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Investigation of the Dosimetric Aspects for Intensity Modulated Radiotherapy versus Three-Dimensional Conformal Radiotherapy in the Low Risk Prostate Cancer

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Abstract: *This study was carried out to evaluate dosimetric differences between Intensity Modulated Radiotherapy (IMRT) delivery techniques (which can be divided into two deliverymodes: Step-and-Shoot (SS)&Sliding Window (SW)) and Three-dimensional Conformal Radiotherapy (3D-CRT).Twenty prostate cancer patients on Eclipse treatment planning system for delivery on a Varian DMX linear accelerator with Multileaf Collimator MLC (Millennium 80-leaf MLC) with 6 MV photon beams were generated using both IMRT & 3D-CRT techniques. Patients had two planning target volumes (PTVs) which were prostate plus seminal vesicles (PTV1) for the primary planand prostate only (PTV2) for the secondary (boost) plan. Dose Volume Histograms (DVHs) of PTVs, Organs atRisk (OARs), conformity index (CI), Homogeneity Index (HI), Paddick index, Gradient Measure (GM), and Health Tissue IntegratedDose (HTID) were recorded. Statistical analysis, the two-tailed paired t-tests, were performed to compare the results between IMRTs and 3D-CRT plans. The data was tested by the Statistical Package of Social Sciences (SPSS v25.0) with statisticalsignificance level set at $p < 0.05$. In conclusion, the IMRT technique was clearly able to increase the dose delivery to the target volume, improve conformity and homogeneity indices,andspare OARbetter in comparison to the 3D-CRT technique.*

Keywords: *Intensity modulated radiotherapy, prostate cancer, sliding window, step-and-shoot, three-dimensional conformal radiotherapy.*

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I. Introduction

The main purpose of radiotherapy treatment planning is to restrict the radiation dose coverage of the PTV with sparing of the OAR and minimize the dose to the Health Tissue (HT)which is the non-target. 3D-CRT and IMRT techniques were used to confine the radiation dose to PTV wherethe latterproved to have an advantage of sparing the OAR.In other words, it is difficult for3D-CRT to spare the OAR withoutcompromising the PTV coverage.[1],[2],[3],[4]

There were several studies on the selection of beam energy and other IMRT parameters, such as the number of fields and beam orientations for treatment of prostate cancer patient in radiotherapy.[5],[6],[7],[8],[9],[10],[11],[12],[13],[14],[15]

Because of the prostate cancer's deep-seated targets, high-energy photon beams are commonly used for 3D-CRT due to its high penetration power. Nevertheless, low-energy photon beams in IMRTs is the preference today due to its benefits such as minimizing the head leakage, internal scatter, and eliminating any concern of secondary neutrons dosage [5],[6],[7],[8],[9],[11],[16]. The low energy plans of IMRTs are clinically equivalent with those of high energy in terms of target coverage, conformity, homogeneity, and OAR savings when a sufficient large number of radiation fields are used.[10],[12]

Since IMRT is becoming popular for treatment of prostate cancer patients, it is important to investigate its potential benefits over 3D-CRT. In our study, we have compared the different dosimetric parameters between 3D-CRT and IMRT treatment plans with low energy photon beams.

II. Materials and Methods

Twenty patients with localized carcinoma of prostate were treated with 3D-CRT and/or IMRTfor this study.The patient's age spanned between 53 to 71 years with a mean age of 62. All the patients were low risk (based on Tumor stage, Gleason score and Prostate-Specific Antigen (PSA)). All patients were set in the supine

position and CT scans were acquired on a flat table top with a multi slice diagnostic CT scan Toshiba Scanner Alexion (Model TSX-034A, Toshiba medical systems, Japan) advanced edition 16 slices. The slice spacing was 5 mm over the entire treatment area for all patients. Finally, the CT data was imported as a Digital Imaging and Communications in Medicine (DICOM) format to contouringworkstation via local area network system.

2.1 Target and critical volumes delineation

The planning target volumes and OARswere delineated by radiation oncologist onthe CT slices using contouring workstationSoma Vision® (version 11, Varianmedical systems, Palo Alto, CA). For eachpatient, two different treatment volumes weredefined;PTV1 (Clinical TargetVolume (CTV1)+margin) and PTV2 (CTV2 + margin). Themargins were expanded based on theinstitutional protocol for 3D-CRT.I.e. 0.8 cmalong the transverse direction, 0.8 cm along thecranial caudal direction, 0.8 cm anteriorly and0.5 cm posteriorly.

