT plans contributed a higher dose to adjacent normal tissues and causes to increase the prescribed dose to target volume.

Table 8. The average of H.I and C.I in three methods and energies

	Step and shoot IMRT	3DCRT
The average of H.I in 3 range of energies	**0.1515**	**0.1884**
The average of C.I in three ranges of energies	**0.944**	**0.941**

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5. Conclusion

In general, multiple-field radiation leads to decrease the volume of healthy tissues that received high dose of radiation and increase the volume receiving low-dose radiation. Therefore, theoretically, there may be an increased risk of second malignancies. However, this can be rather difficult to interpret when we apply it to modern radiation techniques in which multiple radiation fields are used [3]. There is little difference between 3DCRT and IMRT, for three ranges of energies 6, 10 and 18MV, in the ID to the rectum while for bladder the cumulative dose has been higher in IMRT Vs. 3DCRT. The little difference in ID in rectum originated from the greater average dose in 3DCRT treatment planning in comparison of step and shoot procedure (table4, 5) and in bladder, the reduction of average dose in IMRT compared to that of 3DCRT is not noticeable, thus the excess number of monitor units and treatment time lead to the increasing in integral dose. In other hand, in both techniques the intersecting area between the bladder and PTV is the same. Therefore, the little differences in average dose of bladder in both techniques has not the radical role on increasing of integral dose in IMRT. Contrary to bladder in rectum beside of the bigger intersecting volume between PTV and rectum for IMRT plans (10mm increasing of CTV towards rectum in IMRT against 8mm in 3DCRT), the reduction of average dose is noticeable in IMRT vs. 3DCRT. In rectum the discrepancy of average dose has bigger weight to increasing of integral dose in 3DCRT while the monitor unit and treatment time have been increasing in IMRT. This means that in IMRT regarding to the dose of target volume and increased amount of prescribed dose (80Gy) vs. 3DCRT (70Gy), the healthy tissues received the same dose similar to 3DCRT and it is the worthy benefit, while the target volumes in this method attained highest dose and the results of treatment became better, obviously.

In addition, we infer from this study that IMRT proved better and precise conformation of dose distribution and concavity according to the target volume vs. 3DCRT (Figures 2a, 2b and 2c). 3DCRT also has the acceptable results according to H.I and C.I. Both treatments have good results in prostate cancer treatment but according to the results, the ability of escalation prescribed dose to PTV, IMRT has the better condition from the clinical view while preserved organs at risk in the better condition.

The data provided evidence that it is necessary to consider the integral dose, conformity and homogeneity indexes as the important factors for choosing the optimal treatment plan, especially for the prostate cancer treatment.

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