2.2 Dose prescription, planning and treatmentdelivery machine

The treatment was done withEclipse® (version 11, Varian medicalsystems,Palo Alto, CA) planningsystem by using a 6 MV photonbeam. VarianMillennium 80 MLC fitted in high energy linearaccelerator Clinac DMX® with OBI option used for3D-CRT and IMRT treatment delivery. Thedose prescriptionfor the first phasewas 50.4 Gy/27 fractions (i.e. 1.8Gy/fraction), while that for the second phase(boost) was24Gy/12 fractions (i.e.2Gy/fraction)and 30.6Gy/17 fractions (i.e. 1.8 Gy/fraction) for both techniques 3D-CRT and IMRT respectively. The dose homogeneity of -5% and+7% was set as the initial plan acceptancecriterion as recommended by the ICRU.[17],[18]

2.3 Treatment planning techniques

In the 3D-CRT technique, the radiation dose was delivered for PTV1 and PTV2 with fivecoplanar split fieldsof gantry angles 0°, 45°, 90°, 270°, and 315° also known as ‘sunrise’[19]. A 5 mm margin was given to MLC field apertures from PTV1 and PTV2 using beams eye view for penumbra regions of photon fields. All plans were created using the Source to Axis Distance (SAD) isocentric technique.Calculationsweretakenusingthe Analytic Anisotropic Algorithm (AAA) with acomputation grid size of 2.5 mm.

Radiation dose deliverieswere planned in two phasesusingthe IMRT technique. IMRT plans were generated for both 6 MV photon beam using two delivery modes (SS) and (SW) with seven coplanar non-opposed beam arrangementsof 0°, 51°, 103°, 154°, 206°, 257°, and 308° gantry angles for the PTV1and PTV2 for all patients to ensure identical beam angle arrangements.

Radiation dose of 50.4Gy and 30.6Gy with 1.8Gy/fraction were planned for PTV1 and PTV2 respectively. The inverse plan Dose Volume Optimizer (DVO version 11.0.31) ofEclipse planning system was used for IMRT planning. Appropriate dose-volume constraints for IMRT plan optimization for PTV and critical organs (rectum,bladder,femoral heads and Penile bulb) were used. For PTV1 and PTV2, optimization constraints were such that 100% PTV volume should get 99.2% and 98% dose minima, while dose maxima should be less than 102.2% and 103% for zero % volume respectively. The upper and lower priorities were 190. The doses to the OARs were restricted by the RTOG guidelines for critical structure dose. Depending on the PTV doses (PTV1: 50.4 Gy; PTV2: 30.6 Gy), the dose to critical organs was scaled for two IMRT phases. A full list of PTV1, PTV2 and OAR plan constraints are shown in Tables 1 and 2. Normal tissue doses, in general, were limited using the Varian Eclipse Normal Tissue Objective option during optimizationwhich attempts to achieve a certain dose falloff around the PTV based on user-set parameters. Normal tissue doses for all cases were set to fall from 105% to 60% of the prescription dose starting 3 mm from the PTV, with a fall-off rate of 1. This fall-off parameter is a unit less value that affects the character of an inverse exponential dose fall-off.

Table 1. The initial dose-volume constraints for primary plan

Structure	The initial dose-volume constraints	Relative priority
PTV1	$D_{100\%} \geq 99.2\%$ of the prescription dose	190
	$D_{max} \leq 102.2\%$ of the prescription dose	190
CTV1	$D_{100\%} \geq 99\%$ of the prescription dose	100
	$D_{max} \leq 103\%$ of the prescription dose	100
Rectum	$V_{50\ Gy} \leq 0\%$	100
	$V_{35\ Gy} \leq 10\%$	100
	$V_{27.5\ Gy} \leq 25.3\%$	100
	$V_{15\ Gy} \leq 55.5\%$	120
Bladder	$V_{50\ Gy} \leq 0\%$	75
	$V_{24.9\ Gy} \leq 30.3\%$	75
	$V_{14.1\ Gy} \leq 50.3\%$	75
Femoral heads	$V_{20\ Gy} \leq 25\%$	50
	$V_{7\ Gy} \leq 100\%$	50
Penile bulb	$V_{41.5\ Gy} \leq 35\%$	100

	$V_{25\ Gy} \leq 70\%$	70
	$V_{15\ Gy} \leq 90\%$	70

PTV1, primary planning target volume; $Dn_{\%}$, dose coveringn$_{\%}$ of the target volume; Dmax,maximum dose received;CTV1, primary clinical target volume; Vn_{Gy}, the percentage volume of organ receiving ≥nGy.

Table 2. The initial dose-volume constraints for boost plan

Structure	The initial dose-volume constraints	Relative priority
PTV2	$D_{100\%} \geq 98\%$ of the prescription dose	190
	$D_{max} \leq 103\%$ of the prescription dose	190
CTV2	$D_{100\%} \geq 98\%$ of the prescription dose	100
	$D_{max} \leq 103\%$ of the prescription dose	100
Rectum	$V_{20\ Gy} \leq 0\%$	100
	$V_{12\ Gy} \leq 15\%$	100
	$V_{10\ Gy} \leq 25.6\%$	100
	$V_{6\ Gy} \leq 45\%$	100
Bladder	$V_{22.5\ Gy} \leq 0\%$	75
	$V_{14\ Gy} \leq 17\%$	75
	$V_{10\ Gy} \leq 25\%$	75
Femoral heads	$V_{10\ Gy} \leq 22\%$	50
	$V_{9\ Gy} \leq 40\%$	50
Penile bulb	$V_{10Gy} \leq 90\%$	60
	$V_{17\ Gy} \leq 70\%$	60
	$V_{27\ Gy} \leq 35\%$	60

PTV2, boost planning target volume; $Dn_{\%}$, dose covering $n_{\%}$ of the target volume; Dmax, maximum dose received; CTV2, boost clinical target volume; Vn_{Gy}, the percentage volume of organ receiving ≥ nGy.

2.4 Comparative evaluation

For comparisons between different techniques, plan sum was created for all courses. The plans were compared using the Dose Volume Histogram (DVH) method.

2.5 Dose Volume Histogram

All plans were optimized such that at least 95% of the target volume PTV (PTV1 and/or PTV2) received 95% of theprescribed dose.

2.6 Dosimetric and volumetric analysis

Dosimetric analysis of different plans were performed by both qualitative and quantitative methods. Target coverage was evaluated to compare maximum and mean doses to PTV1 and PTV2 in primary, boost and sum plans.

The RTOG conformityindex (CI) was defined by the ratio of the total tissue volume receiving at least 95% of the prescribed dose to the volume of PTV[20]is given in(1).

Homogeneity of dose within a target volume has been assessed by using the homogeneity index (HI) [21] as defined by (2).

The values of CI and HI ideally should be unityand zero, respectively. A greater CI and HI indicates lower conformity and higher heterogeneity (i.e. homogeneity decreases), respectively.

CI does not consider the location and the shape of the 95% isodose volume (V_{95}) relative to PTV.Another index was used in this study called Paddick index(or Conformation Number (CN))[22],[23] which considers the coverage of the target volume with 95% isodose (i.e. quantify the degree of conformality). The Paddick's definition of conformity index is defined as (3).

The Gradient Measure (GM) defined in the Eclipse planning system indicating dose slope (gradients) around target was calculated from both primary and boost plans. GM was defined by the difference in centimeters between the equivalent sphere radii of the prescription and half prescription isodoses. Thus,asmaller GM indicateshigher dose gradients aroundthe target.

Sparing OAR was assessed by comparing the meandoses (D_{mean}) and irradiated volumes that received at least 70,66.6, 50, 40 and 20 Gy to the rectum and bladder in the sum plans. For the femoral heads, themean doses (D_{mean}) and irradiated volumes receiving more than50, 45, and 30 Gy were calculated fromthe sum plans.

Finally, the mean doses (D_{mean}) of the penile bulb while(D_{mean}), V5 Gy, and integrated dose for the health tissue (HTID) were calculated for primary, boost, and the sum plans. The HTID[20] has been defined by (4).It was calculated to find the dose received outside the target by a health tissue (Body-PTV) as a plan quality.

2.7 Statistical Analyses

The data wascompared by the SPSS v25.0 (SPSS Inc., Chicago, IL). By using a paired two-tailed Student's t-test to determine whether there is any statistically significant difference in any of the parameters examined with statistical significance p-values< 0.05.

III. Results

The size of PTV1 and PTV2 varied considerably among patients under this study. Also, bladder and rectum volumes vary among patients depending on their filling i.e. patient'spreparation. The amount of bladder and rectum receiving higher doses equal to PTV depends on their volumes. When bladder and rectum volumes are small, their distance from the PTV decreases. Therefore, their overlappedvolumes increase resulting in a greater percentage in high dose areas and vice versa. The mean volumes and the volume ranges of PTV1, and PTV2, were 155.42±31.72 (range90.1-204.2) cm^3, and134.48±34.61 (range 71.7-204.1) cm^3, respectively. Whilstin the OAR rectum, bladder, left femoral head, right femoral head, and penile bulb, were 70.07±36.26(range 29-197.8) cm^3, 182.95±132.43 (range 58.6-537.9) cm^3 ,170.22±20.31 (range 138.3-201) cm^3,170.65±22.06 (range 138.3-203.8) $cm^3$and 2.92±1.25(range 1.2-4.9)cm^3, respectively.

Table 3. The dosimetric comparisonbetween IMRT and 3D-CRT techniques in the primary and boost plans

Variable	IMRT		3D-CRT	P-value		
	SS	SW		SS vs. SW	SS vs. 3D-CRT	SW vs. 3D-CRT
Primary plan (mean ± standard deviation)						
CI	1.2±0.05	1.2±0.09	1.29±0.07	0.993	<0.001 [a)]	<0.001 [b)]
HI	0.05±0.01	0.04±0.01	0.05±0.01	<0.001 [b)]	0.024 [c)]	0.246
CN	0.8±0.02	0.82±0.07	0.73±0.03	0.395	<0.001 [a)]	<0.001 [b)]
GM (cm)	3.08±0.47	3.09±0.51	3.74±0.25	0.683	<0.001 [a)]	<0.001 [b)]
D_{max} to PTV1 (Gy)	53.41±0.22	52.83±0.34	51.68±0.42	<0.001 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to PTV1 (Gy)	50.53±0.25	50.60±0.29	50.40±0.03	0.044 [b)]	0.043 [a)]	0.01 [b)]
D_{mean} to rectum (Gy)	25.46±3.07	25.53±3.06	27.61±3.76	0.005 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to bladder (Gy)	25.02±6.64	25.18±6.66	28.75±7.62	<0.001 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to left femoral head (Gy)	15.06±2.32	15.15±2.28	20.38±2.23	0.004 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to right femoral head (Gy)	14.25±3.13	14.42±2.85	20.31±1.93	0.604	<0.001 [a)]	<0.001 [b)]
D_{mean} to HT (Gy)	1.86±0.28	1.88±0.29	2.24±0.31	0.04 [a)]	<0.001 [a)]	<0.001 [b)]
HTID (Gy.cc) $\times 10^3$	96.19±16.45	97.32±16.55	116.09±20.54	0.033 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to penile bulb (Gy)	24.1±7.01	24.11±7.02	22.43±5.57	0.837	0.111	0.111
Boost plan (mean ± standard deviation)						
CI	1.05±0.03	1.06±0.04	1.27+0.07	0.181 [a)]	<0.001 [a)]	<0.001 [b)]
HI	0.06±0.02	0.06±0.02	0.05±0.01	<0.001 [b)]	0.021 [c)]	0.261
CN	0.88±0.03	0.88±0.04	0.75±0.03	0.936	<0.001 [a)]	<0.001 [b)]
GM (cm)	3.08±0.44	3.13±0.44	3.49±0.30	0.032 [a)]	<0.001 [a)]	<0.001 [b)]
D_{max} to PTV2 (Gy)	32.27±0.22	31.97±0.23	24.62±0.18	<0.001 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to PTV2 (Gy)	30.38±0.18	30.36±0.2	24.02±0.07	0.264	<0.001 [a)]	<0.001 [b)]
D_{mean} to rectum (Gy)	9.97±2.13	9.96±2.18	10.80±2.47	0.881	0.02 [a)]	0.02 [b)]
D_{mean} to bladder (Gy)	12.2±4.50	12.27±4.57	11.22±3.98	0.045 [a)]	0.001 [c)]	<0.001 [c)]
D_{mean} to left femoral head (Gy)	7.96±1.2	8.06±1.22	9.27±1.09	0.033 [a)]	0.001 [a)]	0.003 [b)]
D_{mean} to right femoral head (Gy)	7.65±1.46	7.69±1.46	9.31±1.03	0.289	<0.001 [a)]	<0.001 [b)]
D_{mean} to HT (Gy)	0.91±0.17	0.91±0.17	0.92±0.14	<0.001 [a)]	0.138	0.331
HTID (Gy.cc) $\times 10^3$	47.17±9.51	47.43±9.59	48.17±9.87	<0.001 [a)]	0.052	0.149
D_{mean} to penile bulb (Gy)	14.72±3.90	14.72±3.93	11.38±2.76	0.955	<0.001 [c)]	<0.001 [c)]

A P-value < 0.05 is considered significant. The paired t-test was used to determine whether there was a statistically significant difference.IMRT, intensity-modulated radiotherapy; SS, step-and-shoot; SW, sliding window; 3D-CRT, three-dimensional conformal radiotherapy; CI, conformity index; HI, homogeneity index; CN, Conformation number; GM, gradient measure; PTV1, primary planning target volume; PTV2, boost planning target volume; D_{mean}, mean dose; D_{max}, maximum dose received; HT, health tissue; HTID, health tissue integrated dose; Vn_{Gy}, the percentage volume of organ receiving n Gy.[a)] IMRT (SS) significantly better than compared technique, [b)] IMRT (SW) significantly better than compared technique, [c)] 3D-CRT significantly better than compared technique.

Table 4. The dosimetric comparison between IMRT and 3D-CRT techniques in the sum plans

Variable	IMRT		3D-CRT	P-value		
	SS	SW		SS vs. SW	SS vs. 3D-CRT	SW vs. 3D-CRT
Sum plans (mean ± standard deviation)						
D_{max} (Gy)	84.78±0.36	84.04±0.48	76.13±0.47	<0.001 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to PTV1 (Gy)	78.96±1.48	78.98±1.51	72.93±1.13	0.55	<0.001 [a)]	<0.001 [b)]
D_{mean} to PTV2 (Gy)	80.84±0.41	80.84±0.44	74.48±0.13	0.891	<0.001 [c)]	<0.001 [c)]
D_{mean} to rectum (Gy)	35.44±5.04	35.50±5.07	38.42±5.95	0.387	<0.001 [a)]	<0.001 [b)]
V_{70Gy} of rectum (%)	10.69±3.88	10.69±3.89	12.56±3.89	0.948	0.01 [a)]	0.013 [b)]
$V_{66.6Gy}$ of rectum (%)	12.74±4.40	12.86±4.50	15.51±4.36	0.589	0.001 [a)]	0.001 [b)]
V_{50Gy} of rectum (%)	25.06±6.85	25.03±6.78	29±7.32	0.803	0.001 [a)]	0.001 [b)]
V_{40Gy} of rectum (%)	37.86±8.3	38±8.25	47.93±10.60	0.247	<0.001 [a)]	<0.001 [b)]
V_{20Gy} of rectum (%)	71.75±12.23	71.96±12.34	75.84±13.19	0.004 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to bladder (Gy)	37.22±10.97	37.38±11.03	39.5±12.19	0.004 [a)]	0.002 [a)]	0.003 [b)]
V_{70Gy} of bladder (%)	17.23±7.87	17.36±7.96	15±7.09	0.037 [a)]	<0.001 [c)]	<0.001 [c)]
$V_{66.6Gy}$ of bladder (%)	19.31±8.9	19.43±9.06	18.96±9.11	0.113	0.491	0.379
V_{50Gy} of bladder (%)	31.41±14.23	31.64±14.37	34.66±18.13	0.004 [a)]	0.007 [a)]	0.01 [b)]
V_{40Gy} of bladder (%)	41.5±18.01	41.75±18.1	50.84±23.97	0.003 [a)]	<0.001 [a)]	<0.001 [b)]
V_{20Gy} of bladder (%)	68±20.19	68.32±20.25	76.22±22.87	0.002 [a)]	0.001 [a)]	0.002 [b)]
D_{max} to left femoral head (Gy)	49.52±6.9	49.72±6.99	52.67±3.12	0.332	0.079	0.101
D_{mean} to left femoral head (Gy)	23.02±3.39	23.21±3.35	29.64±3.23	0.001 [a)]	<0.001 [a)]	<0.001 [b)]
V_{50Gy} of left femoral head (%)	0.36±0.74	0.37±0.8	1.68±1.51	0.748	0.006 [a)]	0.006 [b)]
V_{45Gy} of left femoral head (%)	1.3±2.08	1.34±2.19	9.82±4.84	0.588	<0.001 [a)]	<0.001 [b)]
V_{40Gy} of left femoral head (%)	4.13±4.57	4.32±4.65	27.36±7.79	0.256	<0.001 [a)]	<0.001 [b)]
V_{30Gy} of left femoral head (%)	30.55±10.72	32.56±10.01	63.81±8.79	0.179	<0.001 [a)]	<0.001 [b)]
D_{max} to right femoral head (Gy)	49.63±9.56	50.28±9.9	52.36±3.3	0.004 [a)]	0.217	0.362
D_{mean} to right femoral head (Gy)	22.17±4.17	22.32±4.19	29.985±2.87	0.006 [a)]	<0.001 [a)]	<0.001 [b)]
V_{50Gy} of right femoral head (%)	0.34±0.81	0.4±0.93	1.60±1.93	0.063	0.016 [a)]	0.023 [b)]
V_{45Gy} of right femoral head (%)	1.38±2.17	1.541±2.32	8.97±5.37	0.007 [a)]	<0.001 [a)]	<0.001 [b)]
V_{40Gy} of right femoral head (%)	4.87±5.61	5.12±5.69	25.47±8.49	0.004 [a)]	<0.001 [a)]	<0.001 [b)]
V_{30Gy} of right femoral head (%)	28.47±11.26	28.64±11.37	63.94±8.16	0.674	<0.001 [a)]	<0.001 [b)]
D_{max} to HT (Gy)	83.26±0.63	83.01±0.46	75.63±0.5	0.072	<0.001 [c)]	<0.001 [c)]
D_{mean} to HT (Gy)	2.77±0.44	2.78±0.44	3.16±0.44	<0.001 [a)]	<0.001 [a)]	<0.001 [b)]
V_{5Gy} of HT (%)	11.52±1.84	11.58±1.85	11.07±1.81	<0.001 [a)]	0.001 [c)]	<0.001 [c)]
HTID (Gy.cc) $\times 10^3$	142.96±25.32	143.91±25.53	163.7±30.02	<0.001 [a)]	<0.001 [a)]	<0.001 [b)]
D_{mean} to penile bulb (Gy)	38.83±10.21	38.84±10.23	33.79±7.65	0.866	0.003 [c)]	0.003 [c)]

A P-value < 0.05 is considered significant. The paired t-test was used to determine whetherthere was a statistically significant difference.IMRT, intensity-modulated radiotherapy; SS, step-and-shoot;SW, sliding window;3D-CRT, three-dimensional conformal radiotherapy; PTV1, primary planning target volume; PTV2, boost planning targetvolume; D_{max}, maximum dose received; D_{mean}, mean dose; HT, health tissue; HTID, health tissue integrated dose; Vn_{Gy}, the percentage volume of organ receiving n Gy.[a)] IMRT (SS) significantly better than compared technique, [b)] IMRT (SW) significantly better than compared technique, [c)] 3D-CRTsignificantly better than compared technique.

3.1 Dosimetric outcome

Table 3 shows the dosimetric outcomes of the plans created using IMRT (ss), IMRT (sw), and 3D-CRT techniques. Using mean of dosimetry parameters, we found statistically significant difference in planning target volume coverage ordose to the OARs except for the right femoral head (between IMRT comparison)and penile bulb (for all comparisons) in the primary plan, that achieved a lower dose for the IMRT technique compared with 3D-CRT for the formerand vice versa for the latter.In the boost plan, we found no statistically significant difference (between IMRT comparison) in planning target volume, rectum, right femoral head, and penile bulb.Whereas, for the HT appeared (between IMRT and 3D-CRT comparisons)not significant.

3.2 PTV conformity index, homogeneityindex, Paddick's index, and gradient measure

The mean PTV conformity index (CI) for 3D-CRT was1.29, and 1.2 for both IMRT in primary plan; while it was 1.27for 3D-CRT, 1.06for IMRT (SW), and 1.05 for IMRT (SS) in the boost plan. The PTV

homogeneity index (HI) was 0.05 for 3D-CRT, 0.04 for IMRT (SW) and 0.05for IMRT (SS) in the primary plan, while it was 0.05 for 3D-CRT, 0.06 for IMRT (SW) and IMRT (SS) in the boost plan.

The Paddick index (CN) was smaller for 3D-CRTthan IMRT (SW) (−0.84, $p<0.001$), and (−0.71,$p< 0.001$) than IMRT (SS) in the primary plan, and also the smallestone (−0.13, $p<0.001$) for both IMRT in the boost plan. The Paddick index difference between IMRT (SW)and IMRT (SS)were (0.13, $p<0.395$), and (-0.0002, $p<0.936$)in the primary and boost plans, respectively whichis considered clinicallyinsignificant.

The mean PTV gradient measure (GM) was a smallest value (3.08, 3.08) for IMRT (SS) than the values of (3.09, 3.13) for IMRT (SW), and (3.74, 3.49) for 3D-CRTwhich means higher dose gradients around the target (PTV1, PTV2). There was no significant difference between the IMRT (SW) and IMRT (SS) plans for PTV1 (P=0.683).

3.3 Organs at risk (OARs)

The dosimetric findings for the OARs are reported in Table 4. From that table IMRT showed a better degree of sparing in the rectum, left femoral heads, right femoral heads and healthy tissue when compared with 3D-CRT, but vice versain the penile bulb. For sparing of the bladder, IMRT techniques are better from the low dose to the D_{mean}, whereas 3D-CRT was better in the high dose volume $V_{66.6Gy}$ and V_{70Gy}.

3.4 Healthy tissue irradiation, and Health tissue integrated dose (HTID)

From the above tables, IMRT showed spare more toHTwhen compared with 3D-CRT.HTIDwas 17%, 2%and 13% lower using IMRT compared with 3D-CRT in primary, boost and sum plans, respectively; in spite of the low dose prescription for 3D-CRT than IMRT in the boost and sum plans.

IV. Discussion

It is always coveted in conformal radiation treatment to shape the prescribed isodose volume completely around the target volume to achieve the CI of 1.0, but because of irregular shapes of PTV, close nearness of critical organs and inaptitude of field shaping devices such as MLC transmission and leaf width, make it difficult to be obtained practically.

In the present study our aim was to appreciate the potential benefits that could emerge from the introduction of different modern techniques with increased plan and delivery complexity for prostate cancer patients. Both IMRT techniques showed a methodical and significantly improvement over 3D-CRT in terms of coverage of thetarget andsimultaneously reducing dose to OARs, like previous studies.[24]

In another paper compared the plan quality of 12 patients (plans done with 3D conformal and intensity-modulated radiation therapy). IMRT plans were created for comparison and they compared the target coverage, dose homogeneity, monitor units (MU), and treatment delivery time. Their results showed that IMRT improved target coverage an average of PTV95%(95.8%, 94.7%), PTV5% (105.65%, 103%)for IMRT and 3D-CRT, respectively.Also, IMRT allowing significant reduction in the doses received by the rectum, bladder and femoral heads compared with 3D-CRT [25]. This was similar to our results achieved. According to the tables 3 and 4, IMRT (SS) was slightly superior to IMRT (SW).

In another study selected 10 patients divided in two groups, similar to our findings, the use of IMRT (SW) appeared to improve dose distributions to PTV and the critical structures (including the rectum andbladder)where better coverage was found for the IMRT (SW) technique than for the 3D-CRT planning.This difference in attributed to the use of inverse planning of the IMRT that allows better intensification of the dose to the target, and reductions in dose to these OAR allowed generally accepted constraints to be more frequently satisfied using IMRT (SW) than 3D-CRT.[26]

The results of our study clearly demonstrate the superiority of IMRT in conforming and shaping the doses to the given target volumes, which should also be reflected in significant organs at risk protection, proving better therapeutic ratio. It was possible to decrease the maximum dose to the bladder, and rectum, and significantly reduce the dose to the health tissue with IMRT compared to 3D-CRT. Corresponding results were reported in a study that compared dose plans of 24 patients for IMRT and 3D-CRT with localizedcarcinoma of prostate [27]. Their results also concluded superiority of IMRT in improving target volume coverage and critical organ protection. Their mean CI forIMRT (SW) vs. 3D-CRT was (0.98±0.87) vs. (0.97±0.22) and (0.98±0.64) vs.(0.97±0.93) as compared to a CI of (1.2±0.09) vs. (1.29±0.07) and (1.06±0.04) vs. (1.27±0.07) in ourstudy for PTV1 and PTV2, respectively (P value <0.001).[27]

A paper showed that over 15 patients, the same results values appeared between different IMRTs techniques for the PTV and OARs.On the other hand, the CN for PTV81 for step-and-shoot (SS) beat on sliding window (SW) which is the same as our results for PTV1 and opposite forPTV2.[28]

In another study, a comparison ofdosimetric treatment planning parameters using (SW) IMRT technique with one or more beam energy for 20 patients with prostate cancer[29]. In general, the use of low energy photon beams 6 MV minimizes the radiation head leakage, internal scatter, and secondary neutrons.[5],[6],[7],[8],[16],[30] However, it also requires a greater number of MUs [29],[31], to deposit high doses in the area peripheral to the target, resulting in an increase in the health tissue integrated dose and radiation exposure to the OARs [6]. Otherwise, the integrated dose to the normal tissues was lower in the IMRT by about 12 % than the 3D-CRT, and this would also reduce the radiation-induced secondary cancer.[32],[33]

The integrated dose was 17% lower using IMRT compared with 3D-CRT in this study. It is believed that a larger number of MUs would result in a higher integrated dose[34].However, the integrated dose does not solely depend on the number of MUs delivered [35]. It also depends on the target volumes and shapes, the corresponding aperture sizes and shapes, and the combination of MUs [36]. In addition, the large number of beams used in IMRT plans would not increase the integrated dose significantly [37]. The variation in integrated dose was smaller than 1% for the plans with four or more beams.[38]

Integrated dose and the normal tissue volume receiving lowradiation doses are two important parameters to evaluatethe delivery efficiency of a treatment planning system (TPS). Ideally, lessof the integrated dose indicates an optimal physicalefficiency of a given treatment program.Ithas been shown that 97% of the photon energy was deliveredto the normal tissue in a typical coplanar prostate plan,regardless of the number of beams used.[38]

In this study, IMRT was shown to spare more healthy tissue compared with 3D-CRT, similar results were demonstrated in some other studies[39]. Radiation was delivered to the patient's body with IMRT at seven fixed angles whereas 3D-CRT only delivered radiation at five fixed angles.

We only studied the integrated doses of 6 MV photons, whichare mostly used in IMRT. In this study, we have compared the integrated dose and the low-dose volume in the normal healthy tissues with IMRT (SS), IMRT (SW), and 3D-CRT. IMRT (SW) plans increased the integrated dose to the HT, significant difference was found in the volume receiving 5 Gy whencompared with IMRT (SS) plans. IMRT (SS) with low intensity levels such as 10 L slightly degraded the dose uniformity in the target volumes. In DMLC the beam is continuously switched on, which means increases the dose to the OARs due to transmission and leakage through the leaves[40]. It has been reported that for deep-seated targetsand coplanar plans, the integrated dose (ID) is nearly independent ofbeam energy[5].These results supportthe expectation from geometric considerations that the HTID decreases with increasing tumor size for similar anatomic sizes andincreases with increasing size of anatomical district for similar tumor size[38]. For conformal therapy there is a lower limit for the HTID for an individual patient that is essentially independent of the large number of beams used (4 or more), beam orientation, and relative beam weighting[38]. HTID can be distributed among the various health tissues in a variety of ways, but cannot be reduced except by increasing the beam energy, or reducing the beam margins. Another possibility for reducing HTID may involve changing the beamcharacteristics in some other way, such as fluence modulation. Therefore, plan optimization becomes essentially a process of moving dose around within the patient to find the most favorable distribution[38].Moreover, integrated dose is dependent on the coplanarity of the plan, tumor depths, and number of beams[41].

Finally, IMRT compared with 3D-CRT, provides one more degree of freedom by allowing dose intensity modulation within each individual beam. As a result, the dose distribution can conform to the target to an extent that was not previously possible. In addition, the dose constraints assigned to critical structures in the optimization process allow better preservation of organs function than that achieved by conventional 3D-CRT.

V. Conclusion

The major using of IMRT over 3D-CRT are itsadvantages of the coverage target volume and sparing of OARs with a steep dose gradient. For all that IMRT requires intensive resources and efforts for treatment planning, verification of dose delivery, and accurate patient setup. The majority of prostate cancer patients are treated using IMRT technique because of the evident dosimetric advantages and clinical outcomes.

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Equation 1:

$$\text{RTOG Conformity Index} = \text{CI}_{95\%} = \frac{\text{V}_{95\%}}{\text{V}_{\text{PTV}}}$$

Where $V_{95\%}$ and V_{PTV} are the volumes receiving 95% of prescribed dose and volume of PTV.

Equation 2:

$$\text{Homogeneity Index} = \text{HI} = \frac{\text{D}_{5\%} - \text{D}_{95\%}}{\text{D}_{\text{p}}}$$

Where D_p, $D_{5\%}$, and $D_{95\%}$represent the dose prescription,the dose received by 5% and 95% of the target volume,respectively.

Equation 3:

$$\text{Paddick index} = \frac{\text{TV}_{95} \times \text{TV}_{95}}{\text{V}_{95} \times \text{TV}}$$

Where TV_{95} is the target volume (TV) covered by the 95% isodose volume (V_{95}).

Equation 4:

$$\text{Health Tissue Integrated Dose} = \text{NTID} = \text{D.V}$$

Where D and V are the mean dose and structure volume.

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